

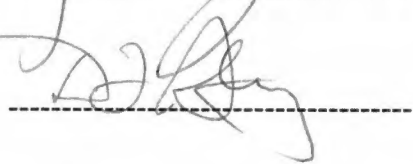
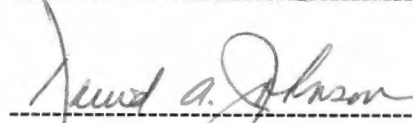
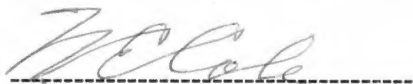
To the Graduate Council:

I am submitting herewith a dissertation written by William Edward Schramm entitled "Sustainable Development in Amazonia: Can Industrial Innovation Increase Competitiveness and Contribute to Environmental Enhancement." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology.



Frank McCormick, Major Professor

We have read this dissertation
and recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor and
Dean of The Graduate School

Sustainable Development in Amazonia:
Can Industrial Innovation Increase Competitiveness and
Contribute to Environmental Enhancement?

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

William Edward Schramm

May 1998

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Dedication

To my parents for demonstrating a love of learning and to Stella and Liam for making the successful completion of this effort possible.

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ABSTRACT

As the greatest contributor to environmental degradation worldwide, industry must undergo great change to achieve environmental sustainability. Required change will be fundamental in nature, test industry's capacity to modify current practice, and demand a degree of commitment that regulation alone cannot generate. Environmental protection approaches that produce economic benefits for industry would provide incentives for this change. This research investigated the most promising means of achieving such a goal: (1) modifying production processes to prevent environmental hazards before they occur and (2) improving production management.

Previous studies of cleaner production methods have focused on the major industrial economies of North America and Europe. The current research considered facilities in a developing country context (i.e., Brazil) and found numerous examples of environmental actions that resulted in both improved environmental and economic performance. Results indicate that 33% of firms studied used process modification as one means of addressing environmental concerns; 100% of these firms realized economic gains from these environmental efforts.

In this research, companies that realized economic gains from their environmental efforts shared a number of characteristics that were observed only rarely in other companies. The most basic of these characteristics was the establishment of a formal environmental program containing the following features: a written statement of environmental policy, clearly defined environmental goals, clear leadership on environmental issues and periodic audits of environmental management systems by a

group from outside the facility. Certain facilities whose environmental programs displayed additional features were still more likely to realize economic gains from their environmental efforts. These additional features were: periodic self-assessments of environmental performance, active employee involvement programs, and strong links between quality improvement activities and efforts to improve environmental performance.

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1. Introduction

The topic of sustainable development has received considerable attention in the last decade. The 1987 Report of the World Commission on Environment and Development (the Brundtland Commission) moved the subject of sustainability to the world stage, while preparations for the 1992 United Nations (U.N.) Conference on Environment and Development (The Earth Summit) in Rio de Janeiro, Brazil served to increase this focus. The Rio Conference produced a statement of agreement on principles of sustainability, Agenda 21, and treaties related to climate change, biological diversity, desertification, and ocean fishing. Governmental action on these agreements and treaties since 1992 has been mixed. Recently, attention on sustainability was refocused with a special session of the U.N. General Assembly (June 23-28, 1997). This session assessed the progress of member states in fulfilling the commitments that were made at the Rio Conference.

The impetus for the current interest in sustainable development has been a growing recognition of the sheer magnitude of human economic activity and its consequences. Since World War II, the world population has more than doubled and the world economy has more than quadrupled. The result is that for the first time human numbers and impacts are perceived as a potential threat to global life support systems. Phenomenal growth in the scale of human activity is expected to continue. In fact, projections suggest that by the year 2050 the world population will again double and the world economy will increase fivefold (Smart, 1992). The primary concern related to sustainability is that future population and economic growth (if matched by growth in the

use of water, soil, energy and other natural resources and by the generation of industrial wastes) will turn today's difficult environmental problems into unmanageable problems.

The best known definition of sustainable development is that used by Brundtland Commission: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The Commission's report makes it clear that there are environmental, economic and social factors that must be considered to achieve the goal of sustainability. Some more recent definitions of sustainability have the advantage of making the significance of environmental, economic and social objectives of sustainability more explicit. For example, McCormick (in press) defines sustainable development as development that: integrates economic, environmental and social values during planning; equitably distributes benefits during implementation; and ensures that opportunities for continued development remain undiminished to future generations.

Regardless of the specific definition used, there is strong evidence that none of these objectives is being achieved based upon current technologies and practices (Goodland, 1991).

1.1 The Issue of Industrial Sustainability in Context

Few people are concerned with economic systems for their own sake. Rather concern centers on environmental and social systems. The relationship of economic, and particularly industrial, sustainability to the needs of biophysical and social systems is quite simple. Without changes in current practice to make industrial activity sustainable

(or a drastic, and unlikely, reduction in industrial activity), environmental sustainability will not be achieved. Without environmentally sustainable human activity, the protection of biophysical systems and the satisfaction of human needs will not be achieved.

Smart (1992) defined the global environmental burden from industrial activity as the product of three factors: global population, income or gross national product (GNP) per capita, and environmental impact per unit of GNP. Braden Allenby (1995) suggested that the first two factors, population and per capita income, are modified primarily through cultural evolution and, consequently, change slowly. Change in the third factor, environmental impact per unit GNP, however, is determined largely by technical change, which can be rapid. Allenby argued that while technical change is not sufficient to achieve sustainability goals, it is critical in that it must "buy time" for cultural change to occur.

1.2 The Role of Government

Government action was the primary (if not the sole) focus of early work in environmental economics. This was reasonable under a "compliance" paradigm in which government defined not only the quantity of reductions in environmental releases, but also, to a large extent, the means of reduction. Such a focus, however, is no longer sufficient for two reasons. First, governments worldwide are moving away from "government-directed" regulatory systems in which government sets the rules for the use of environmental resources, often defines the particular technologies to be used, monitors compliance and punishes violators (i.e., command and control mechanisms) and toward

"market-mechanisms" to protect environmental resources. Market mechanisms use various instruments (e.g., taxes, subsidies, tradeable permits, information) to influence decisions made within markets. This is done by ensuring that market prices for environmental goods and services reflect "calculated" values that correspond to the "true" value of these resources to society. Second, there is considerable doubt that a government-directed approach is capable of achieving sustainable industrial practices at a socially acceptable cost.

Currently, there is a growing perception that if sustainability is to be achieved, it will occur through the integration of economic, ecological and social goals, and that this will occur, in part, via efficiency that reduces resource demands (inputs) and environmental releases (undesired outputs). This perspective is seen in two of the fifteen sustainability principles enunciated by the President's Council on Sustainable Development (1994). Principle two states that "economic growth, environmental protection, and social equity should be interdependent, mutually reinforcing national goals, and policies to achieve these should be integrated". Principle three states that "along with protective measures, market strategies should be used to harness private energies and capital to protect and improve the environment." Sustainability, no doubt, will require that government modify the rules that define the economic playing field in ways that encourage this integration.

Government, however, cannot mandate that the economic activity occurring upon this new playing field will succeed. There is abundant evidence that industry is willing to internalize environmental costs when necessary to protect its franchise to operate, and to

preserve the value of its capital. This willingness to comply, however, does not necessarily translate into the ability to transform company operations (i.e., to innovate) in ways that ensure environmental and economic sustainability. Government action is necessary, but not sufficient to achieve sustainability.

1.3 The Role of Industry

As the greatest contributor to environmental degradation worldwide, industry must undergo great change to achieve environmental sustainability. Required change will be fundamental in nature, test industry's capacity to modify current practice, and demand a degree of commitment that regulation alone cannot generate. Environmental protection approaches that produce economic benefits for industry would provide incentives for this change.

The required industrial reform will not be successful without the active engagement of industry since the necessary organizational, financial and technological resources can be efficiently provided only by the corporate community (Speth, 1992). Thus, the key questions become "Can industry achieve sustainability" and "Will industry choose sustainability?".

If the commitment of resources in support of sustainability limits competitiveness, then industry would be expected to resist this commitment. If, however, circumstances exist under which the commitment of resources in support of sustainability enhance competitiveness, then industry would be expected to embrace this commitment. Understanding the decision that industry faces in "choosing sustainability" requires an

understanding of the potential of environmentally sound industrial development to improve competitiveness through more efficient resource use, restoration/cleanup cost avoidance and product and process improvement.

There are two primary mechanisms by which industry may contribute to achieving sustainability. The first is through major product redesigns that reduce the inputs required for production, decrease environmental effects associated with product use, extend the product's usable life, and enhance the ability to remanufacture or recycle the product at the end of its usable life. Much of the work on product redesign occurs in corporate research and development (R&D) facilities and is described reasonably well by traditional models of technological change. The conventional model of technological change envisions improvements that are developed outside of the actual production process (e.g., within a R&D facility that may be operated by, or may be independent of, the company). Technological improvements enter the actual production process via an independent process in which management selects and purchases capital equipment embodying technological advancements.

The second mechanism by which industry may contribute to achieving sustainability is through the modification of existing production processes (with minor changes or no change in the product). Work on process modification may occur within a R&D facility or within the production process itself. Industrial process modification is the focus of this research.

Traditional models of technological change do not address the possibility of significant process modification and technical change occurring within the production

process itself. This is due, in large part, to the way that technology itself is perceived.

While conventional economics defines technology in terms of hardware and engineering skill, there is an increasing recognition of the need to expand the concept of technology to include management practices, organizational design and organizational strategy (Cole and Mogab, 1987; Best, 1990). Cole and Sanders (1982) refer to these components as "soft technology".

The effect of environmentally-driven, efficiency-based process modifications on corporate competitiveness and on environmental quality depends upon the ability of individual facilities to internally identify and implement process changes that take advantage of synergies between environmental and economic goals. Environmental-economic synergies result from a particular approach to environmental concerns. Rather than addressing the control of pollutants once formed, this approach emphasizes increasing efficiency, reducing or avoiding the creation of pollutants, and limiting resource requirements (i.e., an eco-efficiency focus). Economic and environmental benefits then arise because reductions in resource use and environmental releases produce parallel reductions in input, capital, waste management, waste disposal and remediation costs. For example, Moto-Honda in Manaus performs numerous painting operations and uses approximately 11,500 liters each month of paint thinner to clean paint guns. Disposal of paint-contaminated thinner was a difficult and costly problem. An employee team studied the problem and proposed that equipment to recover and recycle the paint thinner be developed and installed. Plant engineers designed and installed the system. The recycling operation recovers 70% of the paint thinner that previously required

disposal (about 8000 liters per month).

The environmental benefits of this effort result from a reduction in the quantity of thinner requiring disposal. Financial benefits derive from 1) a reduction in environmental protection costs because less waste thinner requires disposal, and 2) a reduction in operating costs because a valuable resource (i.e., thinner) is conserved. The capital cost of the recovery system was US \$7,000. Since the company pays US \$1.20 per liter for thinner and the system recovers 8000 liters of thinner each month, the company saved US \$10,000 in thinner costs during the system's first month of operations. Competitiveness gains achieved through eco-efficiency actions such as this act as an internal incentive for companies to pursue sustainable industrial practices.

Simultaneously advancing the economic and environmental goals of industry, however, requires the development of management systems and organizational structures that support increased recognition and exploitation of environmental-economic opportunities (i.e., systems that stimulate process innovation). Conventional economics contains very little to aid understanding of organizational phenomena (Leibenstein, 1987).

While the question of internal incentives is basic to understanding the likelihood of industry efforts to achieve sustainability, the most basic questions about such incentives and the environmental-economic synergies from which they arise (e.g., their abundance) remain unanswered and largely unaddressed (Fisher and Schot, 1993; Jaffe and Palmer, 1994). This is particularly true in the setting of less developed countries.

Jaffe et al. (1994) note that virtually no rigorous attempts to quantify the

hypothetical innovation-stimulating effects of environmental regulations have been undertaken. The United Nations in 1994 noted the scarcity of research in this area in calling for the study of eco-restructuring (i.e., economic, technological, and social restructuring for environmental reasons). The lack of research in this area prompted the President's Council on Sustainable Development in 1996 to call for research necessary to: a) help develop, test, and verify the scientific basis of technologies and practices to move toward the ideal of a zero-waste society, and b) evaluate the effectiveness of new technologies and practices in attaining environmental goals at lower cost.

External incentives are also significant. An important question is whether, and to what extent, the business environment motivates companies to pursue implementation of environmental protection systems capable of increasing the recognition of opportunities for profitable innovation that were previously unrecognized. The business environment includes external factors such as government environmental regulation, market reforms (e.g., ISO 14000¹), public and consumer expectations, and competitive pressures.

¹ ISO 14000 is an international standard for environmental management systems. It is issued by the International Standards Organization (ISO) and is adopted by companies on a voluntary basis.

2. Economic and Ecological Perspectives Related to Sustainability

The Brundtland Commission (1987) noted the critical importance of effectively addressing both economic and ecological aspects of sustainability. This section considers these factors with particular reference to issues involved in achieving sustainability of industrial activity.

2.1 Economic Perspectives

Activities occurring within individual production facilities will determine whether industry achieves sustainability. Economic views represent a significant influence on actions taken by many decisionmakers within industry. This section considers views of environmental-economic interactions generally and then addresses issues underlying the current debate regarding the capability of firms to realize competitiveness gains from environmental protection efforts.

2.1.1 Contemporary Economic Thought Relating Industrial Processes, Competitiveness and Environmental Protection

Three perspectives on environmental-economic interactions (i.e., the relationship between improvements in environmental performance and the economic performance of companies) may be identified. Two of these views have broad acceptance within the economic literature. Conventional wisdom within economics presumes that firms purchase and install capital equipment to control pollution at the end of the production process while leaving basic production unchanged. In this view, production costs are

unchanged while pollution control costs are added. Thus, by definition, the overall cost of production increases. This, in theory, makes firms less competitive and suggests a rationale for the resistance of many companies to environmental protection requirements. Economic conventional wisdom is discussed further in Section 2.1.2. The economic literature anticipates that firms will invest in this form of environmental protection only when forced by an external source (e.g., government). The environmental protection approach that leaves production processes unchanged while adding pollution control equipment or infrastructure is referred to as the "static process" approach in this document. In many situations a static process approach would be equivalent to end-of-pipe treatment approaches, although it may also encompass safe disposal techniques.

Firms, however, may adopt a process oriented approach to addressing environmental and economic performance. By seeking process efficiency improvements that reduce resource requirements and reduce (or eliminate) the generation of wastes (i.e., potential pollutants), these alternative approaches limit (or avoid) increases in production costs related to environmental protection. It is argued that in some cases, process oriented approaches lead to reductions in overall production costs.

Process improvements may be achieved by two different means. One approach is to improve efficiency and environmental performance through the installation of production equipment that embodies a new and better technology. This equipment-based approach has fairly broad acceptance within the economic literature. Another approach is to improve efficiency and environmental performance through a stream of small, incremental process modifications (rather than equipment that embodies a significant,

one-time technology change). This internal modification approach is the subject of some controversy (Section 2.1.2; 3.0).

The concept of equipment-based process improvement suggests that firms may protect the environment by shifting to new, more efficient production technologies, if such technologies are available. Since the technology (in conventional economic thought) is embodied in capital equipment: a) its adoption requires capital investment, and b) it is available to any company with the capital required for purchase. While more efficient technology may have the potential to improve environmental performance and reduce production costs (e.g., by reducing resource inputs), its adoption may be limited by the technology's capital requirements or by a company's earlier investments in equipment related to other technologies. This is particularly true if the equipment in place at the facility was expensive and the remaining useful life is significant. This environmental protection approach is referred to as "equipment-based" process change in this document.

The second process oriented approach to improving environmental performance involves making a continuous stream of small, incremental process changes. These small changes may cumulatively have a significant impact on production process characteristics and production efficiency from both an environmental and economic standpoint. Additionally, changes may be implemented quickly and often require little or no capital investment. Since the approach is not dependent on capital equipment, it holds considerable promise for companies whose access to capital is limited. In this document, this approach to environmental protection is termed "incremental" process change.

The distinction between equipment-based and incremental process change is very important. The capital requirements of the former may limit its application and contribute to industry's resistance to environmental reform. The small capital demands of the latter would tend to reduce these barriers. Facilities participating in this research provided examples of all three types of environmental protection efforts (i.e., static process, equipment-based, and incremental). Companies visited also provided examples of process modification that was undertaken for reasons unrelated to the environment (e.g., product quality), but nonetheless lead to improved environmental performance. Thus, the experience of the facilities studied indicate that as environmentally-driven process change may produce "unanticipated" competitive benefits, so process change driven by competitive forces (e.g., the need to enhance quality) may produce "unanticipated" environmental benefits.

The way that companies have traditionally dealt with environmental regulation is best described by the end-of-pipe treatment approach. However, since this approach has been studied in far greater detail than the two process oriented approaches, and because the static process approach, by definition, offers little hope of improved corporate competitiveness, this research focuses on equipment-based process change and incremental process change.

These process-oriented approaches differ significantly from the static process view in that they focus on increasing production efficiency and incorporate the idea that environmental pollution is an indication of inefficiency within production processes. These approaches emphasize changing production processes to prevent environmental

hazards before they occur and, thus, raise the possibility that companies may benefit financially from evaluating their production for ways to reduce environmental impacts.

They accomplish this by:

- a) identifying inefficiencies within production (e.g., by evaluating those aspects of production that produce the greatest volume of waste or involve waste products that represent the greatest ecological or human health risk), and
- b) addressing those inefficiencies (i.e., by evaluating process modification options).

As a result, these approaches represent one of the most promising means of achieving eco-efficiency.

2.1.2 Economic Conventional Wisdom and Eco-efficiency

While anecdotal evidence from industrialized countries indicates that new technologies developed in response to environmental demands can lower production costs, econometric studies suggest that environmental regulations negatively impact productivity and discourage R&D efforts (Barbara and McConnell, 1990; Haveman and Christiansen, 1981; Gray and Shadbegian, 1993; Biglaiser and Horowitz, 1994).

Jaffe et al. (1994) note that conventional wisdom within economics is that environmental demands impose significant costs on industry, slow productivity growth and, therefore, hinder the ability of companies to compete. In a review of the state-of-the-art in environmental economics, Cropper and Oates (1992) share this assessment of conventional wisdom. They note that economic analysis of environmental issues treat pollution as simply another factor of production and indicate that this is reasonable

because attempts to cut back on waste discharges involve the diversion of other inputs to abatement activities and "result in reduced output". Reduced output may be viewed as a cost increase since an unchanged quantity of inputs yields a reduced quantity of output.

This view predicts that the amount of environmental protection that a company can "afford" in a competitive market is limited by the costs of reducing the environmental impacts of production, and that firms will exactly meet (not exceed) the standards of environmental protection mandated by law (Arora and Cason, 1994).

Economic conventional wisdom conflicts with the concept that environmental-economic synergies may significantly influence the environmental protection costs of industry. At this time, the evidence in support of either view is limited. Although economic and environmental gains are attributed to environmentally-driven process modification (Huisinigh et al., 1986; OTA, 1986; OTA, 1993; Dorfman et al., 1992; PCEQ, 1993), the validity and significance of such findings are contested (Oates et al., 1994; Jaffe et al., 1994; Walley and Whitehead, 1994).

Jaffe et al. (1994) note that an innovation stimulating effect from environmental regulation of sufficient size would suggest the possibility of improvements in environmental quality without costs. They note that economists are generally unsympathetic to this view because it requires that firms are unaware of profitable production improvement possibilities that environmental demands bring forth. Further it conflicts with the common assumption that a profit maximizing firm will eventually use the best available technique.

Problems arise when attempting to relate traditional economic analysis of

environmental regulation and competitiveness or innovation, to environmental protection efforts that emphasize efficiency-based process modification approaches (e.g., eco-efficiency). With regard to studies of environmental regulation and competitiveness, Jaffe et al. (1994) indicate that the vast majority of economic analyses are based upon the assumption that environmental demands increase production costs (because they assume end-of-pipe abatement technology). This assumption, however, precludes a proper assessment of environmental protection approaches that utilize techniques other than end-of-pipe abatement. With regard to studies of environmental regulation and innovation, Jaffe and Palmer (1994) note that a) nearly all of the economic literature on the topic is theoretical in nature and b) the capacity to resolve the relationship between environmental demands and innovation based solely on theoretical approaches is limited. Thus, much of traditional economic analysis of environmental issues may not be directly relevant to the analysis of eco-efficiency approaches.

Eco-efficiency arguments differ from the conventional economic view that environmental protection is strictly cost increasing. Although environmental regulations still represent constraints on a firm, there is an acknowledgement that responses other than end-of-pipe abatement are possible. The result is that outcomes are not predetermined by the presence of constraints, rather the outcome is dependent upon the response of the firm to the constraint. The basis for eco-efficiency arguments lies in the recognition that changes in technology may significantly modify the relative quantity and value of production inputs and outputs. Economics has long accepted that technological advances may affect the economic efficiency of production. One difference between

equipment-based process modification (which is generally accepted within economics) and incremental process modification (which is controversial) is the definition of technology. Incremental process modification involves technological change in a broader sense. Changes in soft technologies (e.g., management systems) provide the capacity to produce incremental improvements (i.e., identify and exploit environmental-economic synergies) as part of normal facility operations.

If efficiency enhancing process changes benefit the environment by either reducing the natural resource demands of production or the environmental releases from production, then tradeoffs between economic and environmental objectives will be modified as well (Fischer and Schot, 1993; Smart, 1992). This argument implies that eco-efficiency approaches, where applicable, should be capable of better performance than end-of-pipe treatment approaches.

2.2 Ecological Perspectives in Relation to Sustainability

The concept of sustainability is an integrating one. It incorporates concerns for the environment and continued development, while bringing to the table often ignored community and poverty issues. The Brundtland Report (1987) described the importance of integrating these factors at the highest levels of decisionmaking before actions are taken. Thus, the Commission's concept of sustainability is holistic. This is important as human and natural systems are linked by a web of interconnected processes and the pursuit of short-term economic interest may lead to environmental degradation that, in turn, induces economic costs.

McCormick (in press) notes that the a) basic philosophy of ecology is fully compatible with the integration of economic, environmental, and social values within a comprehensive planning and management framework, and b) holistic philosophy guiding ecological science (Gause, 1934) means that many of the scientific principles and methods that will be required to achieve sustainability are available within ecological science.

McCormick (1992) defined a set of ecological prerequisites for sustainable development. Prominent among these prerequisites was the need to acknowledge the interdependence of ecological, economic, political and social systems. This is made clear by the growing recognition of linkages that were barely noticed a decade ago such as that between poverty and environmental degradation.

Conditions that increase the level of poverty and reduce employment opportunities in LDCs have environmental consequences. Without opportunity, the poor may migrate to open-access lands. Lands available to the poor are generally unoccupied because they are unsuited for development (Browder, 1989). These lands are frequently fragile (e.g., rainforest, drylands, floodplains, hillslopes) and are subject to rapid degradation under intensive use. Environmental degradation today is not solely a byproduct of economic development, but frequently a product of the absence of development. environmental costs.

Ecological and economic systems share significant similarities while also exhibiting important differences. The most critical differences arise from human goal-oriented decision making, humankind's immense control over the natural environment,

and the human capability to respond quickly to change through cultural rather than strictly biological mechanisms (Bernstein, 1981). Characteristics of many environmental concerns (e.g., time lags, uncertainty, and effect thresholds), however, increase the likelihood that human responses will be sub-optimal. This occurs because these characteristics make it easier for decisionmakers to defer difficult choices and delay the implementation of policies requiring contemporaneous payment of environmental costs.

Bernstein notes that the fundamental similarity between ecology and economics is that both seek to understand and predict the behavior of interconnected systems, in which individual behavior and large-scale flows of energy and material are important. Further, both are concerned with the allocation of scarce resources among competing consumers. Similarities between biophysical, economic and social systems can also be cited. For example, each is: dynamic and complex, subject to a variety of constraints, and characterized by a hierarchical structure and numerous linear and non-linear interdependencies. The principles of one field may offer insights that are useful within the others. The following paragraphs discuss several ecological principles and suggest how these principles are reflected in other systems.

Complexity.

Biophysical, social and modern economic systems are immensely complex. With vast numbers of entities interacting at a multitude of levels, our capacity to comprehend or model systemwide aspects of structure and function is limited to fairly crude estimations of interactions occurring at higher levels of organization. Complexity arises

from component interactions; feedback loops; variability in time and scale; and lags, thresholds and discontinuities.

An example from this research indicates the complexity involved in even a "simple" system. A successful effort to reduce the quantity of volatile organic compounds (VOCs) emitted from a furnace at the Alumar aluminum facility in Sao Luis, Brazil resulted in an unanticipated reduction in another pollutant, fluoride. This was the result of a series of interactions within the production process that were little recognized until highlighted by this occurrence. This same production process illustrates variability within other factors that contribute to complexity. The principle pollutants from Alumar's furnace operations are fluoride, VOCs, and carbon dioxide (CO₂). The effect of fluoride is local and occurs over months to years, VOCs have impacts at a local to regional scale that occur over days to weeks, while CO₂ has effects at a global scale occurring over decades to centuries. Threshold levels for effects on vegetation from fluoride are fairly well known, while the threshold levels for CO₂ effects on temperature, and the magnitude of those effects, are subject to much debate.

One significant implication of this complexity is uncertainty. Uncertainty refers to the fact that there are simply things about systems that we do not know. In this sense, uncertainty can be distinguished from risk. Risk implies that there exists sufficient knowledge to estimate both an event's likelihood of occurrence and its consequences. This information permits the management of exposure to risk. Under uncertainty, however, we lack the basic knowledge needed to make estimates that would permit such management. Thus, uncertainty cannot be "managed" in this sense and the consideration

of uncertainty requires different methods and greater margins for error.

Another implication of complexity is that it is easier to manage a simple system than it is a complex one. For example, comparing a natural to a plantation forest, reduced (or at least more specific) data needs, more focused objectives and the acceptance of certain tradeoffs tend to make management of a plantation forest simpler (even though management activities may be more intensive) than the management of a natural forest. Experience with environmental protection in the industrial setting provides an example of this concept as well (i.e., ensuring that potentially damaging substances are maintained within the confines of "simple" manmade environments). Once such substances are released to the natural environment, management is more complex, more expensive and less likely to be successful. In fact, with regard to groundwater, management is probably an inappropriate description of efforts to address the release of industrial materials into the environment. The idea of pollution prevention (i.e., avoiding the production or use of environmentally damaging substances) extends the notion of system simplification.

Resource reuse is a characteristic of biophysical systems that some industrial systems are now attempting to emulate. High levels of resource reuse in biophysical systems derive, in part, from system complexity. It would not be a great exaggeration to say that no waste exists in biophysical systems. For any given organism, virtually all "waste" products are used as resources by other organisms (energy being the most significant exception). Applying this idea to economic systems, pollution is seen as a waste of resources. The Alumar facility provides an example here as well. Efforts that reduced fluoride emissions from the Alumar aluminum smelter also saved a valuable

resource, aluminum fluoride, and saved the facility US \$200,000/year. Two recent concepts, zero emissions policies and eco-industrial parks, are efforts to follow the example of biophysical systems. The first treats an individual company as an "ecosystem" and encourages the recycling of materials within that system. The second considers an inter-firm ecosystem of tightly coupled material exchanges.

Hierarchical structure.

Biophysical, social and economic systems are each characterized by a hierarchical structure. While different levels of organization are characterized by different features and may be viewed as discrete functional entities, each is linked to other levels and is part of a larger whole. Thus, events at one organizational level may affect what occurs at other levels. Table 1 provides examples of this hierarchical makeup². Interactions that characterize higher levels of organization are more likely to approach steady-state conditions than those characterizing lower levels. For example, the loss of a particular species population, or a particular production facility, may represent a significant disruption at the local level, but it is unlikely to have major effects at the biome or regional economy level.

Given the hierarchical nature of these systems, the scale of analysis and point of intervention are significant. Some processes occur at a single organization level. In this event, data collected from a different organizational level may be unlikely or incapable of

² Within biophysical and economic systems, hierarchies of producers and various levels of consumers are also present.

providing insight into the process. For example, aggregate data on production trends within a facility may indicate problems or successes, but is probably incapable of providing information about causes.

The significance of the point of intervention derives from characteristics of both complexity and hierarchy. Ecological experience indicates that steps taken to prevent problems are generally more successful and more cost-effective than measures applied once problems have arisen (e.g., habitat protection vs. species management once the species is endangered). Only in the last decade have industrial environment protection efforts provided confirmation of this ecological experience (e.g., pollution prevention).

System Change.

Biophysical, social and economic systems are each evolving systems. While the systems may move in the direction of an equilibrium state, various processes produce continual disturbance and change. The result is that equilibrium is rarely attained. This constant state of flux means that at any given point in time, a system may follow one of multiple developmental paths. Additionally, components of a system exhibit different strengths in terms of stability and resilience. Stability refers to the ability of a system to remain stable in the face of disturbance. Resilience describes the capacity of a system to rapidly recover from disturbance. The relative strength or weakness of these characteristics may influence the developmental path followed by the system. In industrial systems, flexibility within production systems may be one source of resilience. Cole and Mogab (1994) describe the significance of such flexibility.

Table 1. Examples of Hierarchical Structure in Ecological, Economic and Social Systems

Ecological	Social	Economic
biosphere	world	world economy
biogeographic region	nation	national economy
biome	region	regional economy
landscape	city	local economy
ecosystem	neighborhood	economic sector (local)
biotic community	community	industry (local)
population	family	firm/facility (local)
organism	individual	individual

System history (and, thus, baselines and monitoring) matters because of system change characteristics. The history of a system places constraints on potential directions that the system may take in the future. For example, in biophysical systems, the loss of a species excludes the future possibility of processes dependent upon that species. Similarly, historical events within economic and social systems open or foreclose response options and may, therefore, influence the reaction to a future event. A long-term perspective in system management may protect options unrecognized by a short-term perspective. This is one reason that facilities cite for investing in employees (e.g., retraining workers when their positions are eliminated). Within standard economics, however, history does not play a role in decisionmaking (Leibenstein, 1987).

The changing nature of systems makes the establishment of baseline information and monitoring programs critical to understanding the current state of system processes. In the context of a manufacturing process, this focus on resource movement through the system is quite different from the relatively distance and indirect analyses that underlie most economic analysis. Tracking the productivity impact of an action (production per worker-hour) or economic performance is at a minimum of one step removed from the process being evaluated.

3. Research Objectives

The concept that synergies exist between environmental and corporate goals has been controversial (Section 2.1.2). Although economic and environmental gains are attributed to environmentally-driven process modification, some question the validity and significance of such findings. Further, the evidence that does exist for synergies is derived from industrialized country settings. Little is known of the applicability of environmentally-driven, efficiency-based process modification to the circumstances within less developed countries (LDCs). It is commonly presumed, however, that LDCs present a setting that is generally less conducive to eco-efficiency concepts. Evidence of this perspective is seen in the widespread view that under liberalized international trade, many LDCs will serve as "pollution-havens".

Given the debate over the concept of environmental-economic synergies and, thus, over the capacity of industrial process modification to improve both environmental and economic performance, the first objective of this research is to test the fundamental hypotheses that:

- a) opportunities to concurrently improve environmental and economic performance occur based upon synergies between environmental and economic goals,
- b) these opportunities may be exploited by environmentally-driven industrial process modifications focussed on efficiency improvement, and
- c) when exploited, these opportunities may contribute to enhanced environmental performance and corporate competitiveness.

Information regarding the presence or absence of such opportunities would be a worthy contribution to the debate over the applicability of the environmental-economic synergy concept.

The second objective is to determine whether there is evidence that economic and ecological productivity can be mutually reinforcing in a developing country setting. This objective could be viewed as a corollary of the first objective (i.e., to confirm the occurrence of environmental-economic synergies in a LDC setting).

In the event that successful efforts are identified, the third objective of this work is to determine the factors that contribute to, or hinder, the successful identification and exploitation of environmental-economic opportunities.

The final objective of the research is more applied than the others. Currently, approximately half of the facilities in the industrial district of Manaus (the primary focus of this research) have environmental licenses. In the future, all industries in the Manaus free trade zone will be required to have environmental licenses in order to be eligible for financial incentives offered by the State government. Additionally, compliance with international standards regarding environmental management systems (e.g., ISO-14000) are becoming increasingly important in order to participate in international markets.

Two significant problems confront the Ministry of Environment of the State of Amazonas: a) providing convincing evidence to local managers that economic productivity and environmental protection can be mutually reinforcing in a third world setting; and b) describing management and production practices that companies in Manaus might consider in order to achieve improvements in environmental performance.

Evidence that environmental protection efforts based upon process modification have the potential to enhance competitiveness should be useful to those responsible for environmental regulation in Manaus as they attempt to bring industrial facilities currently in violation of environmental standards into compliance. Thus, the final objective is to contribute to the improvement of environmental practice within the Manaus industrial district. Specifically, this work seeks to provide the Ministry of the Environment with a set of case studies (presented in Appendix A) that would convince facility managers of the feasibility of eco-efficiency based methods of environmental protection (i.e., demonstrate real benefits to local firms). A second means of contributing to improved environmental practice involves supporting technological progress. James Speth, the director of the U.N. Development Program has emphasized that from an environmental standpoint, humanity cannot afford the impacts that would accompany LDC industrialization via second-hand technologies from the developed countries. He has emphasized the need to support LDCs in "leapfrogging" the production and environmental technologies of the past thirty years and employing the latest technology within their development efforts. Case studies of successful process modification efforts would aid such leapfrogging efforts by providing information on factors that aid or hamper state-of-the-art reform efforts at the local level.

4. Site Selection; Setting and Background; Research Methods

This section provides information on the selection of Manaus as the research site, the national and regional economy, and the rationale for the selection of the specific companies that participated in the research.

4.1 Site Selection

Given the goal of confirming the occurrence of environmental-economic synergies generally, and specifically within the LDC setting, Manaus presented a number of benefits as a research site. The first reason for the selection of Manaus is the paradox of Brazil's position as both a developing nation and one of the ten largest economies on earth. Brazil has a number of regions and industrial sectors that are highly developed. Industrial activity in parts of Brazil, including Manaus, is quite intensive. Thus, the potential for significant environmental impacts is present as is the need for effective environmental protection measures. While environmental protection legislation in Brazil is as stringent (and in some cases more stringent) as that in the major industrialized countries of North America, Europe, and Asia, enforcement of this legislation has often been lax, particularly in areas such as Manaus that are removed from Brazil's major industrial centers in the South. Although a tradition of lax environmental enforcement in Manaus reduces the likelihood of observing examples of environmentally-driven process modification, this situation is desirable in that it is a condition that is representative of much of the developing world.

Unlike some smaller LDCs, Brazil is not likely to suffer from a significant gap in

individuals with appropriate training and experience to manage large industrial facilities. While Brazil's educational system has numerous problems (The Economist, 1995), shortages of engineers and managers are not critical. Personnel shortages that exist tend to be worse for Brazilian firms than for multinationals which generally pay more.

The second reason for the selection of Manaus was the rapid expansion of industry within Manaus in the recent past (since 1967) and the strong multinational presence in the Manaus free trade zone. Recent and ongoing investments by industry were thought to increase the likelihood that the management of any given facility would have exposure to the most recent trends in the industry. Similarly, the presence of multinational operations in Manaus would likely enhance the exposure of facility managers (from both multinationals and domestic firms) to a variety of management systems and principles. It was thought that these factors enhanced the likelihood of observing environmentally-driven process modifications.

A third reason for the selection of Manaus is the Brazilian government's efforts to increase the competitiveness of Brazilian industry. Throughout the 1990's, the federal government of Brazil has emphasized product quality improvement efforts as a means of increasing the international competitiveness of Brazilian industry. It was thought that this experience would increase the receptivity of facilities in Brazil to the concepts that underlie environmentally-driven process modification and increase the likelihood of observing these activities.

An additional reason for selecting Manaus for this research is the perspective of the region's political leadership. The development history of Manaus is characterized by

two major events. The first was the rubber boom from approximately 1885 to 1915. The second was the establishment of the Manaus free trade zone and federal government economic incentives to support industrial growth in 1967. An economic and social collapse followed rubber's decline and showed that the basis of the region's first production boom was not sustainable. Policymakers in Amazonas are addressing the possibility that the second (government-incentive driven) economic boom in the area may be unsustainable as well. Leaders seek an alternative basis for development that is sustainable. This is frequently referred to as the "third cycle". As a result, government officials in Manaus are more open to the implications of sustainability-related research in the formulation of future policy than are public officials in most other locations.

Finally, the potential to expand the scope of the research at a later time favored the selection of Manaus. The Brazilian Amazon is the world's most expansive frontier of settlement and economic development (McCormick, 1992). Millions of people have migrated from eastern and southern Brazil to the country's vast western frontier. Experience in other parts of western Amazonia has proven, however, that agriculture is not sustainable in most of this region. While industrial activity may provide limited relief of agricultural pressure on undeveloped lands within northwestern Brazil, the sustainability of industrial activity is also uncertain. Dramatic population increases in Manaus (the population doubled in the last decade) and the city's location in the center of a region whose ecological resources are as fragile as they are vast make Manaus a good location for future consideration of the potential social effects of cleaner production methods in addition to the environmental and economic effects.

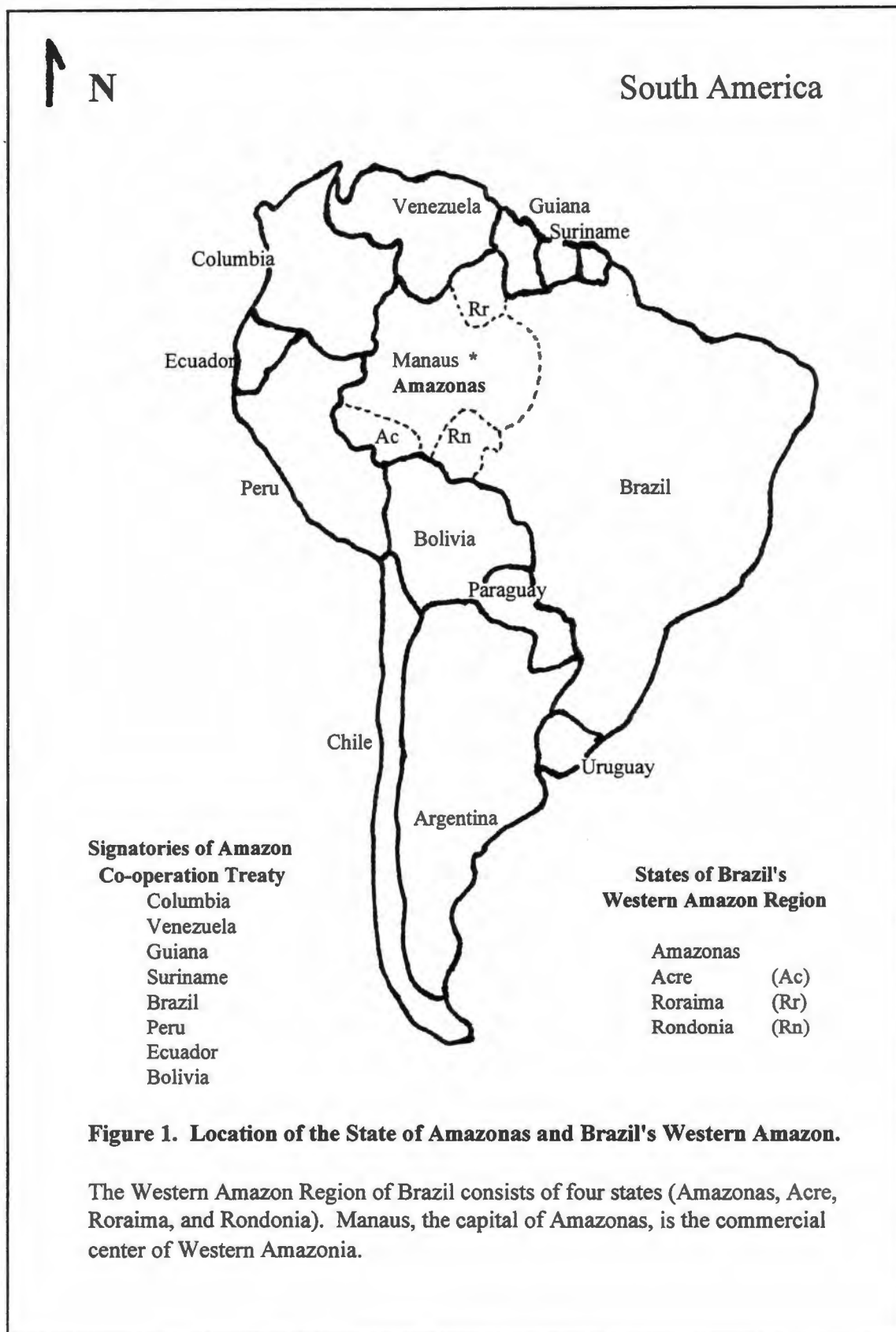
4.2 Setting and Background

This section provides information on the local, regional and national conditions that form a backdrop for the research.

4.2.1 Brazil - Geography and Demography

Brazil is the largest country in Latin America, occupying almost half of the continent of South America (Figure 1). Brazil's Western Amazonia region consists of four Brazilian states (Amazonas, Roraima, Acre and Rondonia), occupies 26% of Brazil's total area and 76% of the total Amazon Basin area. Western Amazonia borders 5 other South American countries (Guiana, Venezuela, Columbia, Peru and Bolivia).

Brazil, with a population of 158 million in 1993, is the sixth most populous country in the world. In relation to its size, the Amazon has a small population. The population of the entire Amazon basin is approximately 18 million of which about 16 million live in the Brazilian Amazon. The State of Amazonas is one of the most sparsely populated portions of the Brazilian Amazon. Although it is the largest state in Brazil (representing 18% of the country's total area), Amazonas has a population of approximately 2 million people (about 1.25% of Brazil's total population). Manaus with a population of nearly 1.5 million people accounts for more almost 70% of the state's population. The State of Amazonas is becoming increasingly urbanized. In 1960, the urban population represented 33% of the State's total population. In 1991, the urban population exceeded 71% of the total population (Browder and Godfrey, 1997).



4.2.2 The Brazilian Economy

Brazil's economy is the tenth largest in the world (WRI, 1992). Economic activity, however, has historically been and remains highly centralized in the South of the country. For example, economic activity within the State of Sao Paulo represents 60% of Brazil's gross domestic product (GDP), while activity within the City of Sao Paulo represents 40% of the country's GDP. Until the institution of economic incentives for development within the Manaus free trade zone, the limited economic activity that did occur in the Amazon region was concentrated primarily in coastal areas.

While in the past the Brazilian economy received considerable protection from foreign competition under a policy of import substitution, the economy is now undergoing significant liberalization. A comprehensive program of trade deregulation was launched in 1988 and strengthened in 1990. The deregulation policy aims to stimulate efficient practices and technological modernization of Brazilian industry through greater exposure to international competition (Brazilian Ministry of Foreign Affairs, 1994). The program has resulted in the virtual elimination of non-tariff barriers to imports and cut mean tariff rates from 51% in 1988, to 32.2% in 1990 and 14% in 1993. In April 1994, Brazil signed the Marrakech Declaration concluding the Uruguay Round of negotiations under the General Agreement on Tariffs and Trade (GATT) and creating the World Trade Organization (WTO). Brazil is actively pursuing increased trade with other South American countries via Mercosur and is also increasing its trade with the European Common Market countries. Mercosur, the Mercado Comun del Sur, is common market originally established among the countries of Argentina, Brazil,

Paraguay and Uruguay. Recently, both Chile and Bolivia have joined as associate members.

The high inflation rates that had plagued the Brazilian economy for decades were reduced dramatically with the introduction of the Real Plan in 1994. A monthly inflation rate that averaged 31% during the year preceding the introduction of the Real Plan fell to 3.4% in the year that followed introduction (Central Bank of Brazil, 1995). Lower income groups, who spend a large proportion of their income on food and other necessities, were disproportionately impacted by the erosion of purchasing power from high inflation and greatly benefited from reductions in the rate of inflation. One consequence has been a relative increase in disposable income and a boom in purchases of consumer durable and nondurable goods, including consumer electronics.

In 1994, the gross domestic product (GDP) of Brazil was US\$ 555.4 billion. Brazilian exports in 1994 totalled US\$ 43.3 billion, while imports were US\$ 31 billion. Although still a modest percentage of Brazil's GDP, Brazilian foreign trade has grown rapidly in the past two decades. From 1970 to 1992, Brazilian exports grew by 1,322%. In the past decade, trade with other Mercosur countries has shown the most significant increases. While total Brazilian trade flows increased 24% in the period between 1990 and 1993, Brazilian trade with Mercosur countries grew 240% (Brazilian Ministry of Foreign Affairs, 1994). The share of industrial goods as a portion of Brazil's exports grew from about 15% in the mid-1960's to more than 70% in the early 1990's. During the same period the share of commodities among exports fell from 85% to under 25%. In 1993, exports were composed of 60.9% manufactured goods, 14.1% semi-manufactured

goods, and 24.3% commodities (Brazilian Ministry of Foreign Affairs, 1994).

Foreign direct investment in Brazil reached US\$ 36.1 billion in 1993. North American investment represents 29% of this total, while investment from Germany and Japan represents 15% and 9.6% respectively.

4.2.3 The Brazilian Quality and Productivity Program

A long economic contraction during the 1980's had significant consequences for Brazil. With a lack of investment, much of the nation's plant and equipment became obsolete. Brazil's new Industrial and External Commerce Policy aims to 1) modernize industrial and commercial activities via increased production and the adoption of international standards of quality, and 2) establish modern production methods for consumer goods and services in the national economy by the diffusion of new technological standards (Suframa, 1994).

A central aspect of Industrial and External Commerce Policy is the Brazilian Quality and Productivity Program launched by President Fernando Collor de Mello in November 1990. The program was intended to respond to changes in the nature of international competition. A worldwide trend toward technology based competition undermined Brazil's traditional comparative advantages based upon abundant and cheap materials, energy and labor (Ministry of the Economy, 1990). Ohmae (1985) notes that labor costs as a percentage of total cost in assembly operations has fallen from about 25% to the 5-10% range due to developments in automation, numerical controls, and computer-aided design and manufacturing.

The Quality and Productivity Program attempts to mobilize and focus private sector efforts toward the improvement of quality and productivity, and to modernize industrial and technological infrastructure. The goal is nothing less than a restructuring of Brazilian industry based upon the creation of a more competitive environment within the country.

The program emphasizes new management methods within industry and education improvements at all levels, including training for the managers of Brazilian business. The program and the modernization intended to follow from it are viewed as a foundation for renewed economic and social development. The program has been endorsed and supported by the current president, Fernando Henrique Cardoso. One of the most visible consequences of the plan in Manaus is the linking by Suframa of federal financial incentives to certification under ISO 9000 (which deals with Quality Management Systems).

4.2.4 Manaus and the Free Trade Zone

Manaus is the Capital of the State of Amazonia and has historically been the principle economic center within Western Amazonia. Located at the confluence of the Rio Negro and Rio Solimoes to form the Brazilian Amazon (Figure 2), European occupation of the Manaus area began with the construction of the Sao Jose fortress on the Rio Negro in 1669. Settlement of what is now the State of Amazonas occurred primarily along the area's principle waterways. A subsistence economy based on small farms along navigable rivers was dominant until the last decade of the 19th century. From

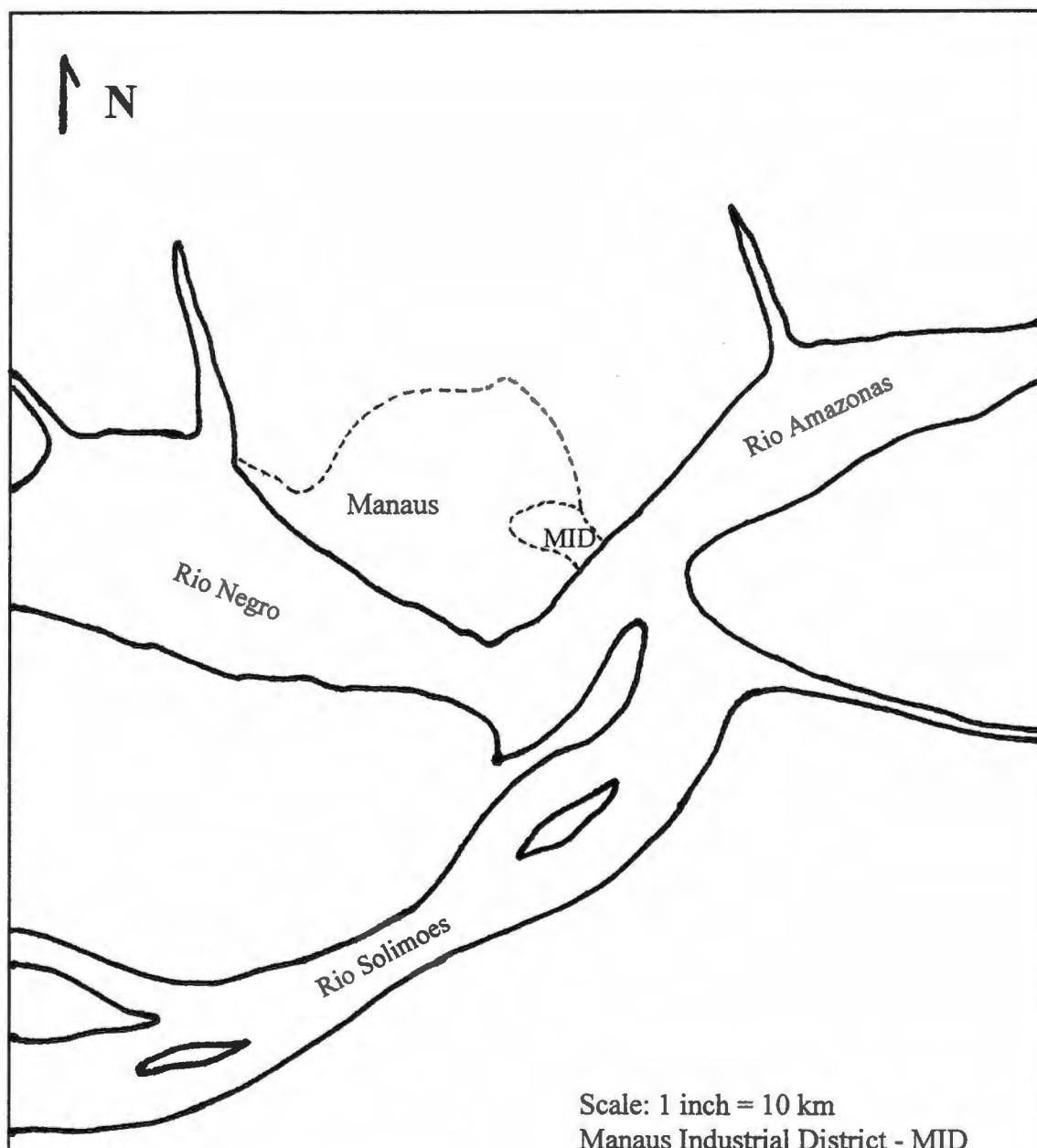


Figure 2. Manaus Region.

The City of Manaus occupies a position on the north bank of the Rio Negro. The city center is located approximately 8 miles upriver from start of the Amazon River at the confluence of the Rio Negro and Rio Solimoes. The Manaus Industrial District is situated on the city's eastern margin near the confluence of the Rio Negro and Rio Solimoes.

approximately 1885 until 1915, natural rubber, the area's chief export, commanded high prices on international markets and spurred a boom in the development of the City of Manaus. The breakup of the monopoly in natural rubber, however, led to a fall in rubber prices, the collapse of the area's economy, and mass emigration. For half a century, Manaus was seen as a town with no future (Suframa, 1996).

In the decades following World War II, development in the Amazon Region occurred primarily in coastal areas such as Para State, while Manaus and Western Amazonia were in decline (Suframa, 1994). One factor that inhibited development of Western Amazonia is its isolation. While located in the center of a continent, Manaus in many ways has an "island" economy in which many goods and foodstuffs must be imported. Manaus is located 1000 nautical miles upriver from the Atlantic Ocean. To this day, road access from Manaus to other parts of Brazil is limited and the air distance to the major cities of southern Brazil, Sao Paulo and Rio de Janeiro, is approximately 2800 km. For comparison, this distance is about two-thirds of the 4300 km air distance from Manaus to Miami, Florida.

In 1957, the Brazilian government decided to encourage economic development in the western Amazon region and established the Manaus free trade zone. Reasons for its establishment included national security issues arising from the demographic vacuum in Western Amazonia. It was not until the issuance of Decree-Law 288 on February 28, 1967, however, that special tax-incentives were provided for facilities in the zone and progress toward the goal of creating an industrial, commercial and agricultural center in the Amazonian interior was initiated (Suframa, 1994). Article 40 of the 1988 Brazilian

constitution guarantees special incentives for facilities in the free trade zone (e.g., tax-exempt status) until the year 2013. The Superintendencia da Zona Franca de Manaus (Suframa) is the federal agency that oversees activities with the Manaus free trade zone. It is tasked with spurring economic development, not only within Manaus, but in the entire Western Amazon region. The scale of this frontier area is truly daunting as it represents fully one-eighth of the continent of South America (Figure 1).

As of June 1996, Suframa reported 617 major and 475 minor manufacturing facilities in operation in the Manaus free trade zone. More than 80 foreign firms had one or more production facilities in Manaus. The total registered investment in the free trade zone was US\$ 6.15 billion, with the electronics sector representing about 65% of total investment (Suframa, 1997). In 1985, Manaus accounted for 91% of total industrial output and 88% of industrial workers within the State of Amazonas (Browder and Godfrey, 1997).

The energy situation in Manaus is serious. Electrical production capacity is currently 510 megawatts and rapidly increasing demand in the Manaus area (especially for industrial and commercial purposes) has brought peak demand to the same level (i.e., 510 megawatts). Due to the remote location of Manaus, infrastructure for importing electricity does not exist. Thus, brownouts and rolling blackouts which have not been seen in Manaus for a decade, could once again become a commonplace occurrence.

While Brazil experienced a recession from 1991 to 1993, production levels in Manaus returned to pre-recession levels by mid-1994 and total production from the free trade zone for 1995 was approximately US \$11.5 billion. This production level

represents approximately 3% of Brazil's industrial production and about 2% of GDP. Electronics (principally consumer electronics) is the primary industry in the free trade zone accounting for 68% of the value of production. For many goods, the production from the free trade zone represents 100% of Brazilian production. This is the case for television sets, video tape recorders and watches. The production of two-wheeled vehicles (motorcycles, motor scooters, and bicycles) is the second most significant sector within the free trade zone in terms of the value of production.

Approximately 75% of the production in Manaus is intended for the domestic market, primarily for consumers in the South. Most of the exports from the free trade zone go to other South American countries. There is a general belief among exporters in Manaus that South American exports will increase with the continued development of Mercosur. In 1992, the source of inputs to production were as follows: 31% of components were imported, 34.4% were produced locally, and 34.6% came from other parts of Brazil.

Much of the production from the free trade zone takes place within the Manaus industrial district (Figure 2). Suframa operates the industrial district in order to provide an additional incentive to companies to locate facilities in Manaus. Suframa develops land, installs infrastructure, and then sells parcels to companies at subsidized prices. Currently, 1700 hectares of the 7400 hectare industrial district are developed and occupied.

4.2.5 Fiscal Incentives

Both the federal and state governments provide fiscal incentives to companies locating in the Manaus free trade zone. Federal incentives (managed through Suframa) include an exemption from the corporate income tax, an exemption from import duties on goods imported for consumption in the free trade zone, and a reduction of import duties on raw materials and parts. State incentives include a reduction in the state's value added-tax.

New industrial and foreign trade policies implemented by the Brazilian government in the early 1990's established standards to strengthen the economy's technological base, foster improved competitiveness, and facilitate export growth. Guidelines were established to ensure that the Manaus free trade zone was integrated in the national effort to globalize the Brazilian economy. This included making fiscal incentives within the free trade zone contingent upon the implementation of a minimum set of production operations at facilities and upon the certification of quality programs at facilities in terms of internationally accepted standards.

In the late 1980's, the Collor administration began cutbacks in federal subsidies for the Manaus free trade zone (Browder and Godfrey, 1997). This and the lessening of national barriers to imported goods and materials in other parts of Brazil (reducing the relative advantage enjoyed by facilities in Manaus) have served to make investments in the free trade zone less attractive to foreign and national capital. This effect is countered by Brazil's current surge in demand for consumer products.

Fiscal incentives provided by the State of Amazonas are contingent upon, among

other things, the possession of an environmental license for the facility from the state's environmental agency. While this requirement has existed for some time, the state has recently initiated more stringent enforcement. In the past year, several facilities have been denied state fiscal incentives for environmental reasons.

4.2.6 Brazilian Environmental Practice

In Brazil, federal legislation related to the environment begins with Article 225 of the Brazilian Constitution. Within Brazil's National Environmental System (SISNAMA), the highest organ of government on environmental matters is the National Environmental Counsel (CONAMA) which was established by public law 6938 in August 1981.

CONAMA is responsible for the formulation of directives related to the national environmental policy (i.e., standard setting), but it does not serve as the federal enforcement agency. Police power is held by, and enforcement is conducted by, the Environmental and Renewable Resources Institute (IBAMA) which was established in 1988. In instances in which there is an appeal from a private entity arising from government actions, CONAMA would hear the appeal.

National Environmental System also establishes central, sectoral, sectional, and local environmental organizations. The central organization is the Special Secretary of the Environment (SEMA). SEMA is part of the Ministry of the Interior and its role is defined in terms of implementation of national environmental policy. Sectional organizations refer to the state level while local organizations refer to municipal entities.

In Amazonas, the environmental agency on the state level is the Instituto de Protecao Ambiental do Amazonas (IPAAM). While the State of Amazonas does have its own environmental legislation, it is fairly limited and IPAAM's enforcement activities relate primarily to environmental standards established by CONAMA. IPAAM is the environmental agency with which facilities in the Manaus free trade zone deal most directly. By law, a facility must have an environmental license in order to operate. In practice, many facilities in the free trade zone are out of compliance. There are three levels of environmental licenses: preparatory (i.e., design review stage), installation (i.e., construction stage) and operational. An example of the application for an environmental license is provided in Appendix B. Once a license has been granted, the frequency of inspections by IPAAM vary depending upon the size of the facility, the nature of its operations and its compliance history. Most participating facilities are inspected on an annual basis. Although IPAAM indicated that it places equal importance on all environmental media, several participating facilities indicated that inspections tended to emphasize potential water pollution problems.

As noted in Section 3.0, only about half of the facilities in the free trade zone currently have environmental licenses. This percentage, however, represents a dramatic increase over the portion of facilities with licenses only a few years ago. It is not only small facilities that lack environmental licenses. Petrobras, one of the largest facilities in Manaus, does not currently have an environmental license.

Additionally, following some well publicized gas leaks from a optical lens facility in the free trade zone during April 1997, individuals responsible of environmental

protection in Manaus recognized that gaps were present in existing environmental legislation. Government officials at the state and municipal levels indicated the need to require disclosure by manufacturing facilities of chemicals used in, or stored at, their facilities. Such legislation would be equivalent to the Community Right-to-Know Act (SARA³ Title III) in the United States.

Some recent steps by Brazil make its environmental protection system more comprehensive than many developed countries. On November 14, 1995, President Fernando Henrique Cardoso signed the "Green Protocol" for financial institutions. The Protocol requires the five major federal government-owned development banks within Brazil to deny credit to businesses that do not comply with environmental regulations (or have outstanding environmental fines issued by IBAMA) and to require assessments of environmental risks in the approval of new loans. While Environmental Impact Assessments (EIAs) were not required for many projects that banks considered in the past, banks will now need EIAs for approval of most projects. State and federal agencies will continue to perform these environmental assessments.

As of February 1996, the governors of six Brazilian States had instructed their State-owned banks to adopt the protocol. The head of IBAMA invited more than 200 private banks to adopt the Protocol. Talks between IBAMA and private banks were initiated in 1996.

³ Superfund Amendments and Reauthorization Act (1986).

4.3

Research Methods

Given the objectives of the research (Section 3), companies visited were not an unbiased sample of firms that operate in Manaus⁴. The primary selection criterion for facilities that participated in the research (i.e., aggressiveness in efforts to improve production methods) was intended to enhance the possibility of finding examples of incremental and equipment-based process change. Companies with significant operations within (or operations closely related to production within) the Manaus industrial district were identified through sources that included Suframa databases, IPAAM research staff, the Brazilian Ministry of Foreign Affairs, the Internet, and inquiries at the U.S. offices of major multinational companies.

As of June 1996, a total of 1092 facilities (617 large; 475 small) operated within the Manaus free trade zone. Total employment was approximately 47,900 persons based upon production in 1996 of approximately US \$ 13.2 billion. The 17 private sector manufacturing companies interviewed in Manaus make up 1.6% of the corporate community in Manaus, but account for 31.7% of total employment and 18.4% of total investment (Table 2). The companies participating in the research accounted for high percentages of total investment in the major economic sectors within Manaus (Table 3).

⁴ A search for environmentally-driven process modification that enhances both environmental performance and competitiveness is in some ways analogous to a search for a member of an endangered species. A successful search is likely to consider habitat requirements of the species and focus search efforts in locations where the probability of locating the species is highest. Similarly, in this research, characteristics thought likely to be associated with environmentally-driven process modification (e.g., aggressive process improvement efforts, factors noted in Section 4.1) were used to narrow the field of search.

Table 2. Background Information Regarding Facilities that Participated in this Research

Facility	Home Country	Economic Sector (Suframa)	Fixed Investment ¹ (US\$)	Number of Employees ¹	Start of Operations ¹
Alumar ^{2,3}	U.S. ⁴	Industria de Mineral Metalico	1,800,000,000	2200	1984
Ariau ³	Brazil	Industria de Ecoturismo		100	1986
Coelma	Germany	Industria de Material Electronico	6,000,000	570	1984
Coimpa	Germany	Industria de Metalurgica	700,000	195	1975
Copelrio ³	Brazil	Industria de Papel (recycling)			
Coplast	Brazil	Industria de Productos de Materias Plasticos	5,400,000	145	1987
Electronorte ³	Brazil	Industria de Estado, Produccion de Eletricidad			
EmTec (formerly BASF)	Korea	Industria de Material Eletronico	45,700,000	1400	1988
Fuji Phot Film	Japan	Industria de Diversas	85,000,000	195	1993
Gillette	U.S.	Industria de Diversas Industria de Productos de Materias Plasticos	57,800,000	1375	1975
Mondane	Switzerland	Industria de Mecanica	2,400,000	650	1976
Moto-Honda	Japan	Industria de Material de Transporte	270,000,000	2350	1976
Outboard Marine	U.S.	Industria de Mecanica	1,700,000	200	1987
Paperboard Manufacturer ⁵	U.S.	Industria de Papel	2,300,000	125	1984
Petrobras ³	Brazil	Industria de Estado, Productos Petroleos	500,000,000 ⁶	300	1955

Table 2 (continued)

Facility	Home Country	Economic Sector (Suframa)	Fixed Investment ¹ (US\$)	Number of Employees ¹	Start of Operations ¹
Philips	Netherlands	Industria de Material Electronico	40,000,000	2890	1973
Recofarma	U.S.	Industria de Quimica	106,500,000	230	1990
Samsung	Korea	Industria de Material Electronico	135,000,000	1325	1995
Seiko	Japan	Industria de Mecanica	1,950,000	275	1975
Sony	Japan	Industria de Material Electronico Industria de Productos de Materias Plasticos	150,500,000	2100	1984
Springer Plastico	Brazil	Industria de Productos de Materias Plasticos	4,800,000	480	1977
Springer-Carrier	U.S.	Industria de Mecanica	7,500,000	80	1981
Xerox	U.S.	Industria de Material Electronico	132,000,000	500	1987
3M ²	U.S.	Industria de Diversas	5,900,000	75	1989
Total (for facilities interviewed)			1,060,650,000 ⁷	15,160 ⁷	
Total (for Manaus free trade zone)			5,770,000,000 ¹	47,900 ⁸	
Facilities interviewed as a percent of total.			18.4%	31.7%	

Source: Suframa. 1996. *Atividades Industriais Perfil das Empresas, Sediadas na Amazonia Ocidental e no Estado do Amapa, com Projetos Aprovados pela Suframa ate Junho de 1996*. Manaus, Amazonas, Brazil. Suframa.

Notes:

¹ Except as noted, data is from Suframa's June 1996 facility database.

² Facility visited is located outside the Manaus free trade zone. Data in table is for facility that company operated in Manaus until 1995.

³ Facility is not included in the June 1996 Suframa database.

⁴ Home country of major partner in consortium.

⁵ Facility requested that the company name not be used.

⁶ Estimated replacement cost of facility.

⁷ Facilities that are not included in Suframa's June 1996 facility database (see note #3) are not included in this figure.

⁸ Suframa January 1997 data.

Table 3. Economic Sectors, Production by Sector, and Sectoral Investment Represented by Participating Facilities

Economic Sector (Suframa)	Production by Sector as a Percent of Total Production in Free Trade Zone during 1996	Percent of Sectoral Investment Represented by Participating Facilities
Industria de Bebidas	1.2	0.0
Industria de Couros, Peles e Assemblhados	*	62.7
Industria de Editoria e Grafica	*	0.0
Industria de Material Electronico, Electronico e de	68.6	12.3
Industria de Madeira	0.4	0.0
Industria de Mecanica	3.3	2.5
Industria de Metalurgica	0.9	1.3
Industria de Minerais Noa Metalicos	0.4	0.0
Industria de Mobiliario	*	0.0
Industria de Papel, Papel ao e Celulose	*	18.3
Industria de Borracha	*	0.0
Industria de de Productos Alimentares	*	0.0
Industria Quimica	5.6	74.2
Industria de Productos de Materias Plasticos	2.5	50.1
Industria de Textil	0.7	0.0
Industria do Vestuario, Artigos de Teccidos e de Viagem	*	0.0
Industria deMaterial de Transporte	9.4	53.9
Industria da Construcao	*	0.0
Industria Diversas	5.1	71.6
Production from sectors marked with asterisk (*)	1.9	4.4

While Suframa classifies producers within 19 sectors, four of these sectors (electronics, transportation equipment, chemicals, and "diversas") accounted for 88.7% of production in 1996. Within these four sectors, companies participating in the research represented the following percentages of total sectoral investment: electronics, 12.3%; transportation, 53.9%; chemicals, 74.2%; and "diversas" (a catch-all group), 71.6%.

In addition to information collected in interviews with senior managers, engineering and environmental staff, and production line personnel at participating facilities, background and supplemental information on the region and individual companies was collected through: discussions with staff at the corporate headquarters of companies whose facilities were visited, Suframa, IPAAM, the Brazilian Ministry of Foreign Affairs, representatives of the U.S. Commerce Department in Brazil, and environmental consultants in Manaus. Literature was obtained from the companies participating in the research, Internet homepages, industry trade associations, and other published sources.

4.3.1 Rationale for Case Study Approach and Details on Study Design

The case study method was selected for two related reasons. First, it is the method that provides the most detailed information about firm practices. Second, regulators at IPAAM suggested that because it provides detailed information on real-life experience, it is the type of information that is most useful to them in efforts to convince facilities that are not currently in compliance to modify their practices. Case studies are presented in Appendix A.

Detailed information of the kind provided by case studies is not available from most studies in this subject area because they have tended to utilize theoretical approaches or aggregate data. In this regard, case studies avoid or mitigate some significant problems. First, the data aggregation effects (e.g., the inability to resolve interacting factors) are precluded by an evaluation at the level of the production line. This is beneficial in assessing both direct costs and benefits, and indirect effects (e.g., potential effects on productivity and innovation). Second, unlike theoretical research, case studies are not reliant on assumptions about behavior. This is significant because individual behavior is thought to be an important aspect of the practices under investigation. Finally, case studies are also more amenable to the interdisciplinary approach required by the subject matter, allowing the consideration of economic, ecological and organizational factors.

The case studies addressed different industries in order to document the potential use and implications of process modification methods in the broadest possible range of industrial settings. The industrial sectors that participated in the research were selected to represent the major industrial activities in Manaus. Participating facilities represented the major subdivisions of industry: heavy industries (e.g., chemicals, metals, and energy sectors), durable goods (e.g., transport equipment and electronic equipment/appliances sectors), and consumer goods (e.g., food/beverages and health care products sectors).

For each case study, background information was collected on the parent company, production at the facility, specific production processes used; environmental effects of those processes; and methods used to eliminate, reduce or manage

environmental effects. Before interviews, most companies received a three page questionnaire requesting background information on the facility (Appendix C).

During interviews, the facilities were queried for examples of environmentally-driven process modifications that improved both the environmental and economic performance of the facility. A protocol (Appendix D) was used during interviews to ensure consistency among plant visits. The information sought for each case study included: the means by which the modification plan surfaced; how it was then developed, evaluated, approved and implemented; a detailed description of the process modification and its effect on production; and the outcome for the firm in terms of environmental and economic consequences. Special attention was given to identifying a) quantifiable information on costs and benefits, b) the organizational tools and processes that were used, and c) conditions that helped or hindered successful completion of the modification project. In addition, an effort was made to determine whether process improvements were ad-hoc responses to particular circumstances or represented an ongoing, program for uncovering improvement opportunities.

While much of the information on modification projects came from interviews with participating facility and government staff, subjective findings were compared with objective data on each project. This included accounting assessments of modification costs and benefits and pollution discharge measures.

The study also emphasized connections between case study results and conditions in other Manaus facilities. In addition to case studies of the most promising firms for environmentally-related innovation and process modification, participants included firms

more typical of industry in Manaus (including representatives of the 50% of facilities that do not have environmental licenses) in order to assess the relevance of model firms to other enterprises in the area. As anticipated, detailed environmental performance data or environmental process modification experiences were not available for these firms.

A translator participated in all interviews to ensure that the interpretation of questions and responses was understood by all present.

4.3.2 Limitations of the Case Study Method

The most significant limitation of the case study method involves the ability to make inferences based upon information from the sample group. In this study, the participating facilities provide neither a random nor a representative sample of the manufacturing facilities within Manaus. Thus, from a statistical standpoint, the sample represented by the case studies within this research is biased. As a result, the ability to make statistically valid inferences based upon information from the case studies is limited to the group of facilities sampled.

This limitation is typical of the case study approach. The limited ability to make statistical inferences, however, does not mean that lessons learned from facility within the sample group cannot be applicable to, or appropriate for, facilities outside the sample.

Another case study related issue is the possibility that in discussions, the participants providing information may have an incentive to "paint" themselves or their organization in the best possible light. It was for this reason that documented information was sought both from the facilities and from independent sources.

5. Facilities Participating in the Research

Fieldwork in Brazil resulted in interviews with 24 companies (Figure 3).

Seventeen of these companies were private-sector manufacturing firms in Manaus. Two of the manufacturing facilities involved in this research were located outside of the Manaus free trade zone. One of these facilities is linked to Manaus production in that it is a supplier of a critical input, aluminum, to the second largest industrial sector in Manaus. The other participating facility located outside Manaus had operated a facility within the free trade zone until early 1996. This company was of interest, in part, because it had recently decided to discontinue operations in Manaus.

Two government-owned companies (involved in electrical power generation and oil production/refining) also participated. The three remaining firms were not manufacturing facilities. Two were involved with the recycling of solid waste, while the final company represented the service sector (an ecotourism lodge). The purpose of including the recycling firms was to obtain a broader view of the recycling activities undertaken by the participating manufacturing firms. The company within the tourism sector was of interest because eco-tourism is one of the most rapidly expanding segments of the Manaus regional economy.

Six companies were Brazilian. The other 18 were subsidiaries of multinationals or were partnerships between multinationals and Brazilian firms. In most cases, management of facilities was Brazilian (regardless of ownership). Home countries of the multinationals included the U.S. (8), Japan (4), Korea (2), Germany (2), The Netherlands (1), and Switzerland (1) (see Table 2).

Number of industrial facilities in Manaus free trade zone	1092
Number of companies contacted	42
Number of companies that refused to participate in research	12
Number of companies that agreed to participate, for which a mutually acceptable schedule for a facility visit was not achieved	6
Number of companies participating in research	24
Number of manufacturing facilities participating in research	21
Number of private-sector manufacturing facilities participating in research	19
Number of private-sector manufacturing facilities (located in Manaus) participating in research	17
Of the manufacturing facilities interviewed:	
- number with equipment-based process modifications ^a	4 of 21 (19%)
- number with incremental process modifications ^a	6 of 21 (24%)
- number with both incremental and equipment-based process modifications ^a	3 of 21 (14%)
Types of environmental protection efforts observed at participating facilities:	
- Number of incremental process modifications ^a	19
- Number of equipment-based process modifications ^a	4
- Number of static process approach	6
Process modifications that were related to production activities	16 of 23 (70%)
Process modifications that were related to production support activities	7 of 23 (30%)

^a Modifications that enhanced environmental and economic performance.

Figure 3. Summary Information Regarding Participating Facilities and Types of Environmental Protection Efforts

6. Results - General

Company interviews (and the information that firms provided) lead to the identification of 23 examples of equipment-based and incremental process change that contributed to both environmental performance and corporate competitiveness (Figure 3). These examples were obtained from 7 of the 21 participating manufacturing facilities (i.e., 33%). This set of examples, however, was not exhaustive. Discussions with company representatives surfaced a number of other potential examples, although insufficient documentation prevented the confirmation of synergies between environmental and economic outcomes.

A basic information set was sought for each process modification example, although the data actually available varied considerably from one example to another. The minimum set of information sought included: quantity of waste reduced (or the quantity of resources/energy conserved), percentage reduction in waste generation (or resource/energy use), medium affected (air, water, land), time required for implementation, capital cost (if any), annual savings as a result of the change, payback period, and effect on production (if any). Summary information related to these factors is provided in Figure 4.

In nearly all cases, facilities implementing process modifications had analyzed the effects of modifications in terms of the effect on the environment and the effect on production volume or rate. However, the facilities generally did not carry the analysis through to the point of quantifying the economic impact of a particular change. Thus, in a number of instances, engineers at a facility became aware of the specific economic

Percentage reduction in wastestream^a (or resource use):		
	range	25-100%
	average	71.6%
Implementation time^b:		
	range	1-30 months
	average	10.1 months
Payback period^c:		
	range	2 days to 11 months
	average	5.3 months
Effect on production (volume or rate)^d:		
- increases	range	25 to 265%
	average	91%
- decreases		none observed
Capital cost		
- equipment-based and incremental modifications ^e	range	\$0 to \$2 million
	average	\$240,000
- equipment-based modifications ^f	range	\$7000 to \$2 million
	average	\$759,000
- incremental modifications ^g	range	\$200 to \$50,000
	average	\$ 14,600
- incremental modifications with zero capital costs		11 of 19 (58%)
Savings		
- in first year following implementation ^h (operating cost reductions plus avoided costs)	range	\$2300 to \$21 million
- recurring (annual) equipment-based modifications ⁱ	range	\$168,000 to \$2.3 million
	average	\$1,348,000
incremental modifications ^j	range	\$2,000 to \$9.1 million
	average	\$738,500

^a Based on 20 examples for which data was available.

^b Based on 20 examples for which data was available.

^c Based on 9 examples for which data was available.

In the 11 examples that involved no capital costs, the payback period is undefined.

^d Based on 7 examples for which data was available.

In six additional examples, there was an increase in yield or rate, but percentage increase is unknown.

^e Based on 10 process modification examples for which data was available.

^f Based on 3 examples for which data was available.

^g Based on 7 examples for which data was available.

^h Based on 18 examples for which data was available.

ⁱ Based on 3 examples for which data was available.

^j Based on 15 examples for which data was available.

Figure 4. Summary Information Regarding Performance Characteristics for Observed Process Modifications

benefits of their actions only during the process of reviewing and analyzing process changes as part of this research.

Incremental process modifications (19 examples) were found in 6 of 21 facilities (or 29% of the participating manufacturing firms). Equipment-based process modifications (four examples) were identified in 4 of 21 facilities (or 19% of the participating manufacturing firms). There was considerable overlap between the groups of firms that uncovered equipment-based and incremental process modifications. In fact, three of the four companies that uncovered equipment-based process changes also uncovered incremental process changes. Information provided in Sections 5 and 6 is summarized in Figure 3.

In addition to the equipment-based and incremental process changes, six environmental protection efforts based upon the static process approach (i.e., the production processes were unchanged) were identified (Table 4). In these cases, control measures improved environmental protection, but also increased production costs.

Table 4. Environmentally-Driven Process Modification and Process Supplementation

	P/ PS ¹	quantity ² (per year)	% ³	time to implement	capital cost ⁴	annual savings ⁴	NPV ^{4,5}	payback period	effect on yield ⁶
Incremental process change									
Alumar - carbon bake ovens	P		100	30 months	0	1 million	56 million	⁷	33%
- smelter fluoride emissions	P	47 tons	52	30 months	0	9.1 million	33 million	⁷	0%
- acid neutralization	P		100	3 months	2000				100%
Philips - copper treatment	P	100kg CuCl	50	6 months	1030	4200	14,800	3 mo.	0%
- energy conservation	PS	938,000 kwh		3 months	3000	75,000 ⁸	280,400	0.5 mo.	NA
- solid waste	PS	558 tons		12 months	30,000 ⁸	84,000	287,000	4 mo.	NA
3M - solid waste	PS	468 tons ⁹	42	12 months	50,000 ⁸	240,000	856,000	2.5 mo.	NA
- shift from solvent to water based process for masking tape	P		100	18 months		prod. cost cut by 50%			265%
- energy conservation:									
Scotch Brite	P	38,400 kwh 432 hrs steam	33	12 months	0	42,400	160,000	⁷	33%
Adhesive A-796	P	4775 kwh/load	66	12 months	0	334/load		⁷	¹⁰
Adhesive FC-206-F1	P	1492 kwh/load	66	12 months	0	104/load		⁷	¹⁰
new ceiling panels	PS	630,000 kwh	25	8 months	0 ¹¹	50,400	190,000	⁷	NA

Table 4. Continued

	P/ PS ¹	quantity ² (per year)	% ³	time to implement	capital cost ⁴	annual savings ⁴	NPV ^{4,5}	payback period	effect on yield ⁶
Moto Honda - water conservation	PS	10 to 112 m ³ (per faucet)	100	6 months	16,000	2,000 to 19,500	24,500	2 years	NA
- electricity conservation (air leak maintenance)	P	225,000 kwh	25	6 months	0	21,900	82,600	⁷	0%
Recofarma - tank cleaning	P	1340m ³ water	93	1 month	200	38,900	146,600	2 days	¹⁰
- production scheduling	P	79m ³ water	77	1 month	0	2,300	8700	⁷	¹⁰
- revised drum handling	P	2250m ³ water	100	1 months	0	65,000	245,350	⁷	¹⁰
Xerox - pallet reuse	PS	3000 pallets	100	9 months	0	44,000	166,000	⁷	NA
- toner loss	P	245 kg	50	9 months	0	298,000	1,125,000	⁷	¹⁰
Equipment-based process change									
3M - solvent recovery system	P	4000 tons	94		2,000,000	2.3 million ¹²	8,682,000	11 months	0%
Xerox - reduction of solvent use	P	216 tons	90	12 months	270,000	1,584,000	5,709,000	2 months	25
Moto Honda - recycling of thinner	P	245 tons	70		7,000	160,800	600,000	0.5 month	0%
Gillette - energy conservation (lighting, compressors, generators)	PS			¹³					NA

Table 4. Continued

Process Supplementation									
	P/ PS ¹	quantity ² (per year)	% ³	time to implement	capital cost ⁴	annual savings ⁴	NPV ^{4,5}	payback period	effect on yield ⁶
Petrobras - o/w separator upgrade	PS		87	18 months	25,000	NA	NA	NA	NA
- addition of retaining basin	PS			18 months	4 million	NA	NA	NA	NA
- addition of treatment plant	PS			30 months	6 million	NA	NA	NA	NA
Paperboard facility (addition of treatment plant)	PS					NA	NA	NA	NA
Alumar - construction of residue ponds	PS								NA
Springer Carrier (improved testing equipment)	P	169 kg of refrigerant		12 months	120,000	NA	NA	NA	NA

kg - kilograms

kwh - kilowatt-hours

CuCl - copper chloride

Notes:

¹ Modification occurred in a "production" or "production-support" setting.² Quantity of waste reduced or resources saved.³ Percent reduction in wastewater or in the quantity of resources used.⁴ Amounts are indicated in US dollars.⁵ The Net Present Value (NPV) assumes a 10 year investment period and a 25% discount rate.⁶ Percent increase in yield or production capacity. No process change resulted in reduction in yield.⁷ When the amount invested is zero, the payback period is undefined.⁸ Estimate based upon information provided by the staff of facility.⁹ Waste generation at 3M Sumare plant fell by 40% per ton of production between 1990 and 1995. During the same period, waste recycling increased from near zero to 75% of waste generation.¹⁰ Yield (or production capacity) increased, but detailed information on the percentage of increase is unavailable.¹¹ No capital cost was incurred because the facility already had excess panels in storage on-site.¹² Figure is net of equipment operating expenses.¹³ Implementation occurs as existing equipment requires replacement.

7. Results - Specific

Specific results are summarized under three headings: a) accomplishments of companies applying process modification approaches to improve environmental performance, b) characteristics shared by companies that have successfully undertaken process modification for environmental purposes, and c) factors that motivate companies to undertake environmental protection efforts.

7.1 Process Modification Accomplishments

In the examples identified, process changes were implemented for two reasons. The first reason was the removal environmental risks. In some cases, environmental regulation was the driving force, although in most of the examples no regulatory mandate existed. The second reason was the conservation of natural resources. The processes that were the subject of modification efforts represent both production support (e.g., equipment maintenance, facility management, shipping) and production. Of the 23 process modification examples identified, 70% were related to production activities (Table 4). The processes themselves varied considerably in terms of scale, inputs, potential environmental releases, and the environmental media (air, water, land) affected. Process modifications were implemented on wastestreams whose scale varied by multiple orders of magnitude. For example, process modifications ranged from actions that lead to the recovery and reuse of 4000 metric tons of waste solvent each year (resulting in annual savings of US\$ 2.3 million) to changes that reduced the quantity of water entering a wastewater treatment facility by 79 m³ per year (resulting in annual savings of

US\$ 2300). Resource and energy conservation efforts showed a similar variation in scale. The percentage reduction in the original wastestream (or resource requirement) provides an indication of the effect of process modifications that is independent of process scale. The percentage reduction ranged from 25% to 100% (i.e., the complete elimination of the wastestream). The average reduction was 71.6% based upon 20 process change examples for which this information was available.

Capital costs associated with the projects examined ranged from \$0 to \$2 million, while first year cost savings (operating cost reductions plus avoided costs) ranged from \$2300 to \$21 million. Project implementation time ranged from 1 to 30 months. The average implementation period was 10.1 months based upon 20 process change examples for which this information was available. The payback period (or time required to recoup the initial capital investment) for the process modifications studied ranged from two days to 11 months. Payback period is commonly used as an indicator of investment risk (shorter payback periods represent lower risk). The short payback periods observed (i.e., less than 1 year) are indicative of very low risk investments.

The modifications studied also influenced production volume or production capacity. Based upon information from 16 of the process modification examples, modifications increased the volume (or rate) of production in 69% of the cases (in no case did production volume decline). Increases in production volume (or rate) ranged from 25% to 265% and averaged 91% (Table 4; Figure 4).

Activities at 3M Corporation's Sumare plant provide an example of the manner in which process modifications effect yield and production capacity. The process for

production of "Scotch-Brite" tape at Sumare was evaluated for opportunities to reduce energy consumption. Following this evaluation, a number of small process modifications were implemented with the result that the number of passes through the process oven that were required to dry the product was reduced from three to two. The change reduced energy consumption by reducing steam generation and electricity use required. Further, because passage through the oven was the time limiting step within production, the change also reduced production time by one-third. This reduction in production time for the product had the effect of increasing the production capacity of the existing equipment.

7.2 Characteristics of Companies Undertaking Process Modification for Environmental Purposes

Companies with successful programs for environmental process change (i.e., those that provided examples of process modification that enhanced environmental and economic performance) shared characteristics that were observed only rarely in the companies that did not provide examples of environmentally-driven process modification (Table 5). The most basic of these characteristics was the establishment of a formal environmental program. The following program features were observed at each of the facilities that provided examples of successful equipment-based or incremental process modification: a written statement of environmental policy, clearly defined corporate environmental goals, clear leadership on environmental issues, and periodic audits of environmental management systems by a group from outside the facility (Figure 5). Descriptions of these program characteristics are provided in Section 7.2.1.

Table 5. Characteristics of Environmental Programs at Participating Facilities

Company	Envir Policy*	Envir Goals*	Leadership ¹	Employee Involvement	Corp ²	Self ³	Audit sup/subs ⁴	Cust ⁵	Envir-Quality Prog. links	Cost Acct ⁶	Mat Acct Mat Bal ⁷
Alcoa ⁸	Yes No	Yes Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes
Philips ⁸	Yes No	Yes Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
Sony	Yes No	Yes No	No	No	No	No	No	No	No	No	No
3M ^{8,9}	Yes No	Yes Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Recofarma ⁸	Yes No	Yes Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No
Xerox ^{8,9}	Yes No	Yes Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
Springer Plastico	No No	No No	No	No	No	No	No	Yes	No	No	No
Mondane	No No	No No	No	No	No	No	No	No	No	No	No
Copelirio	No No	No No	No	No	No	No	No	No	No	No	No
Moto-Honda ^{8,9}	Yes Yes	Yes Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
Coimpa	Yes Yes	Yes Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Outboard Marine	No No	No No	No	No	No	No	No	No	No	No	No
Em Tec	No No	No No	No	Yes	No	No	No	No	No	No	No
Eletronorte	No No	No No	No	No	No	No	No	No	No	No	No
Petrobras	Yes No	Yes Yes	No	No	Yes	Yes	No	Yes	No	No	No

Table 5. Continued

Company	Envir Policy*		Envir Goals*		Leadership ¹	Employee Involvement	Corp ²	Self ³	Audit sup/subs ⁴	Cust ⁵	Envir-Quality Prog. links	Cost Acct ⁶	Mat Acct Mat Bal ⁷
Springer Carrier	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No
Gillette ⁹	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	No	No	No
Coplast	No	No	No	No	No	No	No	No	No	No	No	No	No
Samsung	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No	No
Ariau	No	No	No	No	No	No	No	No	No	No	No	No	No
Coelma	No	No	No	No	No	No	No	No	No	No	No	No	No
Fuji Photo Film	No	No	Yes	No	No	No	No	No	No	No	No	No	No
Seiko	No	No	No	No	No	No	No	No	No	No	No	No	No
Paperboard Producer	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No

* The first entry in column refers to the Corporation; the second entry refers to three facility visited.

Notes:

¹ Leadership responsibility for environmental issues within company is clearly defined.

² Staff from corporate office perform environmental audits at facility.

³ Facility staff perform self-assessments of performance (including environmental performance).

⁴ Facility staff perform assessments of suppliers and subcontractors.

⁵ Customers evaluate the environmental performance of facility.

⁶ Facility uses cost accounting system that applies environmental costs to individual products rather than to overhead.

⁷ Facility uses materials accounting and materials balancing as a means of identifying process modification opportunities.

⁸ Facilities implementing incremental process change.

⁹ Facilities implementing equipment-based process change.

Basic Characteristics^a:

Environmental Policy
Corporate Environmental Objectives
Environmental Leadership
Periodic Environmental Audits

Supplemental Characteristics^b:

Periodic Self-Assessments
Employee Involvement
Links between Quality Improvement and Environmental Quality Efforts
Facility Environmental Objectives

^a Facilities that implemented equipment-based process modification and those that implemented incremental process modification both displayed these characteristics.

^b Facilities that implemented incremental process modification displayed these characteristics in addition to those listed as "Basic" characteristics.

Figure 5. Environmental Program Characteristics Associated with Successful Process Modification

Four additional characteristics were observed in all of the facilities that provided examples of incremental process change. These characteristics were periodic self-assessments of environmental performance, active employee involvement programs, strong links between product/process improvement activities and efforts to improve environmental performance, and facility environmental goals (Figure 5). Descriptions of these program characteristics are provided in Section 7.2.2.

7.2.1 Features Associated with both Equipment-Based Process Change and Incremental Environmental Process Change

The following characteristics are shared by both the facilities that made equipment-based process changes and those that made incremental process changes.

7.2.1.1 Environmental Policy

Each of the companies with successful programs for environmental process change had established formal, written statements of environmental policy. Generally, this policy was addressed in employee training, and appeared to be clearly understood by the production staff and the managers questioned. At one facility, the policy was posted on a large sign at the main entrance to the facility. Most of these policies indicated the corporations' preference for pursuing a preventive approach to environmental issues (i.e., avoiding the generation of waste rather than addressing the management of wastes once created). Environmental policies also stated that the focus of environmental programs should be the reduction of environmental risk rather than simple compliance with

environmental regulation. In other words, corporate policies adopted an approach that viewed compliance with environmental regulation as a minimum and committed the company to pursue continuous improvement in environmental performance even when performance exceeded the requirements of environmental law. Each of the multinational companies with successful programs for environmental process change had established corporate standards for environmental performance. These standards exceeded corresponding local standards.

7.2.1.2 Corporate Environmental Objectives

The parent corporation of each facility with a successful program for environmental process change had established specific objectives for improving environmental performance, as well as timetables for implementing those objectives. Objectives varied from company to company, but in all cases served as a mechanism to drive action on environmental issues. Personnel at facilities indicated that it was important that the goals be challenging, but achievable. For example, 3M Corporation intends to reduce releases to air, water and land by 90% by the year 2000, using 1990 as the base year. Similarly, Xerox plans by 1998 to reduce municipal, hazardous and chemical wastes by 90%; reduce air emissions by 90%; reduce water discharges by 50%; and increase energy efficiency to within 10% of each facilities theoretical optimum (based upon individual facility baselines).

Some companies have also established goals that are intended to highlight to employees the intentions of management even though the goal may not yet be achievable.

For example, one 3M Corporation goal is the elimination of all water discharges.

7.2.1.3 Environmental Leadership

Each of the facilities with successful programs for environmental process change have clearly established lines of responsibility on environmental issues. Responsibility for environmental performance rests with line management (i.e., the same people who are responsible for production are responsible for the environmental effects of production). This begins at the corporate level and extends to the facility level (i.e., the plant manager and production managers). Some corporate policies specifically noted that environmental responsibility began with the chief executive officer (CEO). Other companies had given a member of the board of directors (or a committee of board members) specific environmental responsibility.

This responsibility was often emphasized by including environmental performance as one criterion in evaluations of manager performance. The emphasis on management responsibility was particularly strong at Alumar (Section A.4). The facility eliminated its separate (and more easily ignored) environmental performance objectives document and incorporated environmental objectives into the annual operating plan. This is the basic management plan for the facility and is the document against which management performance is measured.

For most of the companies interviewed, giving line management clear responsibility for environmental performance represented a shift in practice. Previously, at facilities large enough to have a separate environmental staff, that staff had borne full

responsibility for environmental performance. The shortcoming of this approach was that environmental staff often lacked the authority needed to change practices at the facility. Environmental staff are still expected to provide leadership on environmental issues, but their role would now be better described as "internal consultants" to line management.

Some facilities strive to increase cross-disciplinary experience. At Alumar environmental engineers work closely enough with production engineers that they fill in for production staff at times. At another facility, the environmental manager was formerly the production manager.

Industry in Manaus is also working cooperatively to provide opportunities to increase worker skills. The association that represents companies with operations in the Manaus free trade zone encouraged the University of Amazonas to develop a series of "specialty degrees". These post-graduate programs are similar to a masters degree, but tend to focus narrowly on specific topics (Figure 6). Courses of study last one year, are intensive and are scheduled to permit attendance by professionals who are employed full-time. The companies of the free trade zone are the primary source of financial support for the specialty degree program. Degrees are offered on a wide variety of topics with 40 to 50% of the topics being directly applicable to the needs of facilities in the free trade zone.

7.2.1.4 Periodic Environmental Audits

Each of the facilities with successful programs for environmental process change undergo periodic environmental performance audits by personnel from outside the facility. In most cases, auditors were from corporate headquarters, although there were

Strategies for Business Competitiveness
Management and Planning of Construction
Environmental Engineering
Workplace Safety Engineering
Production Engineering
Industrial Automation
Environmental Analysis
Work Management
Environmental Management
Environmental law
Labor law
Eco-tourism
English
Portuguese

Figure 6. **Examples of Specialty Degrees Offered
by the University of Amazonas**

instances in which the auditors came from other company facilities or from outside of the firm. The period between audits varies from company to company and ranges from once each year to once every three years. Audits covered all areas related to environmental performance including: environmental management systems, systems to identify waste reduction opportunities, process monitoring and management, waste management and recordkeeping, employee training, and reviews of violations of regulatory requirements. The audit generally resulted in a formal report with specific "findings" or areas in which the facility could improve performance. Facilities were required to respond to findings by developing a plan of action that would lead to the resolution of each finding. The plan included a timetable and mechanisms for monitoring progress toward implementation. Confirmation of finding resolution was always part of the next audit.

7.2.2 Supplemental Features Associated Specifically With Incremental Process Change

In addition to characteristics shared with facilities that have made equipment-based process changes (Section 7.2.1), the companies that pursued incremental process change displayed additional traits. These characteristics are described in Sections 7.2.2.1 to 7.2.2.4. Programs of two facilities that has been particularly successful in applying incremental process modification methods display two characteristics not seen in other programs. These characteristics are described in Sections 7.2.2.5.

7.2.2.1 Periodic Environmental Self-Assessments

All of the facilities that provided examples of incremental process modification conducted periodic self-assessments of environmental performance. Corporate staff generally encouraged personnel at each facility to undertake self-assessments, although they were not necessarily mandatory. Self-assessments covered the same areas that were covered in the environmental audits (Section 7.2.1.4). Self-assessments were typically conducted annually, although some facilities conducted assessments every six months. In some cases, the results of self-assessments were reported to headquarters personnel, while in other cases, they were solely for the benefit of the facility staff. As with the external audits, self-assessments resulted in improvement plans, timetables for implementation, and measures for monitoring the progress of implementation.

7.2.2.2 Facility Environmental Objectives

The facilities with successful incremental process change programs had established facility-level environmental objectives (in addition to corporate objectives). For example, Moto-Honda has a 1997 objective of reducing electrical power use by 6% per unit of production.

7.2.2.3 Employee Involvement

The facilities that successfully uncovered opportunities for incremental process modification each had a program to encourage and implement employee suggestions. These programs addressed all aspects of operations and were not limited to environmental

issues. Most suggestion programs included incentive-reward systems as well. The facilities with the most active employee suggestion programs tended to have a greater number of incremental environmental process modifications.

In the companies with successful suggestion programs, it was not uncommon for production line personnel (those who typically have the least formal education) to provide input that lead to important process modifications. Some managers noted that in the past, they had only used the employee's hands and now are asking employees to use their minds as well. To back this up, some companies are providing substantial training for all employees (up to 60 hours per year) intended to support workers in recognizing and analyzing opportunities for improvements. This training includes statistical process control and what Imai (1985) refers to as the seven tools of quality control (Pareto diagrams, cause and effect diagrams, control charts, histograms, scatter diagrams, graphs and check sheets).

Employee involvement is also encouraged by sharing information on production processes, the facility's environmental objectives, and progress toward those objectives.

This "social" aspect of company activities has an analogue in development planning theory (i.e., the importance of consulting with local people and including them in the design of a development project). In both cases the rationale is the same: those closest to a situation have information that those more removed from the setting will not.

7.2.2.4 Links Between Quality Improvement and Environmental Quality Efforts

The facilities that successfully uncovered opportunities for incremental process modification linked efforts to improve product/process quality with efforts to improve environmental performance. Several managers noted that they considered these efforts indistinguishable in several critical ways. For example, both efforts require significant employee input and training that supports the capacity of employees to provide that input. These managers perceived both efforts as a drive for efficiency (treating the generation of environmental wastes as a sign of process inefficiency) and, therefore, applied similar tools and approaches.

7.2.2.5 Materials Accounting, Full Cost Accounting Efforts

Materials accounting is used to identify sources of wastes and activities that result in the generation of wastes. It involves the tracking of individual chemical inputs to, and outputs from, processes. The tracking of inputs includes quantities brought onsite, in inventory or created in plant operations. The tracking of outputs includes quantities consumed in plant processes, received from processes as coproducts or waste, or shipped as product. Materials accounting is more common within the chemicals industry than in other economic sectors. Two participating facilities that had particularly successful environmentally-driven process improvement efforts used materials accounting, one of these facilities is in the chemical sector.

Full cost accounting efforts attempt to incorporate environmental protection costs into the facility's accounting system and assign those costs to individual processes rather than to facility overhead. The types of environmental costs addressed include pollution control, waste disposal, regulatory compliance, and insurance. Full cost accounting requires that a materials accounting system be implemented first.

By identifying the principle waste producing processes or those that involve high costs related to environmental protection, these approaches provide facilities with insights into the areas in which process modification efforts might be most fruitful.

7.3 Motivating Factors

All companies interviewed were keenly aware of, and were concerned about, environmental issues. This was true both for facilities that had already established strong environmental programs and for facilities that had yet to take the first steps in establishing an environmental program. The level of concern observed in companies that had not initiated environmental programs was unanticipated. Managers of these facilities indicated that their concern was the product of a belief that a) market changes (regardless of government action) demanded the implementation of environmental programs, and b) that the competitive position of the company would be compromised if environmental programs were not soon implemented.

All the companies interviewed were asked to discuss the factors that motivated them to initiate (or consider initiating) environmental efforts (Figure 7, Table 6).

Companies Without Environmental Licenses

- Environmental reviews by corporate customers
- Customer expectations
- Increased government enforcement of environmental standards
- Links between financial incentives and acquisition of an environmental license
- Worldwide acceptance of ISO 14000
- Bank loans and the Green Protocol

Companies With Environmental Licenses

- Corporate policy
- Corporate image
- Current regulation and the possibility of more stringent future regulation
- Consumer expectations
- Outcome of environmental audits

**Figure 7. Summary of Motivations for Environmental Protection Activities
Among Participating Facilities**

Table 6. Motivations for Environmental Protection Efforts Among Participating Facilities

Company	Policy of Corp ¹	Audit ²		Corp Customer Demands ³	Consumer Demands ⁴	Fin Incen ⁵	Loan Req ⁶	Disposal Issues ⁷	Reg ⁸	Future Reg ⁹	Liability ¹⁰	PRTR ¹¹	Oper Eff ¹²	Energy Eff ¹³	Yield ¹⁴
		Corp	Self												
Alcoa	*	x		x	x				x				*	x	x
Philips	*			x	x			x							
Sony	*														
3M	*			x				x			x		*	x	x
Recofama	*												x		
Xerox	*	x	x	x	x			x	x	x	x		x	x	x
Springer Plastico				*		*	x		x						
Mondane															
Copelrio															
Moto-Honda	*	x	x		x				x				x	x	
Coimpa	*	x	x		x			x	x	*	x		*		*
Outboard Marine															
EmTec	x				*								x	x	x
Elettronorte															
Petrobras	*	x	x		*			x	*	x	x		x	*	x
Springer Carrier	x	x	x					x			x				
Gillette	*														

Table 6. Continued

Company	Policy of Corp ¹	Audit ²		Corp Customer Demands ³	Consumer Demands ⁴	Fin Incen ⁵	Loan Req ⁶	Disposal Issues ⁷	Reg ⁸	Future Reg ⁹	Liability ¹⁰	PRTR ¹¹	Oper Eff ¹²	Energy Eff ¹³	Yield ¹⁴
		Corp	Self												
Coplast															
Samsung	*		x							x			x	x	
Ariau															
Coelma	x	x						x					x	x	
Fuji Photo Film	*			x		x		x		*			x	x	
Seiko															
Cardboard Producer	x	x	x	x	x			x	x	x			x	x	

x Staff at facility considered this factor important.

* Staff at facility considered this factor very important.

Notes:

¹ Policy of Corporation regarding environmental issues.

² Audits of environmental systems and environmental performance by corporate personnel and self-assessments by staff of facility.

³ Demands that corporate customers place on their suppliers and subcontractors.

⁴ Demands that the consuming public place on companies supplying products.

⁵ Requirements related to financial incentives offered by governmental entities.

⁶ Requirements related to qualifying for bank loans.

⁷ Issues and problems related to the disposal of industrial wastes.

⁸ Environmental regulations - current and future.

⁹ Potential liability for improper disposal of industrial wastes.

¹⁰ Pollutant release and transfer registry (PRTR). As of 1996, Brazil did not have a PRTR. Agenda 21 (Chapter 19), the action plan developed as part of the Earth Summit in Rio de Janeiro in 1992, called upon countries to develop PRTRs. The U.S.'s PRTR is called the Toxics Release Inventory.

¹¹ Gains in operating or in energy efficiency.

¹² Gains in energy efficiency.

¹³ Gains in energy efficiency.

¹⁴ Increases in product yield or production rate.

7.3.1 Companies Without Environmental Licenses

Companies that had yet to implement environmental programs noted that the factors pushing them toward the development of environmental programs included:

- environmental reviews by corporate customers.

A number of companies now conduct reviews of the environmental performance of their suppliers (e.g., Philips, Xerox, Springer-Carrier). Several managers indicated that for many intermediate goods, the potential suppliers are very competitive in terms of price and quality. In these instances, the supplier's environmental performance will increasingly be used as a discriminating factor.

Suppliers appear to be taking this situation quite seriously. In interviews, suppliers that have not yet initiated environmental management programs noted a concern that their current environmental performance could lead to the loss of contracts. These firms are, consequently, beginning reviews of their environmental performance and environmental management systems.

- consumer expectations.

Companies selling final goods note growing concern about both their environmental performance and perception of that performance by the public. Consumers increasingly demand products that are produced in an environmentally friendly fashion. Further, consumers often expect that there will be no increase in cost associated with enhanced product environmental attributes. This demands

that companies find ways to improve environmental performance while increasing efficiency.

Related to customer expectations regarding a specific product is their view of the company generally. Several facilities noted that they had modified production related practices to avoid the use of tropical woods (e.g., as material for pallets or as a fuel source). The stated driver for these actions was the desire to avoid being seen as contributing to the destruction of rainforests.

- increased governmental enforcement of environmental standards.

Several of the managers interviewed had experience in southern Brazil. These individuals generally thought that enforcement of environmental regulations in Manaus was less stringent than in southern Brazil. However, they also thought that this situation was changing rapidly and that governmental reviews of company activities were becoming more certain and more professional.

- links between financial incentives and the acquisition of an environmental license.

Some facilities attributed their attention to environmental concerns to the possibility of losing financial incentives from the State of Amazonas if an environmental license was not obtained or was allowed to lapse.

Brazil's Federal Law 6.938 (August 1981) requires the forfeit of governmental fiscal benefits for entities that are not in compliance with regulations (state or federal). While not enforced by Suframa with regard to

environmental regulations as of April 1997, managers interviewed expect that the receipt of federal government incentives by facilities will eventually be linked to the possession of an appropriate environmental license from the state. In fact, during April 1997, IPAAM, the state environmental agency was considering bringing a lawsuit against Suframa to force the agency to implement reviews of facility compliance with state and federal regulations before granting or renewing fiscal incentives.

- worldwide implementation of ISO 14000.

ISO 14000 is an international standard for environmental management systems. It is issued by the International Standards Organization (ISO) and is adopted by companies on a voluntary basis. Issuance of the first edition of ISO 14000 (September 1996) raised concerns that the failure to become certified under ISO 14000 may ultimately inhibit a facility's ability to compete internationally. There was a sense among managers that certification may effectively become a "requirement" for access to certain markets, particularly the European Community. Additionally, some managers believe that the receipt of federal government incentives may eventually become linked to ISO 14000 certification (in the same way that the Brazilian Quality and Productivity Program lead to links between federal incentives and ISO 9000 certification).

- bank loans and the Green Protocol of banks.

As noted in Section 4.2.6, the "Green Protocol" requires federal development banks within Brazil to deny credit to businesses that do not comply with environmental regulations. A number of state banks have also adopted the protocol.

Managers of some facilities were concerned that the implementation of the Protocol means that loans needed for future expansion would not be available until the facility meets the requirements for, and obtains, an appropriate environmental license.

7.3.2 Companies With Environmental Licenses

Companies that already have environmental licenses noted that their motivations for environmental efforts derived from:

- corporate policy.

For multinationals, corporate policy was the primary motivating factor for environmental efforts. In interviews, managers noted that experience with environmental issues and regulation in other countries, led corporate management to conclude that environmental efforts need to be proactive. In this sense, Brazil (and other countries) have benefited from actions of the countries that lead in the establishment of environmental laws. For example, the concept of retroactive

liability introduced by CERCLA⁵ (Superfund) legislation in the U.S. has had worldwide impact even though, to date, the practice has not been followed by other countries. This impact is indicated by responses to a 1991 survey on environmental issues by McKinsey and Company (over 400 chief executive officers and senior managers from the world's largest companies participated, including 30% of all corporations with sales exceeding US \$5 billion). Two-thirds of those surveyed agreed with the statement: "On most environmental and product safety related issues, firms will be held accountable for tomorrow's laws".

The establishment of an appropriate corporate policy is the first step in building a foundation supportive of a proactive approach to environmental issues (characteristics of policies are described in Section 7.2.1.1). Interviews with participating multinational corporations indicated that experiences that lead to the adoption of proactive environmental approaches frequently involved problems with, and liability issues related to, the disposal of industrial wastes in the home country and in the United States.

- current regulation and the possibility of more stringent future regulation.

While current regulation was a concern to managers, they were still more motivated by the expectation that regulations would become more strict in the future. Managers believed that long-term productivity would be enhanced by

⁵ Comprehensive Environmental Response, Compensation, and Liability Act (1980).

"getting ahead of" environmental issues rather than waiting for government action to define environmental requirements.

- consumer expectations.

On this topic, companies with environmental licenses shared the concerns of companies that lacked environmental licenses (see Section 7.3.1).

- the outcome of environmental audits.

Some managers noted that they were quite surprised by the results of the initial environmental audit at their facility. For some, the biggest surprise involved waste disposal and the potential for liability related to actions undertaken by the facility. However, nearly all managers expressed surprise at the quantity of potential valuable material discarded.

7.3.3 Changes in Motivation with Process Modification Experience

Some managers noted that as the facility gained experience with process modification efforts, the motivation for the efforts shifted. For example, in the Alumar Case (Section A.4) the initial motivation was achieving compliance with an environmental regulation. However, the experience with process modification at the carbon bake ovens of Alumar was pivotal for the facility's staff. After a series of failures in the application of quality improvement techniques, the team addressing environmental issues at the carbon bake ovens was not only successful, but produced substantial

financial benefits. This occurred through the avoided cost of environmental protection equipment and through a reduction in operating costs that were not directly related to environmental compliance. The carbon bake ovens represented the first success in the application of quality improvement techniques. The facility manager attributed this success to the fact that the environmental issue provided a clearly defined problem with obvious consequences and a deadline for action. Staff related more readily to the concrete notion of meeting an environmental requirement than to the vaguely defined arguments about the need to improve quality previously presented. In other words, an environmental "heart attack" grabbed the attention of staff in a way that slowly declining market share (akin to high blood pressure) could not.

The experience of the carbon bake ovens changed Alumar. Success showed the potential of quality improvement approaches and turned a skeptical staff into "believers". The approach has since been applied throughout the facility (in and out of areas related to environmental performance) leading to substantial productivity gains and making Alumar one of the world's most energy efficient aluminum smelters. Management now relates environmental releases with process inefficiencies. The result is that motivations for environmental management efforts include the potential for operational efficiency gains and improvements in product yield.

8. Discussion

The research results provide data relevant to the treatment within economics of environmental protection efforts that are not based upon end-of-pipe treatment technologies, environmental decisionmaking at the facility level, sectoral variations in environmental efforts, and governmental policy frameworks for environmental protection. These topics are addressed in the following sections.

8.1 Issues Regarding Economic Thought on Environmental Protection and Competitiveness

The most controversial aspects of environmentally-driven process modification involve its economic impacts. The significance of economic thought in decisionmaking and the treatment of eco-efficiency concepts within economics are considered in this section.

8.1.1 Importance of Economic Thought

Economic conventional wisdom is significant because it influences the way that managers and engineers analyze process modification opportunities (i.e., it affects what they look for and, thus, what they find). For example, some of the participating facilities that implemented process modifications, analyzed those changes for effects on resource use and productivity without carrying the analysis through to the point of quantifying economic impacts. Engineers and management at these facilities indicated that this was, in part, because there no expectation that the facility would benefit economically from the

action and because environmental expenditures were treated as an overhead function and, therefore, not related to specific production processes.

Even though economic benefits were quite substantial in some cases, engineers and management were unaware of the benefits of their actions in economic terms. It is possible that process modification efforts at these facilities receive less management support than they would otherwise as a result of this.

Since economic opportunities resulting from environmental-economic synergies appear to have a strong impact on management practice when recognized (Section 7.3.3), factors that contribute to or hinder such recognition are significant.

8.1.2 Conclusions from Empirical Studies

The significance of synergies between environmental and economic goals, and the innovation-stimulating effect of environmental demands is debated (Oates et al., 1994; Walley and Whitehead, 1994; Jaffe et al., 1994; Palmer and Simpson, 1993). Conventional economic wisdom holds that improvements in environmental quality increase costs and limit competitiveness.

As noted in Section 2.1.2, however, economic analyses that assume environmental protection measures increase production costs have limited applicability to environmental protection efforts that are not based upon end-of-pipe pollution abatement techniques. Consequently, in efforts to understand eco-efficiency approaches the relative importance of empirical studies that involve no assumption about the cost impact of environmental protection increases. Although empirical studies that relate

competitiveness to environmental protection are less common than theoretical studies, the empirical evidence that exists fails to support some significant theoretical expectations. The results of this research are consistent with the results of existing empirical work.

8.1.2.1 Effect of Environmental Regulations on Competitiveness

Jaffe et al. (1994) evaluated more than 100 empirical studies broadly related to the topic of environmental regulation and competitiveness. They find that the conclusion from theoretical analyses that environmental regulation hurts competitiveness is not supported by the existing empirical data. They conclude that "there is little to document the view that environmental regulations have a measurably adverse effect on competitiveness". Jaffe et al., however, also failed to find evidence that environmental regulation stimulates innovation and competitiveness.

Conclusions about the overall relationship between environmental protection efforts and industrial competitiveness are not supported by the design of this research. The results, however, do indicate that in the context of developing countries, opportunities to concurrently improve economic and environmental performance are available; may be exploited by environmentally-driven, efficiency-based process modification efforts; and when exploited may improve environmental performance and competitiveness. Further, in some facilities, the recognition and exploitation of these opportunities are common events.

This research does not indicate, or attempt to imply, that environmental protection efforts, taken in their totality, can be made costless. Rather it documents that under

specific circumstances that include the analysis of production processes with both environmental goals and efficiency in mind, environmental and economic benefits can be simultaneously realized. This result conflicts with conventional economic wisdom, but is supportive of one of the conclusions of both Jaffe et al. (1994) and Dean (1992) (i.e., "there is little to document the view that environmental regulations have a measurably adverse effect on competitiveness") in that it suggests a mechanism by which adverse effects of environmental regulation on competitiveness may be limited.

This research found evidence that environmental regulation may stimulate innovation (e.g., Alumar) and in this area contradicts the findings of Jaffe et al.

8.1.2.2 Effect of Environmental Regulations on Innovation

Most economic studies of environmental regulation and innovation are theoretical in nature. Conclusions are mixed: some suggesting that environmental regulation encourages R&D efforts (used as a proxy for innovation), other suggesting that regulation discourages R&D. The few empirical studies that specifically relate the stringency of environmental regulation to research are more consistent, suggesting that environmental regulation encourages research (Lanjouw and Mody, 1993; Jaffe and Palmer, 1994).

Although the research reported here does not support conclusions about traditional R&D efforts which occur outside of the context of production, it did find evidence of innovation occurring within the context of production as a direct result of environmental demands (e.g., Alumar, Moto-Honda, 3M). While economics has traditionally discounted the possibility of innovation occurring as part of production, the observation

of innovative activity in this setting is supportive of the idea that environmental demands encourage innovation.

8.1.2.3 Environmental Overcompliance

Economic conventional wisdom implies that firms will exactly meet (not exceed) the standards of environmental protection mandated by law (Arora and Cason, 1994). Arora and Cason, however, in a discussion of the U.S. regulatory framework, indicate that voluntary overcompliance efforts (where companies intentionally engage in environmental protection activities beyond those required by law) are now observed. This research extends Arora and Cason's observation to the LDC setting. Given the evidence found in this research that environmental and economic gains can go hand-in-hand, environmental overcompliance makes economic sense for some facilities (i.e., those with an environmentally-driven, efficiency-based approach to environmental management).

Numerous examples of facilities undertaking environmental protection efforts that exceeded the demands of local environmental law were observed. This was particularly true of facilities operated by multinational corporations. Many facilities applied home country environmental standards (which exceeded Brazilian standards) or corporate environmental standards (that in some cases exceeded both home country and Brazilian standards). Corporate environmental policy frequently mandates the same environmental standards be applied to company operations regardless of location.

As noted in Section 7.3.2, the host countries of multinationals with strong

environmental programs benefit from the company's learning experiences in relation to strict environmental regulation elsewhere. While it cannot be said that all facilities operated by multinationals have environmental programs that exceed local standards, the generalization that multinational corporations locate operations in LDCs to take advantage of weak environmental legislation and enforcement is not supported by the evidence in Manaus.

In some cases, the facility benefited financially from environmental protection efforts exceeding local requirements (e.g., Moto-Honda, Xerox, Recofarma); while in other cases, the activity increased operating costs on a per unit basis (e.g., Moto-Honda, Springer-Carrier, Alumar, paperboard manufacturer). Thus, environmental protection activities in excess of regulatory demands were not limited to situations in which the facility realized an economic benefit from the action.

8.2 Issues Related to Environmental Decisionmaking

Sustainability will not be achieved without increased efficiency in all aspects of production. Environmental-economic synergies and their exploitation by process modifications to increase environmental performance and economic efficiency were observed as part of this research (Section 8.1.2.2). Engineers and production managers face decisions daily that influence the efficiency and cost-effectiveness of environmental protection efforts. Since economic conventional wisdom holds that environmental protection must increase costs, however, managers and engineers, to the extent that they are influenced by conventional wisdom, would be expected to expend less effort on the

search for environmental-economic synergies than is economically efficient.

Given the existence of synergies⁶, an economically efficient search level for process modification opportunities related to these synergies should be greater than zero, assuming that managerial costs associated with innovation in the environmental arena are no higher than in other areas (there is no a priori reason to expect that managerial costs related to process improvement in the environmental arena exceed those in other areas). However, for 67% of the manufacturing firms participating in this research, the search level for environmental-economic opportunities is zero.

Jaffe et al. (1994) note that, given limited resources, the real question is not whether searches produce new ideas or opportunities, but whether the particular searches generated by environmental demands (e.g., regulation) lead to more or better ideas than the searches in which a facility would otherwise engage. While the point made by Jaffe et al. is reasonable, no definitive answer is possible. The economic concept of opportunity cost is associated with known alternatives. The relative performance of different searches, on the other hand, is unknown until the searches are completed (not likely when the selection of one search area precludes selection of another). Nonetheless, there is no reason to expect environmental searches to offer less opportunity than alternative searches and several reasons to anticipate that they may offer more.

First, it is not necessarily the case that the alternative to a search for environmental-economic opportunities is a search of other business functions for possible

⁶ Even researchers who question the significance of environmental-economic synergies (Walley and Whitehead, 1994; Jaffe et al., 1994) acknowledge their existence.

improvements. The possibility exists that at some facilities the alternative action is "no action" (i.e., no search). In this case, an environmental search obviously offers more promise than the alternative.

Second, the experience of participating facilities indicates that clearly defined problems with obvious consequences and a deadline for action motivate workers more effectively than non-specific issues lacking real drivers (Section 7.3.3). To the extent that environmental searches tend to be more focused (e.g., responses to specific regulatory requirements or established corporate/facility objectives), they may prove more effective motivators and, thus, may result in more successful searches.

Third, Fischer and Schot (1993) indicate that industrial approaches to environmental issues have evolved since the early 1970's. The initial period (approximately 1970-1985) was characterized by a general response they define as "resistant adaptation". Environmental management at nearly all firms (87%) was either crisis-oriented or cost-oriented. They describe a second phase (approximately 1985-1993) as "embracing environmental issues without innovating". Companies began to define environmental issues as their responsibility; as issues that could not be ignored without threatening the survival of the company. Environmental issues were not, however, incorporated in strategic planning efforts. By 1993, Fischer and Schot suggest that a small minority of firms were moving beyond a compliance approach to environmental issues. However, the fact that nearly all firms emphasized compliance until quite recently and that a high percentage of companies persist in this approach suggests that the environmental arena has probably undergone less examination for

process improvement opportunities than other aspects of firm operations. Thus, it is reasonable to hypothesize that the environmental arena holds as much or more opportunity than other areas of operations.

Several results from this research that conflict with economic conventional wisdom are potentially significant in that they may encourage decisionmakers within production facilities to support search efforts for environmental-economic synergies at a level more closely approximating an economically efficient level.

8.2.1 Performance of Different Environmental Management Methods

Environmental protection efforts that emphasize efficiency-based process modification can perform better than end-of-pipe approaches. This is seen in the case of the carbon bake ovens at Alumar (Section A.4.1). In this instance, a solution based upon end-of-pipe treatment would have required a capital expenditure of US \$20 million. The problem, however, was resolved with a series of relatively small process modifications that did not require capital expenditures. Further, the process changes resulted in environmental performance that exceeded regulatory requirements by nearly 100%. Had an end-of-pipe treatment approach been used, design criteria would have called for meeting or slightly exceeding the regulatory requirement. The process modification approach applied also resulted in a substantial improvement in operational efficiency. With the use of an end-of-pipe treatment been used, operational efficiency would be expected to remain unchanged or decline slightly.

8.2.2 Source of Benefits

The economic benefits resulting from environmental protection efforts that emphasize efficiency-based process modification do not derive solely from a decrease in the cost of environmental protection or compliance activities. The examples identified in this research show that cost savings may also result from a reduction in operating costs that are not directly related to environmental protection (e.g., Alumar, Moto-honda, Xerox, 3M, Philips). Thus, savings would result even if environmental protection costs were zero. This is precisely the case in the Xerox do Brazil effort to reduce solvent use (Section A.3.1). Nearly 99% of the total cost reduction realized derived from production activities that were not directly related to environmental protection activities. It is important to note, however, that in most of the cases identified, the process improvement opportunities that lead to these "unanticipated" financial benefits were recognized only because the facility was committed to improving environmental performance.

8.2.3 Economic Justification

The experiences of facilities participating in this research indicate that many environmentally beneficial changes to production processes are justifiable on a purely economic basis. A priori assumptions of an environmental-economic tradeoff in environmental protection efforts are not supported by the detailed examination of production floor experience in this research. Rather, there is evidence that both the environmental and economic impact of environmental protection efforts is tied to the approach used to address environmental challenges (e.g., end-of-pipe treatment vs.

process modification). Engineers from companies with successful process modification programs indicated that in the past there was an expectation that environmental protection efforts would carry a "cost penalty" (e.g., Alumar). They note that frequently this expectation prevented the identification of opportunities that would have enhanced productivity. When detailed investigations were ultimately conducted, the cost penalty often failed to materialize.

It can be difficult, however, to assess the full economic impact of a process modification decision and to separate environmental aspects of the decision from other decision criteria (particularly for decisions involving equipment investments). Detailed analyses are often required. For example, one participating facility, a paperboard manufacturer⁷, made the decision to switch from oil based to water based paint. The changeover required the replacement of machinery used to apply paints to the cardboard at a per machine cost that varied from US \$250,000 to \$600,000. While the environmental benefits of moving to water based paints were substantial, the economic benefits (derived from the lower cost of water based paint and the elimination of disposal costs for used paint and cleaning fluids) did not clearly justify the switch. Further analyses, however, indicated that new equipment had a larger capacity, was more efficient and produced higher quality paperboard. Thus, the decision was economically justifiable based on a combination of gains (some environmentally related and some not).

⁷ Facility management requested that the company name not be used.

8.2.4 Environmental Protection, Resource Efficiency and Competitiveness

Environmental protection actions that reduce resource use and environmental effects may also increase competitiveness. This occurs because the process scrutiny undertaken to resolve environmental issues may lead to the recognition of process inefficiency or resource waste that, when corrected, enhances competitiveness (e.g., Alumar, Moto-honda, 3M, Recofarma, Xerox, Philips). Interviews indicated that facilities that successfully apply process modification approaches to resolve environmental issues have managers with a perspective that could be summed up as follows: operational excellence has economic and environmental benefits, while management and operational deficiencies impose both economic and environmental costs. These managers focus on continually improving environmental performance, rather than on determining the minimum effort necessary to achieve environmental compliance.

8.2.5 Capacity to Improve Performance Rapidly

Rapid progress is possible in improving environmental and economic performance. For example, in less than two years, Alumar reduced the opacity of emissions from its carbon bake oven smokestacks by one-third (Section A.4.1). The alternative action was the installation of a gas treatment facility. It is unlikely that such a facility could have been designed, constructed, tested and put in service in less time.

8.2.6 Technological Capabilities

Most companies, large and small, have the technological capabilities that are required for environmentally-driven, efficiency-based process modification. Participating facilities that identified opportunities for incremental process modifications found that these changes were: small, relatively simple, and under the facility's control in that they did not require regulatory approval (e.g., Alumar, Recofarma, Coimpa).

The goal of efficiency-based process modification efforts is to a) identify those potential changes that are the easiest to fix or produce the greatest total benefit for the least cost (in terms of both time and money), and b) to implement these changes first. This approach is, therefore, fully consistent with cost-effectiveness concepts.

As no group is likely to have greater knowledge about, or understanding of, the facility's processes than the employees of the facility, the success of these efforts appear to depend on the ability of management to harness the experience of employees. Several managers indicated that the "real" issues involved in successful implementation of process modification programs are attitudinal, rather than technical.

8.2.7 Development of "Indigenous" Technologies

The development of "indigenous" technologies is a potential source of comparative advantage for facilities utilizing efficiency-based process modification. The facilities with successful incremental process modification efforts develop "indigenous" technological advances as a part of the production process. As noted in Section 8.1.2.2, economics has tended to discount the possibility of this form of technological

advancement. For the company, however, advantages of developing technology in this manner include the fact that the technology:

- a) is homegrown and, thus, appropriate to the facility's circumstances,
- b) is not based upon capital investment, and
- c) is, in effect, proprietary and, therefore, improves the position of the company relative to competitors (unlike process change resulting from the purchase of new equipment).

The capacity to develop technology internally would be especially significant to companies in developing nations. The development process in these nations may be limited if it is dependent upon technology from developed countries (especially capital-intensive technology).

8.3 Characteristics of Environmental Protection Efforts in Different Economic Sectors

In a 1991 research report, McKinsey and Company indicated that firms in different industrial sectors tend to view their opportunities for environmental improvements differently (i.e., firms in sectors that are closer to the end user anticipate a greater portion of their total environmental improvement deriving from later stages of the product life cycle). McKinsey and Company classified companies within three principle economic sectors (i.e., heavy industry, durables and consumer goods). Facilities representing each of the economic sectors defined in the McKinsey report participated in this research.

The McKinsey report noted that heavy industries (e.g., metals, chemicals) tended to see the greatest opportunity for environmental performance improvement from production process improvements. Managers from the durables sector (e.g., transportation equipment, electronics) saw the most potential for environmental improvement coming from improvements to the end product, while managers from consumer goods companies (e.g., food products) tended to emphasize waste management. McKinsey attributed this focus on different parts of the product life cycle to differences in production systems, products and product functions.

While variations in the principle areas of environmental focus consistent with the McKinsey findings were observed for facilities participating in this research, differences observed were a matter of "degree of emphasis" rather than representing entirely different philosophies. Sony and Philips (in the durables sector), for example, emphasized product improvements to a greater extent than did Alumar (in the metals sector). Sony and Philips reported largescale efforts to reduce product energy requirements and weight, and to increase the ease of recycling both products and packaging (e.g., reducing the number of materials used). Nonetheless, Philips provided examples of production process modification to improve environmental performance.

Consistent with the McKinsey findings regarding the consumer products sector, Coca Cola, the parent company of Recofarma, emphasizes reductions in material use in packaging and increasing recycling program effectiveness. Production process improvements, however, were observed within all economic sectors.

Potential economic benefits for companies were not limited to improvements

made at the production stage of the product life cycle. Environmental protection efforts may enhance product characteristics or quality in ways that influence sales (e.g., Sony is developing portable radios and tape players that operate substantially longer on a set of batteries than did older models).

8.4 Policy Related Issues

In addition to goals, appropriate government environmental policy must consider the effectiveness and efficiency of regulatory alternatives, initiatives from other sources such as the public or the regulated community, and desirable program characteristics. Research results related to these topics are discussed in this section.

8.4.1 Results of Different Forms of Environmental Regulation

Traditional environmental regulation (i.e., command-and-control regulation) is a more important factor driving efficiency-based process modification in Manaus than are "innovative" or market mechanism approaches to environmental regulation.

Environmental policies of facilities in Manaus (particularly those of multinational corporations) are influenced not only by Brazilian law, but also by corporate experiences in the home country and other countries in which the corporation operates. The vast majority of these home country environmental regulations, as well as most of Brazil's environmental regulation is based upon command-and-control principles. Managers interviewed were uniform in the view that the most important contribution government could make to improved environmental performance in Manaus was more stringent

enforcement of existing environmental requirements. Managers suggest that clarifying ambiguities about, and filling gaps in, current environmental law would be another important contribution. These managers would like a clearer understanding of what is expected of them and would like to see all facilities held to the same standard.

One environmental policy based upon market mechanisms, The Green Protocol, is beginning to influence facilities in Manaus (Section 7.3.1). The significance of the Protocol is related to the pressure that it places upon facilities that have not previously considered environmental issues (specifically those that lack environmental licenses) to review their environmental performance and implement the changes needed to obtain an environmental license.

As yet, however, market-mechanisms do not appear to have played a significant role in encouraging adoption of the environmental protection approaches that are the focus of this research (i.e., incremental or equipment-based process modification).

8.4.2 ISO-14000

Non-government environmental initiatives are poised to have a significant impact on operations in Manaus. ISO-14000 was producing change in Manaus within a month of its implementation in September 1996. In particular, ISO 14000's emphasis on extending environmental responsibility upstream and downstream within the production process has had impacts. Many large manufacturers in the free trade zone had initiated, or had informed suppliers that they would initiate, reviews of supplier environmental performance. Further, suppliers were informed that continued relations between the

companies depended upon satisfactory performance in these reviews.

Small and medium-sized suppliers represent a high proportion of facilities in Manaus that currently lacking environmental licenses. Managers of many of these facilities viewed this notice from their customers as "a shot across the bow" and environmental issues began to appear on the agenda (e.g., Springer-Plastico).

8.4.3 Compatibility of Environmental Management Systems and Sustainability Principles

Characteristics of environmental programs that successfully identified and exploited environmental-economic opportunities (Section 7.2) share a number of characteristics with sustainability principles. Overlap between sustainability principles and characteristics of the more successful environmental programs studied during this research suggests a commonality to effective efforts to address environmental and economic concerns regardless of scale.

In 1996, Andrew Steer, director of the World Bank's Environmental Department, proposed principles relating environmental sustainability to governmental policymaking. Some examples from this set of principles are presented below along with a discussion of related properties from environmental programs within participating facilities:

- Incorporating environmental concerns from the start.

Activities in facilities successfully applying process modification approaches for environmental ends are consistent with this concept. Giving

responsibility for environmental performance to those with production responsibility (i.e., line management) is intended to ensure that those making decisions with the potential to impact the environment, clearly bear the responsibility for integrating environmental considerations at the time that issues arise (e.g., Alumar, Moto-Honda, Philips, Recofarma, Xerox).

- Setting priorities carefully.

Corporate and facility environmental policies and objectives played a prioritization role for participating facilities. For example, Xerox's environmental policy indicates that "protection of the environment ... from unacceptable risks takes priority over economic considerations and will not be compromised". Tools such as audits and self-examinations also serve a prioritization function (e.g., Alumar, Moto-Honda, Philips, Recofarma, Xerox, 3M).

- Harness win-win opportunities.

Environmentally-driven, efficiency-based process modification efforts are effectively a search for win-win opportunities (i.e., instances in which a process change entails benefits for the environment and for the financial position of the company). Corporate environmental policies, objectives, audits, designations of environmental responsibility, and support of employee involvement are efforts to harness win-win opportunities (e.g., Alumar, Moto-Honda, Philips, Xerox, 3M).

- Involve citizens thoroughly.

This idea is analogous to efforts within companies to encourage employee participation (e.g., Xerox). By involving and supporting workers in search efforts, facilities increase the likelihood of recognizing improvement opportunities.

Employee involvement efforts of participating facilities have included encouraging (and recognizing/rewarding) employee suggestions, providing training that enhances the employee's capacity to make valuable suggestions, providing varied work experience that similarly enhances employee capabilities, sharing information about company goals and objectives and about specific processes, and encouraging (and providing time for) teams of employees to select and pursue process improvement activities.

- Management is more important than technology.

The experience of participating facilities is consistent with this statement. Process modification efforts in support of environmental goals are the result of management systems and organizational structures (Figure 5) rather than technological capabilities in the traditional sense. Evidence that efficiency-based process modification can be more cost-effective than end-of-pipe treatment approaches (Section 8.2.1) indicates that equipment embodying new technology cannot be assumed to provide results that are superior to incremental modifications.

Limiting consideration to "soft technologies" that underlie incremental improvement, management direction is still a more significant determinant of action than technology. For example, personnel at the Sony facility in Manaus were skilled in terms of recognizing and implementing process modifications for the purpose of improving production processes and product quality. In some cases, these quality-driven process modifications provided "unintended" environmental benefits. The Sony facility in Manaus, however, provided no examples of environmentally-driven process modification and staff indicated that none had ever been sought. Management had not emphasized action in the environmental arena. Thus, despite the process modification skills evidenced by the staff, no process modification efforts for environmental purposes had been undertaken.

In 1996, Sony Corporation committed to achieve ISO-14000 certification for all production facilities by early 1998. At the time of the visit to the Manaus facility (Nov. 1996), Sony personnel were initiating development of plans for an environmental review of operations and the implementation of an environmental management system consistent with ISO-14000. It is possible, therefore, that the Sony facility will provide increased emphasis to environmental aspects of operations in future process modification efforts.

9. Conclusions

The conclusions that follow are based upon the case studies of facilities that participated in this research. As noted in Section 4.3.2, case studies do not support statistically valid inferences beyond the group of facilities sampled. Nonetheless, it may be possible to apply lessons learned in one context to other settings.

Conclusion #1. The test of the fundamental hypothesis (Section 3) was positive. Opportunities to concurrently improve economic and environmental aspects of many operations are available; may be exploited by environmentally-driven, efficiency-based process modification; and when exploited may improve environmental performance and competitiveness (e.g., Alumar, Recofarma, 3M).

Additionally, process modification undertaken for reasons other than environmental concern such as product quality, may nonetheless lead to improved environmental performance (e.g., Sony).

Conclusion #2. The exploitation of opportunities presented by environmental-economic synergies is not limited to industrialized countries. Economic and ecological productivity in LDCs can be made mutually reinforcing (at least in the context of industrial environmental protection efforts emphasizing process efficiency).

Environmental-economic opportunities, however, are underutilized. Two-thirds of participating firms made no attempt to search for such opportunities. This may be a result of the fact that there is an expectation among staff of many participating facilities

that addressing environmental concerns will increase production costs (e.g., Springer-Plastico, Springer-Carrier).

Conclusion #3 Environmentally-driven, efficiency-based process modification efforts in response to environmental demands (e.g., environmental regulation) lead to process innovation at participating facilities (e.g., Alumar, Moto-Honda, 3M, Recofarma, Xerox, Philips).

Conclusion #4. In addition to compliance with Brazilian environmental standards, most multinationals participating in this research also applied home country environmental standards (that exceeded Brazilian standards) (e.g., Recofarma) or corporate environmental standards (that generally exceeded both home country and Brazilian standards) (e.g., Xerox).

Conclusion #5. Environmental protection efforts using process modification can perform better than end-of-pipe approaches (i.e., may reduce environmental releases to a greater extent than, and at a cost that is less than, applicable end-of-pipe treatment approaches) (e.g., Alumar).

Conclusion #6. The economic benefits derived from environmentally-driven process modification did not result solely from a decrease in the cost of environmental protection activities. The examples identified show that cost savings also result from

reductions in operating costs (e.g., Alumar, Moto-Honda, Xerox, 3M, Philips).

Conclusion #7. Many environmentally beneficial changes to production processes are justifiable on a purely economic basis. Economic benefits were the product of avoided costs (e.g., Alumar), reductions in environmental protection costs (e.g., Alumar, Moto-Honda, Philips, Recofarma), and cost reductions in other areas of production (i.e., those not directly related to environmental protection) (e.g., Alumar, Moto-Honda, Philips, Xerox). Cost reductions that arose from outside the environmental protection area resulted from more efficient resource use (e.g., limiting input demands and increasing recycling).

Conclusion #8. Environmental protection actions that reduce both resource use and environmental effects may also increase competitiveness (e.g., Alumar, Moto-Honda, Philips, Xerox).

Conclusion #9. Improvements in environmental and economic performance as a result of environmentally-driven, efficiency-based process modification may be rapid (e.g., Alumar, Moto-Honda, Philips, Recofarma, Xerox, 3M).

Conclusion #10. The technological capabilities required for incremental process modification are not beyond the capacity of most firms (large or small). One issue, however, is the willingness of facility management to adopt appropriate management

approaches and invest in developing the basic skills required (e.g., employee training).

Conclusion #11. The development of "indigenous" technology is a potential source of comparative advantage.

Conclusion #12. Experience under a command-and-control system of environmental regulation has been the most significant factor motivating companies that currently have effective environmental protection programs to pursue environmentally-driven, efficiency-based process modification.

Conclusion #13. A number of Manaus facilities that lack appropriate environmental licenses are currently attempting to come into compliance with existing environmental regulation. Three factors appear to be primarily responsible for this occurrence: more stringent enforcement of environmental regulations by state government, the Green Protocol, and ISO-14000 (e.g., Petrobras, Springer-Plastico).

Conclusion #14. Characteristics of environmental programs that successfully identified equipment-based process modifications included: statements of corporate environmental policy, specific corporate environmental objectives, clear environmental leadership and periodic audits of facility environmental programs.

Conclusion #15. Characteristics of environmental programs that successfully identified incremental process modifications included: statements of corporate environmental policy, specific corporate and facility environmental objectives, clear environmental leadership, periodic audits and self-assessments of facility environmental programs, employee involvement initiatives, and links between quality improvement and environmental quality efforts.

Conclusion #16. Characteristics of environmentally driven, efficiency-based process modification efforts share a number of characteristics with sustainability principles. There appears to be a commonality to effective efforts to address environmental and economic concerns.

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Appendices

Appendix A

Case Studies of Participating Manufacturing Facilities

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Appendix A - Case Studies

The case studies provide an overview of some process modification activities in participating companies. Cases come from companies representing all of the major industrial sectors within the Manaus free trade zone. The electronics sector which is the single most important industrial sector in Manaus (representing 68% of total production and about 65% of total investment) provided the largest single group of cases studies (five). As noted in Section 5, fieldwork in Brazil resulted in interviews with 24 companies. Six of these companies were Brazilian owned and operated. The other 18 companies were subsidiaries of multinationals or were partnerships between multinational firms and Brazilian firms. The home countries of multinationals included the United States (8), Japan (4), Korea (2), Germany (2), The Netherlands (1), and Switzerland (1). The cases provide examples of equipment-based and incremental process modification approaches, as well as examples of the static process approach.

A.1 Case Study 1 Philips da Amazonia

Philips Corporation has operated in Brazil for more than 80 years and Philips da Amazonia has been in operation in the Manaus free trade zone since 1973. Philips' Manaus plant produces television sets, video tape recorders, stereos, and radios. Production is intended solely for the Brazilian market and exceeds one million units per year. Philips da Amazonia in Manaus has over 2200 employees. Employee turnover is between 1 and 2% per year which is low relative to industrial facilities internationally. Philips only other plant Brazil is in Sao Jose dos Campos, Sao Paulo State. It produces television picture tubes that are used by both Philips da Amazonia and other television producers in Manaus. The San Jose dos Campos plant is currently the only facility in Brazil (and one of only two in Latin America) that produce picture tubes and computer monitors. Samsung Corporation, however, has begun construction of a plant in the Manaus free trade zone that will produce picture tubes and monitors.

Philips is one of the oldest and largest electronics plants operating in Manaus. The plant has undergone several expansions since operations began with the most significant occurring in 1992 when a facility to produce printed circuit boards was added. Philips was the first plant in Manaus to receive certification under the ISO-9000 series (in 1993). When the plant was visited as part of this research in November 1996, the facility had already developed a plan to achieve ISO-14000 certification, although ISO-14000 had only become been finalized two months earlier. Philips da Amazonia provides a variety of examples of process modifications that have benefited both the company's economic performance and the environment. The examples presented here involve the

areas of water treatment, energy conservation and solid waste management.

A.1.1 Water Treatment

With the installation of the printed circuit board facility, four major aqueous wastestreams were added to Philips' Manaus operations. Each of these wastestreams required acid neutralization and two required treatment for copper. A water treatment facility was constructed to address these needs. However, while acid neutralization was effective, meeting environmental standards for copper treatment was problematic and expensive.

While considering possible mechanisms of improving copper treatment, a production process evaluation by plant staff noted that the four major wastestreams within the circuit board facility were combined before being sent to the acid neutralization. Combining the wastestreams, however, adversely impacted the process of copper removal that followed wastestream neutralization, resulting in lower overall copper recovery. The efficiency of the reagent used for copper recovery varies with the concentration of copper in the water treated. Since two of the four wastestreams combined did not contain copper, the copper concentration in the combined wastestream was reduced - negatively impacting the effectiveness of copper precipitation.

Minor piping changes were proposed by engineering staff to keep wastestreams that require treatment for the removal of copper separate from other wastestreams until that treatment had occurred. Piping modifications and the addition of a second neutralization tank cost US \$1030. Following the modifications, higher pre-treatment

copper concentrations within the wastestream increased the efficiency of copper removal and resulted in a 50% reduction in the post-treatment concentration of copper in wastewater. The increase in precipitation efficiency of the reagent permitted the use of smaller quantities of reagent. This reduced reagent cost by US \$525 each year. The separation of the waste streams unexpectedly increased the efficiency of the acid neutralization process as well resulting in reduced use of the neutralizing agent, NaOH. This reduced neutralization costs by US \$3675 each year. With a payback period of only three months, this process modification represented a very low risk investment for Philips.

Copper is recovered as copper chloride and improved copper recovery resulted in an 8% increase in the volume of copper chloride requiring treatment (from 1200 kg/month to 1300 kg/month). Treatment is not available within Manaus and, therefore, Philips sends the copper chloride to southern Brazil for treatment and recycling. Shipping costs and port handling fees (US \$310/ton) far exceed treatment costs (US \$41.60/ton) and Philips is now evaluating the addition of equipment that would permit the on-site recovery of copper.

A.1.2 Energy Conservation

Two of the principle structures on the Philips da Amazonia plant site are the television production area and the audio production area. The buildings are each the same size (about 6250 m³) and have roofs that are the same height (6 meters). Although the air conditioning equipment used for each building had the same cooling capacity,

plant engineers were able to maintain a comfortable atmosphere in the audio production facility, but not within the television production facility.

To lower temperatures within the television production area, Philips personnel faced an investment of US \$100,000 in cooling equipment as well as increased electricity use. Philips corporate policy has set a goal of reducing energy use (and the environmental effects that are associated with energy use) by 25% per unit of production by the year 2000 (with 1994 as a reference year). Increased electricity use associated with additional cooling equipment conflicted with this goal. A Philips team studied the issue and concluded that cooling the entire 6 meter height of the building was unnecessary since cool air was required only in the areas where personnel and most equipment were located (i.e., two to three meters above the floor). Modifications were made to the air conditioning ductwork to provide cool air preferentially to areas near the floor.

The ductwork modification resulted in comfortable workspace temperatures in the television production area without an expenditure for additional cooling equipment and without increased electricity consumption. The total cost of modifications to cooling ductwork was approximately US \$3000. Even if the environmental and economic benefits of avoiding increased electrical consumption are ignored, the avoided capital cost of cooling equipment was US \$100,000. Thus, Philips saved US \$97,000 by considering modification of its production facility rather than presuming that the existing space represented an "optimal" design.

This simple modification spurred employees to propose other energy saving

modifications that lead to additional economic and environmental benefits. For example, an employee suggestion built upon the air conditioning experience by proposing that lighting fixtures in the television production area also be lowered. This was done and Philips now obtains the same lighting effect in work areas with 400 fewer lights. Given the plant's operation for two 8-hour shifts daily, 5 days each week, the energy savings realized over the course of a year by operating 400 fewer lights is approximately US \$37,000.

Following the success of efforts in the television production area, facility staff made similar changes to cooling and lighting equipment in the audio production area and realized additional benefits.

A.1.3 Solid Waste

While personnel at Philips da Amazonia felt that potential effluent discharges containing copper represented the greatest environmental risk from plant operations, the environmental issue that presented the largest challenge to plant personnel was the resolution of solid waste concerns. This was the case because of the volume of material involved. Philips receives production components from other factories in Manaus and from around the world. In the past, the disposal of packaging material associated with these component shipments represented not only a significant cost to Philips, but also consumed a large volume of local landfill space.

Philips has used various methods to reduce the volume of solid waste going to the landfill. For example, Philips worked with the other producers of consumer electronics in

Manaus and with local parts suppliers to develop a system of "go and return" boxes. Under this system, local suppliers send components to assembly facilities in cardboard boxes that have been designed to be returned to the supplier for reuse. Since in Manaus suppliers and final assembly facilities are in close proximity, this system permits the reuse of cardboard containers multiple times and greatly reduces the volume of "waste" cardboard.

Philips removes other materials from the wastestream through an active recycling effort. Following a review of factory operations for waste reduction opportunities, Philips da Amazonia implemented a program that separates a number of materials for recycling. Nearly all scrap shipping material (i.e., cardboard and bubble plastic), scrap metal from the component insertion process, and defective housings are recycled (Figure A-1). Philips enhances the value of its recycled material by performing some of the preparatory work for recycling. For example, molded plastic television housings are recycled when inspections reveal imperfections. The majority of manufacturers in Manaus ship the entire housing to local recyclers who "chip" the housings before reprocessing. Philips, however, chips the housings on-site and, thus, increases the value of its recyclable material, while reducing space requirements and transport costs. Although the recycling program at Philips involves a considerable amount of effort (involving 1 full-time Philips employee and 3 to 4 contractor employees), Philips earns approximately \$7000 per month after expenses from the sale of recycled materials.

<u>Material</u>	<u>Quantity Recycled</u> <u>(metric tons per year - 1995)</u>
Cardboard	180
Polystyrene	168
Soft plastic (packing material)	156
Hard plastic (product housings)	30
Metallic bonds*	3
Soldering residue	19.2
Iron	1.8

* These are leftover after automatic insertion equipment has placed components on circuit boards.

Figure A-1. Quantities of Materials Recycled by Philips Electronics

The second largest industrial sector within the Manaus free trade zone is the transportation equipment sector, specifically the production of two-wheeled vehicles. Moto-Honda is the largest company within this economic sector. The Moto-Honda factory began production in 1976. With a total capital investment of US \$270 million, the Moto-Honda facility currently represents the single largest investment in the Manaus free trade zone. Samsung Corporation, however, may surpass this investment with the construction of 800,000 m² plant for the production of cathode ray tubes and computer monitors whose expected cost is US \$450 million.

Production levels at Moto-Honda have increased by 89% in the past two years (1995 production was 180,000 units; 1996 production was 250,000 units; in November 1996, expected 1997 production was 340,000 units). Most of the factory's output is destined for the Brazilian market, although 6 to 8% of production is exported to other South American countries, Europe and Asia.

The company has approximately 2300 workers and operates three shifts each day, 6 days a week. Employee turnover is very low, less than 1% each year. Unlike much of the production within the Manaus free trade zone, Moto-Honda represents what could be called "heavy" industry. Plant activities include the casting, milling, machining, and painting of aluminum engine blocks and components. Metal stamping, plating, plastic injection molding and various surface treatment processes (involving acids, bases and solvents) are required in the production of other components. Even in comparison with other Honda motorcycle facilities, Honda da Amazonas has a broader range of production

activities. Since Manaus is more remote than the location of other Honda facilities, the process of building close supplier relationships has been slow. As a result, production at the Manaus facility is more vertically integrated than at other Honda plants. About 45% of the materials used in final assembly in Manaus are produced by the Manaus factory. Other Honda motorcycle factories, by comparison, produce 15 to 20 % of the inputs to final assembly. As a result of the broad range of activities at Moto-Honda, the facility deals with a greater range of potential environmental impacts than do other Manaus facilities whose production involves a more limited set of processes.

The Honda da Amazonas factory first received ISO 9002 certification in 1994. When visited in December 1996, Moto-Honda was one of two participating facilities that had already developed a plan for achieving ISO 14000 certification and had established a target date for certification (the other was Philips). Moto-Honda's environmental efforts focus on themes of meeting national, state, local, and corporate environmental standards; conserving energy; and increasing the efficiency of resource use. Examples of process modifications that have improved both the economic and environmental performance involve the areas of solvent recycling, energy and resource conservation.

A.2.1 Solvent Recovery

Moto-Honda performs a number of components painting operations. In connection with these operations, Moto-Honda uses paint thinner to clean paint guns. This activity produces a large quantity (approximately 11,500 liters each month) of paint-contaminated (dirty) thinner. Ensuring the proper disposal of this material has been a

difficult and costly problem for the facility.

Honda engineers and production personnel worked in a team to study the problem. After their investigations, the team proposed that equipment to recover and recycle the paint thinner be developed and installed. Plant engineers designed and installed the system. Since starting recovery/recycling operations, Honda recovers 70% of the painter that previously required disposal (approximately 8000 liters each month). The environmental benefits of this effort stem from a reduction in the quantity of solvent requiring disposal. Financial benefits to Moto-Honda derive from 1) a reduction in environmental protection costs because less waste requires disposal, and 2) a reduction in operating costs not directly related to environmental protection because valuable resources are conserved. The capital cost of the recovery system was US \$7,000. Since the company pays US \$1.20 for each liter of thinner used and the system recovers 8000 liters of thinner each month, the company saved US \$10,000 in thinner costs during the system's first month of operations. Thus, the payback period was less than one month.

Additionally, the recovery process concentrates paint residuals in the remaining 30% of thinner. A suggestion by a production worker, lead the company to consider using the thinner with concentrated paint residuals as a paint in certain settings. Moto-Honda now uses this recovery system byproduct to paint streetcurbs and roadway lines within the factory grounds. Thus, this process modification completely eliminated what previously had been a significant waste disposal problem.

Without regard to environmental benefits, the paint thinner recovery system represented a very low risk, high return investment for Honda. Reduced solvent and paint

costs, however, do not represent the total financial gain by Moto-Honda. The company also eliminated disposal costs that had previously been associated with the waste thinner, as well as eliminating the cost of paint for marking facility roadways (Figure A-2).

A.2.2 Resource Conservation

Moto-Honda is undertaking resource conservation efforts in a number of areas. One involves water conservation. Staff are studying the use of water throughout factory operations (from its use of water in the painting of galvanized steel to its use in factory lavatories). Studies of water loss due to dripping or running faucets (a water use quite removed from production) indicate the breath of conservation investigations undertaken at Moto-Honda. Honda personnel found that a slowly dripping a faucet could result in the loss of 26 liters of water a day, while a faucet running with a slight stream of water could lose 300 liters a day. Plant personnel determined that over the course of a year, losses such as these would cost the facility US \$20.50 and \$195.00 respectively. Based upon such studies, Honda personnel decided to install faucets with automatic shut-off valves throughout the factory. Although these faucets cost US \$160.00 each, Honda personnel believe that the investment will be returned within 3 to 4 years.

A.2.3 Energy Conservation

Moto-Honda places great emphasis on increasing energy efficiency. Members of the team that leads this work indicate that efforts include employee education and encouraging employee suggestions on ways to save energy. Efforts also involve the

- motorcycle production

- disposal of approximately 11,500 liters of paint thinner following the cleaning of painting equipment

- Develop and install equipment to permit the recycling of paint thinner. Used paint thinner is first placed in a tank that allows paint residuals to settle. The thinner is then decanted from the residuals. Further residuals separation is achieved by vaporizing and then condensing the decanted fluid. After being passed through a gas eliminator, the thinner is collected for reuse. This process recovers 70% of the thinner. The remaining 30% of the material contains the concentrated paint residuals and is used as a paint in settings where a paint quality is not a concern (e.g., plant roadways and curbs).

Environmental:

- Potential for improper disposal of used paint thinner is eliminated.

- capital investment	US \$ 7,000
- operating cost	US \$ 250/month
- reduction in production costs:	
value of recovered thinner (8000 liters at \$1.20/liter)	US \$ 10,000/month
value of roadway paint substitute (3450 liters at \$0.75/liter)	US \$ 2,500/month
avoided treatment costs (11,500 liters at \$ 0.10/liter)	US \$ <u>1,150/month</u>
	US \$ 13,650/month
Net gain (\$ 13,650/mo. less operating costs of \$ 250/mo.)	US \$ 13,400/month

Payback period (\$ 7000 divided by 13,400/month) = 0.52 months

NPV (5 years with 25% discount rate) US \$ 483,500

Figure A-2. Summary of Environmental and Economic Results: Process Modification for Paint Thinner Recovery at Moto-Honda

establishment of focus areas for energy conservation efforts (e.g., electricity, steam, liquid petroleum gas, gasoline, diesel, and kerosene). These focus areas correspond to the major fuel sources at the facility. Specific targets are established for the reduction of energy use within each of these focus areas (Figure A-3). General employee education efforts address the overall energy situation in Manaus, the means by which various types of equipment at the Moto-Honda facility are powered (including energy loss mechanisms related to each power source), and information on home energy use and means of reducing energy demands at home. Specific education efforts target the job responsibilities of individual employees. For example, many pieces of equipment at Moto-Honda are powered by compressed air. Employees working with this equipment receive detailed training on recognizing air pressure leaks.

Moto-Honda recognizes the environmental importance of these efforts and this is clearly pointed out in materials prepared for employee education purposes. The factory also recognizes the potential financial benefits to be realized by improving energy efficiency. While electricity is only one of the major power sources at Moto-Honda, monthly electricity use is on the order of 2,900,000 kilowatt-hours (kwh). Major electric power uses are: equipment 41%, refrigeration 31%, lighting 18%, and air compression and water systems 10%. Given the cost of electricity in Manaus (approximately US \$0.08 per kwh), electricity costs for Moto-Honda exceed US \$232,000 each month. Reducing demand for electricity would not only reduce costs but would make operations less susceptible to disruptions that could come about if the electric demand situation in Manaus worsens.

	<u>Energy Use - 1995</u> <u>(per motorcycle)</u>	<u>Energy Use - 1996 Goal</u> <u>(per motorcycle)</u>	<u>Percent</u> <u>Reduction</u>
Electricity	146,409 kw	139,088 kw	5.0
Diesel	479 liters	455 liters	5.0
Gasoline	1015 liters	960 liters	5.4
LPG	1629 kg	1548 kg	5.0
BFP (steam)	2240 kg	2128 kg	5.0
Kerosene	4621 liters	4390 liters	5.0

Figure A-3. Moto-Honda Energy Conservation Focus Areas and 1996 Energy Reduction Targets

Energy conservation team members indicate that decisionmaking criteria with regard to specific process modifications are more broad than economic impact. The team considers the effect on overall efficiency (in addition to energy efficiency), the effect on product quality, and the effect on workers. Estimates are also made of the potential economic effect, but this is not considered the most important decision criteria.

Modifications made to improve the energy efficiency of lighting, for example, include lowering lights to improve lighting (as at Philips da Amazonia), adding employee accessible light switches to individual lights (within what were formerly large banks of lights), providing training employees that emphasizes turning off lights when not in use, and automating most lights such that they are turned off during periods such as lunch and breaks. Other modifications include installing capacitors on machines to better control power use, and replacing a number of small cooling towers with a larger and more efficient cooling tower.

A.3 Case Study 3 Xerox do Brazil

The Xerox da Amazonia facility in Manaus is the smallest of three Xerox facilities in Brazil (others are located in Resende, Rio de Janeiro State, and in Salvador, Bahia State). Production at the Manaus facility is currently being expanded and refocused. The facility is moving from the production of new photocopiers and faxes to the remanufacturing of photocopiers. Hulks (i.e., old machines) from Brazil, Mexico and the United States are shipped to Manaus for remanufacture. Following remanufacturing, these machines are sold in Brazil and China. The facility expansion currently underway will result in a production capacity at the end of 1999 that is 250% higher than capacity at the end of 1996.

Xerox offers examples of what might be viewed as the end-members of process modification efforts. As noted in Section 2, economics has traditionally viewed new technology as entering production processes embodied within a piece of equipment. This equipment-based type of process change was the basis of the effort described in the example of solvent use reduction. The actions of the Black Diamond team at Xerox, on the other hand, provide an example of incremental process change.

A.3.1 Reduction of Solvent Use

One of the first steps in remanufacturing photocopiers is the cleaning of the old machines. In Manaus, until August 1996, solvents were used extensively in cleaning hulks (i.e., old machines). Cleaning a single hulk required 13.4 liters of solvent (dirty solvent could not be reused). Xerox Corporation, however, considers solvent use a major

environmental problem and has made a commitment to remove solvents from its production processes whenever possible, without regard to the short-term financial impact. Consequently, Xerox in Manaus installed cleaning equipment that utilizes a new technology (i.e. a spray of frozen carbon dioxide, CO₂, micropellets under high pressure).

The new equipment reduced the cleaning solvents required to clean each machine from 13.40 to 1.35 liters. Given the current remanufacturing rate of about 1500 machines per month (this rate will increase significantly during the next three years), the change in the cleaning process eliminates the use of approximately 18,000 liters of solvent each month. The environmental benefit derives from the fact that proper disposal of solvents is difficult and improper disposal represents a significant threat to groundwater quality. The volatile nature of solvents and health risks associated with solvent inhalation mean that reduced solvent use also benefits worker safety and health.

The new process equipment was installed because it presented a means to further the corporation's goal of reducing solvent use. Financial concerns were not a driving factor in the decision and, consequently, personnel in Manaus did not perform a detailed appraisal of the financial impact of the process change. After installation, however, staff did perform detailed analyses of the impact of the process change on process efficiency. This information was used in the economic analysis of the process change (Figure A-4). The data provided indicate that the process change reduced overall operating costs by reducing cleaning material costs, labor costs, and waste disposal costs.

The old cleaning method required 13.4 liters of solvent per machine at a cost of US \$3.07 per liter. Thus, solvent cost for an individual machine was US \$41.13. The

Facility: Xerox Manaus, Amazonas, Brazil

Problem: use of solvents in photocopier remanufacture

- used solvents to clean machine hulks before remanufacture
- corporation decided to eliminate use of solvents wherever possible

Approach:

- applied new technology with installation of cleaning system that sprays carbon dioxide micropellets under high pressure

Results:

Environmental:

- reduced solvent use per machine cleaned from 13.4 to 1.35 liters
(at production of 1500 machines/month solvent use is reduced by 18,000 liters/month)

Financial:

- capital investment	- cleaning system and CO ₂ tank	US \$ 245,000
	- installation	US \$ <u>25,000</u>
		US \$ 270,000
- reduction in production costs:		
cleaning materials (\$31.53/machine)		US \$ 47,150/month
labor cost (\$55.39/machine)		US \$ 83,100/month
solvent treatment cost (\$0.10/liter or 1.20/machine)		US \$ <u>1,750/month</u>
		US \$ 132,000/month

Payback period $(\$ 270,000 - 132,000/\text{month}) = 2.04$ months

NPV (5 years with 25% discount rate)
(assumes no increase in cost of labor or materials)

Figure A-4. Summary of Environmental and Economic Results: Equipment-based Process Modification to Reduce Solvent Use at Xerox

new cleaning method requires 1.35 liters of solvent and 7.7 kilograms of CO₂ at a cost of US \$0.71 per kilogram. The total cost of materials for the new method is US \$9.60 per machine.

The old cleaning method required 7.59 hours to clean a machine while the new method requires 5.68 hours of cleaning time. At an average labor cost of US \$29.00 per hour, labor cost per machine is US \$220.11 and \$164.72 for the old and new methods respectively. Given the expansion of production at the Manaus facility, the reduction in labor hours required for cleaning has not translated into reduced levels of employment. In fact, the Xerox workforce in Manaus is currently seeing substantial growth.

Xerox da Amazonia paid US \$2000 for treatment and disposal of waste solvent each time the facility's solvent holding tank (approximately 20,000 liters) was filled. Thus, solvent treatment/disposal costs were about US \$ 0.10 per liter. On a per machine basis, this represents US \$1.34 and \$0.14 respectively for the old and new processes.

The economic gain for Xerox as a result of the process change was substantial. The total capital investment involved was US \$270,000 (equipment cost: US \$180,000; CO₂ tank: US \$65,000; installation cost: US \$ 25,000). Production cost savings on a per machine basis were US \$88.08. Based upon the current production rate of 1500 machines per month, Xerox realized a reduction in production costs of about US \$132,000 per month. Thus, the capital investment was repaid in 2.04 months. If the economic benefits resulting from reduced environmental compliance costs are left out of the calculation of the payback period, it increases only slightly (from 2.04 months to 2.07 months). The substantial reduction in monthly operating costs (cleaning cost per machine

was reduced by 34%) and the insensitivity of the payback period to environmental costs indicate that environmental considerations would not be required to justify the process change. Yet, while the change represented an excellent investment, it was uncovered only because of environmental considerations.

It is a common perception that environmentally driven process changes only have the potential to reduce the cost of complying with environmental requirements (i.e., they cannot improve overall operational efficiency). This example, however, indicates that such a perception is erroneous. The process change in this example substantially improved overall process efficiency (reducing costs by one-third). Further, since environmental requirements were not a significant contributor to total cost before the process change (0.5%), nearly all of the cost reduction realized (99%) came from aspects of production (i.e., input costs, labor cost) that were not directly related to meeting environmental requirements.

A.3.2 Black Diamond Team

Xerox da Amazonia strongly encourages employees to participate in team based process improvement efforts. More than 95% of employees at the Manaus facility are involved with teams. The Black Diamond team consisted of 14 Xerox employees and utilized an approach that Xerox refers to as P.S.P. or the "problem solving process". Xerox's P.S.P., is a modified version of Deming's plan, do, check approach.

Most of the 14 team members were production staff although plant engineering and receiving/shipping were also represented. After collecting information and

conducting exploratory research on potential projects, the Black Diamond team selected environmental protection and resource conservation as a theme. Specifically, the team choose to address a) the loss of toner (i.e., dry ink) during the filling of toner cartridges, and b) the disposal of wood pallets that Xerox receives when materials are delivered from suppliers. The team set two goals. The first was to cut toner loss by one-half (annual toner loss at the start of team efforts totalled 490 kilograms). The second goal was to reuse 100% of the wood pallets that Xerox received from suppliers.

The team used various tools to facilitate their work including brainstorming, bargraphs, and cause and effect diagrams. The teams efforts resulted in numerous process modifications. Modifications made to reduce toner loss involved: developing a new tip for the toner loading nossle for use with certain product models (this provided a better fit with the loading port of machines), changing the exhaust system of the loading equipment, lengthening the neck of the tool used to test the quality of toner once loaded, and enlarging the loading portals on several product models. Modifications related to pallets included devising new stacking arrangements for product containers because the pallets available from suppliers differed in size and shape, and developing a system for transporting pallets, when needed, from a neighboring facility.

The team achieved the goals that it established. The reduction of toner loss benefits the environment by conserving energy and resources in toner production. Further, worker safety and health are improved in Manaus by reducing exposure to toner dust. Environmental benefits from the reuse of wood pallets arise because a wastestream is closed. The economic benefits from the team's activities derived from reduced toner

loss, enhanced productivity that accompanied the changes made to reduce toner loss, the elimination of the use of virgin pallets, the elimination of the use of cardboard bottom covers that previously were required for pallets, and the development of new stacking arrangements that permitted the placement of two additional layers of boxes on each pallet. The first year economic benefit of these process modifications was US\$337,142.

Some commentators have suggested that approaches such as this actually increase company costs because the staff involved would have enhanced productivity even more had they spent their time addressing other aspects of the company's operations. Such a statement cannot be proven true or false. In this case, however, environmentally-driven actions clearly did reduce overall operational costs. Alternative activities by team members (individually or as a group) would have to have been quite successful to have exceeded the accomplishments of the Black Diamond team. The team's 14 members held a total of 45 one-hour meetings. Assuming an average labor cost of US \$29 per hour (a rate typical of the electronics sector in Manaus), activities of the Black Diamond team represented an investment by the company of US \$18,270. Thus, in the first year Xerox earned an 18-fold return on its investment in the team. The net present value (NPV) of gains made by the Black Diamond Team (5 years with a 25% discount rate) is US \$1.04 million. Xerox representatives, however, indicate that the company does not consider financial results the primary return from team activities. The main benefits derive from an increased capacity of personnel to work together cooperatively, the development of analytical and leadership skills among workers, and an increased knowledge of the production process among employees.

Alumar (a consortium of Alcoa Aluminum, Shell Group's Billiton Metais, Alcan, and Abalco) is an integrated alumina refining and aluminum smelting facility located near the Atlantic coast in Sao Luis, Maranhao State, Brazil. The Alumar facility is intricately linked to production in Manaus in that it provides a large proportion of the aluminum ingot used by Manaus's second largest industry, the production of two-wheeled vehicles.

When operations began in 1984, the complex represented the largest private investment ever made in Brazil, approximately US \$1.5 billion. With subsequent expansions, the Alumar facility now represents an investment in excess of US \$1.8 billion. Annual production is approximately 1,140,000 metric tons of alumina and 360,000 metric tons of aluminum, making it one of the world's largest integrated alumina and aluminum producing complexes. The Alumar site is large (well in excess of 1000 hectares) and includes its own port facility that receives bauxite, coking coal, oil pitch and caustic soda, and ships refined alumina. Alumar (like the rest of the aluminum smelting industry) considers air emissions to be its most significant environmental issue. Data for Alcoa, the lead member of the Alumar consortium, indicates that 98% of environmental releases reported under the Toxics Release Inventory by its U.S. facilities are air emissions. The disposal of residue from the refining process is a major solid waste issue. Alumar has 2200 employees. The annual worker turnover rate at the facility is about 7%. This rate is typical of other heavy industry sites within Brazil. Turnover rates vary considerably among different groups of workers. Rates for professional staff are

below 1% per year, while the rate for laborers in the smelter's potrooms is substantially higher.

Alumar is a particularly interesting case because the director of the facility indicates that the environmental arena provided the setting for a breakthrough in attempts to apply process improvement techniques (after a number of failed attempts in other areas of production). The plant director attributes this initial success (on the carbon bake ovens project) to a high level of pressure for success and a task that was well defined and narrow (as opposed to a broad call for improved quality). The Alumar experience provides clear examples of process changes that produced both environmental and economic benefits.

A.4.1 Carbon Bake Oven Stack Opacity

Phase 1

Aluminum smelting occurs through the electrolytic decomposition of alumina. This is performed by passing an electric current through alumina in a molten bath. The positive electrode (or anode) in this bath is a solid block of carbon (approximately 6' x 4' x 3'). At Alumar, three carbon bake furnaces (or ovens) produce the anodes used in the "pots" (or electrolytic chambers) where the smelting of aluminum occurs. The oven's smokestacks are required by the site's operating permit to maintain gas opacity (i.e., the reduction of light intensity, or of visibility of an object, viewed through the gas plume) at a level of 20% or less. For a number of years following the start of operations, this requirement represented a significant problem for the plant. Smokestack opacities in the 30% range

were experienced and this represented a permit violation. The facility faced an investment of US \$20 million for a gas treatment facility in order to meet permit requirements.

To address this problem, a team including personnel from the plant's production, maintenance, mechanical/electrical, process engineering and environmental staffs was formed. Although team-based process improvement efforts had been attempted at Alumar previously and had failed, the team approach was tried again, in large part, because few other alternatives existed to the installation of the gas treatment system. The team's goal was defined in its mission statement (i.e., achieve full compliance with the plant's operating permit). Performance indicators at the start of the effort showed that furnace operations were not only unacceptable from an environmental standpoint, but were highly inconsistent. Thus, achieving the team's goal required both a 33% reduction in smokestack gas opacity and a reduction in the variability of furnace operations. A subgoal was to reach compliance without having to build the gas treatment facility.

The Alumar team (like the Xerox team in Section A.3.2) applied an eight-step approach (Figure A-5) to process improvement based upon Deming's "plan-do-check" wheel. The team expected that high gas opacity was related to poor burn efficiency. Possible reasons for poor burn efficiency included a lack of control of flue gas temperatures, inadequate sealing of ovens and flues, and deficient and/or poorly coordinated operational and maintenance practices. Over the course of two years, the

<u>Step</u>	<u>Action</u>
#1	Define problems and qualify improvement opportunities
#2	Select the problem or opportunity
#3	Analyze causes and effects
#4	Generate potential actions
#5	Evaluate and select actions
#6	Test effectiveness of actions
#7	Implement
#8	Monitor

Figure A-5. The Alcoa Eight Step Quality Improvement Process

team significantly modified oven operations. The changes included operational changes (e.g., developing guidelines for when and how oven doors would be opened), small modifications to improve the sealing of oven doors, and improved coordination between the production and maintenance staffs to ensure that maintenance orders were implemented in a timely manner. In essence, the team agreed upon changes to improve performance, implemented those changes, and then monitored the effect of modifications to gage progress and provide input on additional changes. While this approach does not sound difficult, it required far more staff cooperation and communication than had previously been common practice at the facility.

Team efforts reduced stack gas opacity to the level required by the operating permit (20%) and greatly increased the consistency of furnace operations. This was achieved without the installation of a gas treatment facility and, in fact, involved no significant capital investments. As the team's effort eliminated the need for the gas treatment facility, Alumar saved not only the cost of the gas treatment facility (US \$20 million), but also the cost of operating the treatment facility (about US \$1 million/year). Environmental and economics results from the carbon bake ovens are summarized in Figure A-6.

Phase 2

Having accomplished the original goal, the team could have disbanded. The team members, however, believed that additional improvements were possible and decided to continue the process modification effort even though the facility now met environmental standards. As noted in Section 2, efforts such as this (i.e., those that pursue

Facility: Alumar Sao Luis do Maranhao, Maranhao, Brazil

- integrated alumina refinery, aluminum smelter

Problem: stack opacity in the carbon (anode) bake furnaces

- opacity of the stack gas did not meet the 20% operating permit requirement
 (plume opacity was 30% due to unburnt matter - soot and VOCs)
- installation of a gas treatment facility would have cost US \$ 20 million

Approach:

- team-based effort to improve process efficiency
- changes included better control of flue temperatures, better sealing of furnaces, and improved maintenance procedures

Results:

Environmental:

Phase 1 - opacity reduced to near zero within two years without capital investment

Phase 2 - reduced fluoride emissions from 0.25 to 0.12 kg/ton of aluminum produced

Financial:

Phase 1- efficiency improved to point that gas treatment facility was not needed

- | | |
|--|----------------------|
| - capital investment | US \$ 0 |
| - economic benefits | |
| - avoided cost of gas treatment facility (in year 1) | US \$ 20 million |
| - eliminated annual operating cost of gas treatment facility | US \$ 1 million/year |
| NPV (5 years @ 25% discount rate) | US \$ 23.1 million |

Phase 2 - efficiency improved to point that furnace #3 was no longer needed

- | | |
|---|--------------------|
| - capital investment | US \$ 0 |
| - economic benefits | |
| - liberated a corporate asset, furnace #3 (in year 3) | US \$ 30.4 million |
| - eliminated annual operating cost of furnace #3 | US \$ 495,000/year |
| NPV (5 years @ 25% discount rate) | US \$ 20.5 million |

**Figure A-6. Summary of Environmental and Economic Results:
 Alumar Carbon Bake Oven Process Modifications**

environmental performance improvements in excess of legal requirements) are not predicted by standard economic theory. In fact, some commentators argue that such efforts will inevitably reduce productivity - ostensibly because the staff involved would find other, more productive things to do with the time that they had previously applied to meeting the environmental requirement.

By 1994, the continuing effort of the team had achieved burn efficiencies that resulted in "near-zero" stack opacity with no visible emissions. Once again, no significant capital investments were involved in implementing these improvements. An additional environmental benefit associated with the effort was the fact that the same actions that reduced gas opacity also reduced emissions of fluorides from the carbon bake furnaces. Fluoride emissions from the carbon bake ovens that had averaged 0.27 kg per metric ton (kg/ton) of aluminum were reduced to 0.12 kg/ton. While total fluoride levels from Alumar operations had generally met permit requirements from the start of operations, even legally acceptable levels of fluoride have the potential to damage local vegetation. From the standpoint of local ecosystems, the reduction of fluoride emissions was probably a more significant improvement than the reduction in stack opacity.

While the continuation of process modification efforts improved environmental performance, the effect on competitiveness is also important. Did the continued efforts of the team negatively impact productivity as standard economics would predict? The answer is no. In fact, the opposite is the case. The continued efforts improved furnace efficiency to the extent that Alumar's demand for carbon anodes could be met using only

two of Alumar's three furnaces. This allowed one furnace to be shut down. The result was a major improvement in productivity and a significant reduction in costs (annual operating cost of the furnace that was shut down was US \$450,000). In addition, a company asset (Furnace III) worth US \$30.4 million was freed for other uses. Alumar is now considering reactivating Furnace III to produce carbon anodes for sale to other aluminum smelters. Alumar is also considering an expansion of smelting capacity. In the event of a capacity expansion, Furnace III would be available for the production of anodes and would, therefore, represent a significant avoided cost.

A.4.2 Environmental Performance Management Program

The experience of the carbon bake oven team convinced senior management at Alumar that the links between economic performance and environmental protection pursued through efficiency enhancement were so strong that the two objectives were inseparable. Thus, management worked to integrate the lessons of the carbon bake oven experience into the plant's overall operational approach. This led to the development of a system to ensure that environmental aspects of operations were considered by all employees in their day-to-day activities.

The environmental management plan that was implemented at Alumar clearly placed responsibility for environmental matters with the top management. The commitment of senior management was emphasized when environmental goals and milestones were defined, not in a separate (and more easily ignored) environmental plan, but in Alumar's operating plan (i.e., the document against which the performance of

senior management is measured). The Alumar operating plan and environmental indicators are reviewed and revised monthly. From top management, responsibility flowed down to line management. In other words, environment responsibility rested with the same managers who had production responsibility rather than with an environmental department (which does not control production activities). The environmental department role is to offer advice and serve as internal consultants.

Functional areas of the plant join with the environmental department to set up environmental performance objectives and indicators and develop plans to accomplish these objectives. The environmental management performance system includes clear standards for each operation (standard operating procedures were revised to include environmental aspects). These performance standards were communicated to each employee and employees received training that specifically related their work actions to effects on the environment. A formal audit program was implemented and employees now receive direct feedback on environmental performance indicators. These indicators became an additional tool used in assessing the performance of individual employees.

A.4.3 Smelter Fluoride Emissions

Coincident with the implementation of the environmental performance management system, an effort was made to address other significant environmental issues on site, in particular, to reduce fluoride emissions from Alumar's smelter facilities (or potrooms). Aluminum fluoride is vital to the smelting process because it acts as a catalyst and substantially lowers the temperature that the molten bath must achieve for

the electrolytic decomposition of alumina to occur. However, as noted above, fluoride emissions (even at levels permitted by Alumar's operating permit) had the potential to negatively impact local vegetation. The plant's operating permit limits total fluoride emissions from the Alumar facility to 1.25 kg/ton of aluminum produced. To reduce fluoride emissions, Alumar installed a fluoride recycling system that operates with the smelters and has an efficiency exceeding 99%.

Nonetheless, in 1989, Alumar slightly exceeded its permitted limit of 1.25 kg/ton with total emissions of 1.28 kg/ton. Contributions to this total were as follows: potroom operations 1.00 kg/ton, fluoride recycler emissions 0.01 kg/ton, and carbon bake ovens 0.27 kg/ton (the combined emissions from potroom operations and the fluoride recycler constitute smelter emissions). By 1990, process improvement efforts at the carbon bake ovens were reducing fluoride emissions from that source. Consequently, Alumar not only met, but exceeded its permit requirements and had no legal obligation to pursue further emission reductions. Alumar staff, nonetheless, believed fluoride emissions were significant and wished to minimize them.

As with the effort at the carbon bake ovens, a team including representatives of each functional area involved with the potrooms was formed. In evaluating potroom operations, the same eight-step process was followed. Background research was conducted on all aspects of smelter operations. This research was not necessarily complex in nature. For example, the team found that no mechanism was available to provide short-term feedback on the efficiency of the fluoride recycling unit. A production worker solved this problem with a simple tool, a wooden stick wrapped with

black electrical tape. The stick could be pushed through a porthole into the flue that exited the reaction chamber. If the stick was clean when removed, then the reaction efficiency was acceptable. If, however, white powder was visible on the black tape when the stick was removed from the flue, control over the reaction was deficient at that moment. By systematically performing and tracking the results of this simple test, the team was able to begin correlating reaction efficiency with other operational factors.

The team considered a wide variety of modifications to reduce fluoride emissions. These included both structural changes (e.g., reducing the gaps between the side covers on pots) and operational changes (e.g., improved placement of the hood that covers each pot door; increasing hood efficiency by ensuring that no more than two pot doors were open at any time, working to limit the number of anode effects per pot day).

In the period from 1990 to 1995, the actions of the potroom team resulted in the reduction of potroom fluoride emissions from 1.0 kg/ton of aluminum produced to 0.25 kg/ton. This makes Alumar one of the world's best controlled smelters (for comparison, the average fluoride emission rate for all Alcoa corporation smelters is 0.8 kg/metric ton of aluminum produced). The reduction in fluoride emissions was achieved while production capacity was being increased from 250,000 to 360,000 tons/year. Total fluoride emissions from the Alumar facility (i.e. smelter and potrooms) are now 0.38 kg/ton (a level 70% below that required by facility operating permit).

From an economic standpoint, the reduction in fluoride emissions means that less AlF_3 catalyst lost is through to the environment reducing the facility's expenditures for AlF_3 by US \$250,000 a year. More significant, however, is the fact that the same actions

that reduced fluoride emissions resulted in an increase in the energy efficiency of Alumar's smelters. In 1990, the smelting operations at Alumar operated at an efficiency equal to 91.76% of that which is theoretically possible; in 1995, Alumar achieved 95.07% of the theoretical efficiency. This makes Alumar one of the most energy efficient aluminum smelters in the world for its technology class. Given the volume of energy used in the smelting of aluminum (approximately 4,750,000,000 kwh per year for the Alumar facility), an efficiency increase of approximately 3% corresponds to an annual savings in energy costs of more than US \$10 million (given an cost of US \$0.075 per kwh). As with the carbon bake ovens, no significant capital investments were required to achieve these results. The environmental and economic results of the smelter team's activities are summarized in Figure A-7.

Facility: Alumar Sao Luis do Maranhao, Maranhao, Brazil

- integrated alumina refinery, aluminum smelter

Problem: fluoride emissions from aluminum smelter (potrooms)

- fluoride emissions damage vegetation and impact wildlife near site
- while emissions met regulatory requirements, they were of concern to local residents

Approach:

- environmental releases were used as an indicator of process inefficiency
- changes involved improved: pot door operation, management of dumpers (hoods) on pots, maintenance, and process control to reduce anode effects

Results:

Environmental:

- potroom fluoride emissions were reduced from 1.0 kg/ton to 0.25 kg/ton
(this was done without capital investment)
- the modifications make Alumar one of the world's best controlled aluminum smelters*
- the changes that reduced fluoride emissions also increased smelter efficiency from 91.7% to 95.1%. This increased efficiency reduced electric demand per metric ton of aluminum produced from 5584.9 kwh/ton to 5401.3 kwh/ton. This makes Alumar one of the most energy efficient aluminum smelters in the world.

Financial:

- | | |
|---|----------------------|
| - capital investment | US \$ 0 |
| - reduced catalyst (AlF_3) cost (in spite of increased capacity) | US \$ 200,000/yr. |
| - reduced electricity cost associated with increased efficiency | US \$ 8,925,000/yr. |
| NPV (5 years w/ 25% discount rate) | US \$ 28.4 million |
- (assumes no increase in cost of electricity or catalyst)

* Fluoride releases for 1995 from Alumar (i.e., smelter, carbon bake ovens) were 0.38kg per ton of aluminum. Fluoride release rate for all Alcoa smelters in 1995 was 0.8 kg/ton.

**Figure A-7. Summary of Environmental and Economic Results:
 Alumar Smelter Operation Modifications**

The 3M Corporation facility that participated in the research is headquarters for operations in Brazil. Located in Sumare, Sao Paulo State, the facility is the largest of three remaining facilities in Brazil. The Sumare plant is one of 3M's larger facilities (only two U.S. facilities are larger). Production operations in Brazil serve all of South America (activities in other South American countries being limited to marketing and the repackaging of products for local distribution).

Brazilian sales have experienced rapid growth. In 1996, total Brazilian sales were US \$420 million. Expected sales for 1997 are US \$600 million; for 2000, US \$1 billion. To meet growth in demand, annual capital investments in the Sumare plant are planned at the US \$50 million level for each of the next four years.

The major products at Sumare are tapes (masking, packing, and various industrial tapes) and abrasives (e.g., sandpaper). Managers noted that the major drivers for environmental efforts are corporate policy and customer pressure. A number of corporate customers (e.g., Volvo) visit the Sumare facility to inspect environmental operations. Pressure from federal and state environmental regulatory agencies is not considered a major factor. Releases to air are the largest component of emissions for Sumare (and for 3M Corporation generally). Consequently, they are also the primary focus of environmental efforts at Sumare.

The corporation opened a facility in Manaus in 1987 and closed that facility in 1996. The closure of Manaus operations was one reason for interest in 3M. Company management explained that Manaus operations involved the purchase of videotape film

from Italy and the processing of that tape into videocassettes for sale in the Brazilian market. This type of operation had narrow profit margins and corporate headquarters decided on a worldwide basis to get out of this line of business. Managers in Sumare, noted, however, that a contributing factor was high operating costs in Manaus compared to other Brazilian locations.

The Sumare facility provided more examples of incremental and equipment-based process modification than any other single participating facility. The examples presented involve solvent recycling, solid waste reduction and energy conservation.

A.5.1 Solvent Recovery System

Many of the production processes at 3M involve the use of solvents. Corporate policy indicates that the preferred mechanism for addressing environmental effects from solvent use is switch to production processes that are water based, thereby eliminating the use of solvents. Until this objective is achieved large volume of solvents remain in use.

In order to reduce the quantity of solvents requiring disposal, the staff of the Sumare facility decided to install a solvent recovery system at a cost of approximately US \$2 million. The solvent recovery system involves sending suitable gas process wastestreams through a reaction chamber filled with activated carbon⁸. Activated carbon absorbs the solvent. When the absorptive capacity of the carbon is reached, steam is

⁸ This process cannot be used for all wastestreams (e.g., processes that involve acrylic adhesives, phenolic resins or chlorinated solvents). In these situations, the solvents cannot be easily separated from the activated carbon by steam treatment.

pumped through the reaction chamber to release the solvent from the carbon. The steam and solvent mixture is then condensed and the solvent separated and reclaimed. Current system efficiency is 94% resulting in the recovery of 4000 metric tons (about 5.7 million liters of solvent) annually. Given an average solvent cost for the facility of US \$0.45/liter, the value of recovered solvents is approximately US \$2,570,000 annually. After accounting for system operating costs (e.g., electricity and steam generation), the net savings related to solvent recovery are approximately US \$2 million.

The experience at the Sumare plant, led managers to install a similar system in one of the other 3M plants in Brazil in 1996.

A.5.2 Energy Conservation

A variety of energy conservation projects have been undertaken at Sumare. Many of these projects have involved process reviews and modifications to improve performance. For example, a process evaluation by facility personnel led to minor changes in the materials mix for one product, "Scotch-Brite" pads. Before this modification, the product required three passes through a drying unit. Following modification only two passes through the dryer were required. Energy savings from this change amounted to 3200 kwh per month and 36 hours of steam each month. The resultant production cost reduction was approximately US \$42,000 per year.

A similar process review led to production changes for an adhesive tape (A-796). In this case, modifications reduced the required mixing time from 48 to 16 hours. This resulted in reduced energy consumption of 4800 kwh, saving about US \$335/load.

Energy conservation efforts have also occurred in production support areas. For example, translucent panels were installed in the roofs of work areas throughout the Sumare plant (replacing opaque panels). By using natural light to supplement artificial lighting, plant lighting demands were reduced by 25%. This conserved 60,000 kwh of electricity each month and resulted in annual cost savings of US \$42,000.

A.5.3 Solid Waste Reduction

Sumare initiated a program in 1992 to reduce the generation of solid waste as a percentage of production volume and to reduce the amount of the remaining waste that is landfilled. This involved the training of more than 2000 employees in the identification and separation of wastes. It also included efforts to identify potential customers for waste materials. For example, waste floormat material is now sold to a third party and used in making sandals. In the first year of the program, waste disposal costs were reduced by US \$90,000 while earnings from the sale of waste materials exceeded US \$150,000.

Between 1990 and 1996, the quantity of solid waste produced by 3M facilities in Brazil fell from more than 10% of production volume to less than 6%. Additionally, while approximately 60% of this solid waste was landfilled in 1990, about 17% of solid waste went to landfills in 1996. At the Sumare facility, about 75% of waste material is recycled. This translates into approximately 470 metric tons each month.

Recofarma is a subsidiary of the Coca-Cola Company. It produces syrups that bottling plants use to make carbonated beverages. The largest and most significant wastestream at the facility is liquid waste. The plant makes more than 25 different products which vary considerably in terms of the associated wastestream characteristics (i.e., they may be acid or basic, have a high or low biological oxygen demand). The facility holds one environmental license from IPAAM for all activities onsite. IPAAM inspections of Recofarma are annual. The facility is planning to seek ISO-14400 certification. A plan was being developed at the time that the facility was visited (November 1996). Plant personnel expect to achieve certification during 1998.

In order to minimize potential environmental impacts, the facility applies U.S. water treatment standards to operations. Nonetheless, in 1995 plant personnel wished to reduce the amount of chlorine released to the environment (chlorine is used in the final phase of water treatment) since chlorine and organic chlorine compounds have limited biodegradability. Consequently, the plant began efforts to reduce the total quantity of water that required treatment. Since the cost of operating the plant's water treatment facility is directly linked to the quantity of water treated, reducing chlorine releases in this way also reduces operating costs.

As part of this effort, production managers and operators receive training on both general and job-specific environmental management issues. The general training includes visits to the water treatment plant, explanations of treatment plant operations, discussions of how production activities affect treatment facility operations (e.g., may

lead to a treatment plant upset), and information on recognizing opportunities to reduce water use.

Job-specific training relates individual production actions to specific environmental outcomes. It also provides information on appropriate production methods (e.g., loading procedures for hazardous materials - SO_2 , H_2SO_4 , chlorine, phosphoric acid and caustic soda are used at the facility) and responses to specific problems and emergencies. Since the manager of the water treatment facility is the former manager of production operations, his views carry additional weight with production staff.

Efforts to reduce the use and treatment of water at the Recofarma facility have focused on evaluating production processes to identify wasteful and unnecessary uses of water. As a result of these efforts, effluent volume increased by only 10% in 1995 even though production volume increased by 25%. Three examples of measures taken to reduce water use are provided.

A.6.1 Tank Cleaning

One of the first modifications at Recofarma involved the method of cleaning process tanks between the production of different products. In the past, tanks were cleaned by filling the tank with water (7000 liters) and then draining the tank. To reduce water use, spray nossels were installed in each tank at a cost of about US \$350. Tanks are now cleaned with a water spray that uses approximately 500 liters of water. With a water treatment cost of US 2.9 cents/liter, reducing water use during tank cleaning by 6500 liters saves US \$188.50. Given 4 process tanks that are cleaned an average of 4.3 times

per month, the facility saves about US \$39,000 annually from this change.

A.6.2 Production Scheduling

Another process modification to reduce water use involved rescheduling production runs to reduce the number of tank cleanings required. While 25 products are produced at the plant, two products (Coke and Fanta) represent 80% of production. Thus, many other production runs are relatively short. Production runs that previously were done for a portion of a day, once a week are now done monthly or bimonthly for a longer period of time, thereby reducing the number of post-run tank cleanings required.

A.6.3 Revised drum handling

Recofarma's production is shipped in foodgrade plastic barrels that are washed and sealed by the barrel vender. Until 1996, the Recofarma practice had been to re-rinse each barrel before filling with product (using 3 liters of water for each of 3000 barrels/day). A worker suggestion resulted in a procedure change such that barrels now receive a visual inspection and are re-rinsed only as necessary. This modification reduces water use by about 9000 liters/day and saves about US \$62,000 annually.

The Gillette facility in Manaus is one of two in Brazil. The facility completed a US \$95 million expansion in the Spring of 1997 in order to produce Gillette's "Sensor" razor. Manaus is one of only three plants that produce this product (the others are in the U.S. and Germany). The workforce increased by approximately 200 workers following this expansion (from 900 to 1100). Other products include "Trace II" razors, "BIG" pens, and "Oral B" toothbrushes. Production in 1996 was valued at US \$77 million. This value, however, is expected to increase significantly in 1997 with the completion of the facility expansion. Approximately 30% of production is exported.

The facility holds two environmental licenses from IPAAM. One was issued for the components manufacturing facility and the second for the assembly facility. IPAAM inspects the facility annually. Gillette has undertaken a number of process modification for the purpose of protecting the environment, for which information about the effect on production efficiency and costs was unavailable. Process changes in this group include eliminating the use of trichloroethylene (THE) within production, eliminating the production of oil-based inks at the facility, and the installation of water treatment and air monitoring equipment.

The Gillette facility in Manaus has emphasized energy conservation measures within production. Actions include the replacement of existing light fixtures with more energy efficient fixtures. In most cases, this meant the replacement of fixtures that used four 80 watt fluorescent bulbs with a high intensity 120 watt fixture. Given the size of the facility, such a change can represent substantial savings.

The Gillette facility is large by Manaus standards, but it is by no means the largest. Managers report that the facility has approximately 2500 lighting fixtures. With the cost of electricity in Manaus at US \$0.08/kwh, the annual lighting cost with the old fixtures was approximately US \$315,000 when 2 shifts operated (Gillette currently uses two shifts) and US \$400,000 when 3 shifts are used. The switch to more energy efficient lighting conserves 2.47 million kwh of electricity each year and saves the facility approximately US \$200,000 annually.

Gillette also reviews process efficiency as equipment requires replacement. For example, because the operation of some equipment at Gillette requires cool temperatures, the facility has several large chilling or air conditioning units. Staff research indicated that newly available high efficiency compressors were appropriate for the Manaus facility's applications. Thus, plans have been developed for the replacement of current compressors with compressors using new technology as equipment replacement is needed. A similar program is in place for generators at the facility.

Coelma is a subsidiary of Sameness Corporation. The facility started operations in 1993 and assembles telephones. Most of the materials used in assembly are imported from Europe. Production is currently about 700,000 units per year, but an expansion is planned in the next two years that will quadruple the original US \$1 million dollar investment in the facility. Following expansion, a production level of 2.5 million units per year is anticipated. While production is now solely for the Brazilian market, 60% of production will be exported following expansion. There are about 150 employees and management reported that the employee turnover rate is approximately 3% per year.

Coelma has another manufacturing facility located in Curitiba. This plant is substantially larger (3000 employees). The Manaus plant depends on the Curitiba plant for support on environmental matters. Due to the assembly nature of work performed by Coelma in Manaus, the environmental risks of production activities have been viewed as minimal and environmental protection activities have been limited. IPAAM issued one environmental license for the facility and inspects the plant once each year.

The plant intends to seek ISO-14000 certification (although no timetable has been established). Environmental staff from Curitiba were reviewing production processes in Manaus facility during the spring of 1997 and initiated development of an environmental management plan for the Manaus facility.

Degussa Corporation, based in Germany, is the parent company of Coimpa. Degussa has 134 facilities worldwide. The corporation specializes in industrial uses of precious metals producing chemical, metallurgical and pharmaceutical products. The Manaus facility began operations in 1973. Its principle products are silver nitrate for photographic processing, and gold, silver and platinum filling materials used by dentists. All of the production from the Manaus facility is intended for the Brazilian market (about 10% regionally and 90% to the south). The facility employs 130 people. Employee turnover is between 1 and 2% annually.

IPAAM issued three licenses for the Coimpa facility. Metalurgical, chemical and dental operations in Manaus are each covered by a separate license. IPAAM inspections are annual. The only other Coimpa facility located in Brazil is in the south and produces catalytic converters for automobiles. A high percentage of this production is exported.

The corporation has implemented a comprehensive quality improvement program that encompasses environmental protection efforts. Environmental objectives for the facility are established as part of the facilities "Quality Management System". Both the environmental and quality policies for the company are posted on signs at the entrance to the facility. The Degussa Quality Process emphasizes employee education, goal setting, error cause removal, corrective action recognition, and attention to measurement and quality costs. Process improvement efforts include an active employee suggestion program.

The quality effort is tied to environmental efforts that include participation in the

Chemical Manufacturer Association's "Responsible Care" program. This program commits the companies to seek continuous improvement in environmental performance. Coimpa is also seeking ISO-14000 certification.

The plant's manager reported that process improvement efforts (a high percentage were undertaken to improve environmental performance) have reduced facility operating costs by 30% in the past two years. While examples of process modifications that improved productivity were observed, the personnel most involved with environmental issues were unavailable when the facility was visited and no specific examples of environmentally-driven process modification efforts were obtained.

The most significant environmental risk associated with Manaus operations is the possibility of unacceptably high concentrations of metals in aqueous effluent. Given the high value of materials used in production, the facility has a strong incentive to reduce the levels of metals in effluent. The plant operates a system for the recovery of gold and silver from process wastestreams. Following treatment for silver and gold, other metals (mostly iron oxide) are removed by flocculation.

BASF Corporation's Manaus facility included three separate facilities: one producing audiocassette tapes, another producing videocassette tapes, and a third producing styrofoam. The three Manaus plants began operations in 1987 and until January 1, 1997 were operated by BASF, which has four other Brazilian plants. In January 1997, however, BASF sold its entire magnetic tape division to a Korean consortium, Grupo Kohap. This included the audio and video tape facilities in Manaus (but not the styrofoam plant).

The Grupo Kohap facilities (now called EmTec) were visited in April 1997. Facility management at that time was uncertain how new corporate management would address a number of production related issues, including environmental issues. For example, managers did not know whether the new corporation had an environmental policy. BASF held one environmental license for the two tape facilities. This license was transferred to EmTec. The facilities were visited annually by IPAAM when operated by BASF.

Production levels at the tape facilities were flat (at about US \$75 million) for the last several years, due in part, to a lack of investment from BASF, in anticipation of the division's sale. Facility management indicated that intensive competition in the tape market produced declining profit margins. Substantial investment by the new owners was needed to keep the facilities competitive. This investment was expected. Approximately 60% of production is for the Brazilian market. The remaining 40% of

production goes primarily to other South American countries although some goes to the European Union as well.

The facility does not produce magnetic tape. The primary activities involve: plastic injection molding to produce cassette housings, and the cutting and loading of tape. Since no chemical processes occur at the facility, management considers solid waste to be its largest environmental issue. The facility does not have plans to pursue ISO-14000 certification. In fact, the facility's efforts to achieve ISO-9000 certification have been hampered by uncertainty related to the sale. In April 1997, the facility was nearing a Suframa established deadline of July 1997 for achieving ISO-9000 certification. The facility faces a cutoff of fiscal incentives if it fails to achieve certification.

The Manaus facility of Fuji Photo Film began operations in 1993 and is one of two company facilities in Brazil. The other is located in Rio de Janeiro. The Manaus facility cuts and loads photographic paper and film, and assembles "minilab" film development and printing systems. Bulk paper and film are imported from Japan. An expansion of the Manaus facility is planned during 1997 and 1998. The expansion will include the installation of new cutting equipment that will permit the facility to perform the entire process of cutting film spools into fragments for loading into canisters. Currently, Manaus receives the product of the first film cut, film "pancakes", from Rio de Janeiro.

The facility director is from Japan. Fuji Photo Film is one of two participating multinationals whose senior manager was not Brazilian. With 155 employees, the plant represents a US \$20 million investment. Sales in 1995 were US \$40 million; 1996 sales were US \$51 million. Projected 1997 sales are US \$60 million. Production at the Manaus facility is solely for the Brazilian market.

The facility did not have an environmental license as of April 1997. A license application was submitted to IPAAM during early April 1997 and at the time that the plant was visited for this research, plant management was expecting an initial IPAAM visit and review. The facility was in the process of developing an environmental management system in April 1997 that includes a self-examination of environmental performance 3 times a year. Environmental concerns at the facility include solid waste and proper disposal of laboratory chemicals (e.g., spent developer from testing rolls of

film in the facility's lab). Since film and paper arrive on specialized spools and pallets which are returned to Japan for reuse, the principal solid waste issue is scrap paper and film from the cutting process. This material is recycled locally.

The Mondane facility in Manaus does assembly work exclusively. The products include watches, clocks and pens. The facility represents a capital investment of about US \$25 million. Sales from this facility are approximately US \$28 million per year. The plant in Manaus has 205 employees. The Manaus facility and the company's four other facilities in Brazil produce solely for the Brazilian market. The company's management and all of the capital is Brazilian as well, although the technology used is Swiss. The facility was not ISO-9000 certified as of December 1996 and like EmTec had received a July 1997 deadline for certification.

Management indicates that environment issues at the plant are minimal. The facility has no liquid discharges. While metal plating was performed until the early 1990's, this was discontinued because it could be done more cheaply in southeast Asia. The facility does use solvents to clean components, but the quantities are very small (about 2 liters per month). Finally, because both imported components and final products are both small, solid waste (primarily cardboard and paper) is not a major issue, although management indicates it is the biggest environmental issue at the facility. The facility pays a local solid waste recycler to take materials.

IPAAM issued one license for the facility and visits the plant two to three times each year.

The OMC facility in Manaus assembles Johnson and Evinrude brand outboard motors for boats in sizes from 3.3 to 30 horsepower from imported materials. Larger engines are imported directly or are assembled at the company's facility in Campinas, Sao Paulo State. The Manaus facility began operations in 1989 and represents an investment of US \$2.8 million, employs 67 people and produces about 7000 motors annually. All production is for the Brazilian market.

As part of assembly, the facility paints engine housings. This is probably the most significant activity at the plant from an environmental standpoint. Painting is done with oil based paints in an enclosure. One wall of the enclosure is a hood whose negative pressure pulls the paint aerosol through three layers of filter paper before venting the volatile portion of paints to the atmosphere. Paintgun operators wear respirators while involved in painting operations. There are, however, no controls on the paint fumes at the point that they are vented. Contaminated filter paper from the painting process is collected and then incinerated.

The facility is not located in the Manaus industrial district. The facility does not have an environmental license and has not been visited by personnel from IPAAM.

This facility began operations in 1985 and produces corrugated paperboard (cardboard) that supplies 65% of the Manaus market. The inner corrugated portion of the board is made from recycled paper while the two outer layers are produced from virgin material. All three paper layers are produced at other company facilities in southern Brazil and are shipped to Manaus. The company is a subsidiary of a U.S. corporation and has four other facilities in Brazil. The wood for the virgin paper used in production comes from pine plantations that the company owns in Santa Catarina State in southern Brazil. All plant activities are covered by one IPAAM license. Inspections are conducted annually.

Production was 2.6 million m³ per month in April 1997, but a US \$4 million expansion that began in April was to increase production capacity to 4 million m³ per month by October 1997. The facility has 200 employees with an annual turnover rate of 1.5 to 2.0%.

The expansion included US \$700,000 in environmental protection investments, including a water treatment system, the installation of air monitoring equipment and the development of air and water monitoring plans. Until April 1997, the facility was powered by a wood burning boiler. An oil boiler has been installed at the facility, however, and the wood boiler will now serve solely as a backup unit. Management indicated that the plant had experienced difficulty ensuring that wood purchased for the

⁹ The manager of the facility requested that the company name not be used.

boiler had the proper State certifications (i.e., that it was legally cut). As a result, the decision was made to install the oil boiler, in large part, because the company does not wish to be seen as contributing to the destruction of rainforest.

The paperboard facility switched in 1995 from oil based to water based ink. The decision is an example of a situation in which environmental and productivity aspects of decisions are not easily separated. The changeover required the replacement of machinery used to apply inks to cardboard. The cost of the new machines involved varied from US \$250,000 to \$600,000 (there are 4 inking machines).

The change was environmentally beneficial because of a reduced potential for improper disposal of waste ink and solvents used to clean ink from the machines. The economic benefits of the change would result from a reduction in the cost of ink (water based inks are cheaper than oil based inks) and from the elimination of disposal costs for waste ink and cleaning solvent. These cost reductions, however, did not clearly justify the new equipment investment economically.

Additional staff analyses ultimately indicated that in addition to the economic benefits noted, the new equipment had impacts on production capacity and efficiency, and on product quality (each was increased). This combination of environmental gains, cost reductions, and productivity increases did justify the investment.

The Petrobras Reman refinery in Manaus is one of the largest industrial facilities in the region. The facility started operations in 1955 and is the oldest refinery and one of the least efficient refineries in Brazil. The major products are diesel fuel, gasoline and liquid petroleum gas. The facility includes a port and several tank farms. If built today, the facility would represent an investment of approximately US \$500 million. In order of importance, facility management sees the major environmental issues for the refinery as oil spills, other water pollution and air pollution.

The facility currently provides only about one-third of regional demand for fuels and during 1997 and 1998, Petrobras plans to invest about US \$60 million in a expansion that will triple the productive capacity of the Reman facility. The oil refined at Reman after expansion will come a newly discovered field in the area of the Urucu River (a tributary of the Solimoes). Production capacity was 5000 bbls/day in 1995; 11,000 bbls/day in 1997 and plans call for a capacity of 48,000 bbls/day in 1998.

The facility is owned by the Brazilian government. It has 300 employees. The expansion of capacity will not require an increase in staff. Employee turnover has historically been about 1% annually, but is now about 3 to 4%. Management personnel attributed this to retirements and to increased job opportunity elsewhere in the Manaus area.

Historically, the facility has not met State or Federal environmental standards. In fact, the facility still lacks an environmental license from IPAAM. However, in accordance with a 1993 agreement between Petrobras and the State environmental

agency, substantial environmental protection system improvements have been implemented or are planned. In 1996 and 1997, US \$18 million was invested in air pollution control equipment (for SO_x and NO_x). Coincident with plant expansion in 1997 and 1998, the Reman facility will invest an additional US \$10 million on equipment and infrastructure to protect water quality.

The water quality related improvements are planned in two phases. The first phase has a January 1, 1999 deadline for completion and will cost about US \$4 million. It includes the installation of a more advanced oil-water separator that will achieve oil concentrations in released water of 20 ppm. The current oil-water separator releases water with oil concentrations of 150 ppm (this does not meet current standards). Phase 1 also includes construction of a retaining basin to hold the first 30 minutes of rain from a storm event for treatment. The second phase has a January 1, 2000 deadline for completion and will cost about US \$5 to 6 million. It involves the construction of a biological treatment facility for the Reman facility.

The Reman facility has established and is tracking performance on specific environmental objectives. Teams and employee training are being emphasized to address a number of environmental issues, particularly oil spills. IPAAM reports that oil spills at Reman have been a regular occurrence - averaging one or more a month. Reman management reported for 1997, no spills had occurred as of mid-April.

The Reman facility has made or plans a number of environmental protection investments based upon end-of-pipe treatment and infrastructure development. The facility, however, also expects to reap substantial environmental performance benefits

from investments that will be made as part of facility expansion (i.e., in equipment reflecting the latest refining technology). The impact of improved technology on refining costs is significant. In 1995, the cost to refine a barrel of oil at the Reman facility was US \$9 (compared to an average cost for all of Petrobras of US \$2.50). By the end of 1997, the cost to refine a to refine a barrel of oil at the Reman facility will be US \$2.70. Petrobras estimates that after facility expansion and a break in period (i.e., by 2000), the cost to refine a barrel of oil at Reman will be US \$0.91 (compared to an estimated average cost for Petrobras in 2000 of US \$2.40).

The efficiency gains reflected in the cost of refining are expected to be reflected in reduced emissions related to the refining process as well.

The Samsung facility in Manaus which began operations in November of 1995, is one of the newest large facilities in the industrial district. The facility includes the latest design and layout features for the assembly of televisions and video tape recorders (VCRs). In fact, after only a year of operations, it was the most productive Samsung facility outside Korea. Production capacity is 1,000,000 televisions and 600,000 VCRs, although production was expected to be 350,000 televisions and 200,000 VCRs for 1997.

As of April 1997, the plant had not implemented a second shift and had 320 employees. Employee turnover is about 1% a year. Samsung standards for production line workers are higher than any other facility in the industrial district, accepting only high school graduates. Samsung also invests more in employee training than do most other facilities (a total of 60 hours of training per year per employee).

Samsung in Manaus is an assembly facility. The plant uses no process water and activities do not include many of the processes that are associated with increased environmental protection demands (e.g., no stamping, no injection molding, no painting, no surface treatments). The process with the greatest potential for environmental impacts is soldering during production. Soldering is automated using an enclosed bath and an alcohol flux that does not require washing. Fumes are vented from work areas. IPAAM issued one license for the facility and visits annually.

Sony has three facilities in Manaus (components, plastic injection and assembly). Each facility has its own environmental license. The first facility (assembly) began operations in 1983. Sony produces televisions, stereos, car stereos and video-cameras in Manaus. Production has increased dramatically. In May 1995, production was 40,000 units per month. In November 1996, production had grown to 180,000 units per month. The rapid growth in production had at least one environmental impact. Fumes from soldering in the circuit board preparation area increased substantially with increased production. Management indicated that as a result of this, an air treatment system had been purchased. At the time of plant visits (November 1996, April 1997), this equipment had not yet been received.

Sony's Manaus operations have about 2000 employees. Sony management was unable to provide information on the employee turnover rate. The director of Sony operations in Manaus is from Japan. Sony was one of two multinationals participating in this research whose senior manager was not Brazilian. The other facility was Fuji Photo Film.

Sony personnel provided examples of process modifications made in order to improve product quality. Some of these modifications provided environmental benefits as well. For example, the "go and return" cardboard boxes used by manufacturers and suppliers in the industrial district must be heavy to permit reuse multiple times. This requirement means that the boxes tend to be large. For Sony, one result was that more material arrived than was needed on production lines and the large boxes blocked

movement when increased production forced Sony to move production lines closer together. Additionally, components in the cardboard boxes tend to get dusty (leading to quality concerns) and cardboard is very susceptible to damage if wetted (a problem in Manaus where it rains frequently). After studying the issue, a Sony team designed a smaller, foldable plastic box which Sony produced itself in its plastic injection molding facility. While the modification was intended to ensure/enhance product quality, it will also reduce significantly the volume of solid waste generated by Sony's operations.

Sony representatives noted that the facilities had no environmental program in place. In November 1996, the plant's quality manager was tasked with developing a plan implementing an environmental management system. This was seen as preparation for pursuing ISO-14000 certification in accordance with corporate policy. Initial environmental reviews lead Sony to team with BASF to pursue development of a water based paint for use in silkscreening. As of April 1997, Sony was had not yet succeeded in replacing oil based paints for this use.

The Seiko facility in Manaus (like the Mondane Facility) does assembly work exclusively. The sole product is watches. All materials are imported. The facility produces solely for the Brazilian market.

Management indicates that environment issues at the plant are minimal. The facility has no liquid discharges. Metal plating is performed in China, Malaysia and Thailand. As imported components and final products are small, the solid waste (primarily cardboard and paper) generated from operations is not great. The facility pays a local solid waste recycler to take materials.

IPAAM issued one license for the facility and visits the plant once each year.

The Springer-Carrier facility is a subsidiary of the U.S. Corporation, United Technologies. It was built in 1964 to produce automobile air conditioners. The plant sat empty from 1984 to 1994, when the decision was made to restart operations to produce window air conditioners. A US \$1.5 million expansion was underway in April 1997. Following expansion, annual production will rise from its current 58,000 unit level to about 150,000 units. All production is intended for the Brazilian market. The Manaus facility employs 70 people (105 after expansion) compared to 1600 at the company's main Brazilian plant located in Rio Grande de Sul. Employee turnover rates are about 6.5% in Manaus and about 2% in Rio Grande de Sul.

The facility is covered by a single environmental license and is inspected once a year. Management noted that the corporate environmental standards are far more stringent than Brazilian standards. Plant personnel consider the handling and possible venting of ozone depleting chemicals to be the major environmental issue that they face. To address this issue the facility has installed electronic gas injection equipment and has purchased sensitive pressure monitoring equipment. Pressure testing is performed on all units to check for leaks (e.g., bad welds) prior to filling with refrigerant. In cases where leaks are detected after filling, the refrigerant is removed and returned to the vendor for recycling. Before 1992, gas in this situation was simply vented to the atmosphere.

Springer-Plastico began operations in 1976. It performs plastic injection molding producing housings for televisions, VCRs, and microwaves. Springer-Plastico's customers are the assembly facilities within the industrial district (e.g., Mitsubishi, Philco, Philips, Xerox, Sharp). The facility uses 700,000 kg of plastic each month and has 600 employees. Most production is used in the Manaus industrial district, although some is exported to Argentina and Chile.

The facility manager noted that the facility feels pressure on environmental issues from a number of fronts. These include customers, the Green Protocol, state regulators and ISO-14000. For example:

- A number of customers including Xerox, Philips and Springer-Carrier now inspect environmental operations at the facility and have indicated their intention to consider environmental performance in the renewal of contracts with suppliers.
- The Green Protocol has already become policy at the major Brazilian government development banks and some state banks. The Protocol may make it difficult (or impossible) for Springer-Plastico to obtain loaned capital for expansion should it lose its environmental license. This appears to be a possibility.
- The facility obtained an environmental license just before December 1996. IPAAM intends to visit every other month during the one-year license period. The facility was informed that the license could be pulled before the year is completed, if IPAAM observed unacceptable practices.
- The facility manager expressed a suspicion that government fiscal incentives may

someday be linked to ISO-14000 as they are currently linked to ISO-9000.

As a result, the plant has undertaken several environmental investments (e.g., modifying painting operations to provide a "closed system" with no aqueous discharge).

Management believes that its largest environmental issue is solid waste. Operations produce 20 metric tons of plastic and 100 metric tons of other solid waste each month.

Eletronorte is an electric utility owned by the Eletrobras system, a federal government holding company. Eletrobras is responsible for power generation and transmission throughout the Amazon region. The utility operates six electric systems. One of these systems is connected to the power grid that serves Brazil's northeast and one is interconnected with the grid that serves the south of Brazil. The other four systems, including Manaus, are isolated. Capacity and demand within the Manaus system are nearly balanced. This led to brownouts and blackouts in the Fall of 1997 when low water at Balbina prevented power generation.

One half of the capacity for the Manaus system (about 250 megawatts) comes from the Balbina hydroelectric facility north of Manaus. The other half of the system's capacity comes from oil-fired and diesel-fired thermal generating units located in two locations within Manaus. While Eletronorte does air monitoring near its facilities, it has no air emission control equipment on its facilities and no current plans to install such equipment.

Demand is growing rapidly (15% a year). One response by Eletronorte has been the development of 18 pilot conservation projects. All but one of these projects are aimed at commercial and industrial users. System losses from unmetered "taps" into the power grid (known as "gatos") are estimated at 25%.

Appendix B

**Example of an Application for an Environmental License
in the State of Amazonas, Brazil**

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Appendix C

**Background Information Questionnaire Sent to Participating Facilities
In Advance of Visits**

Background Data

Facility Name: _____; Location _____; Company representative _____

Facility Information:

- 1) total investment in plant and equipment _____; year facility was established _____
- 2) major facility upgrades/expansions - year _____;
major products _____
- 3) total value of sales in 1995 _____; in 1996 _____; expected 1997 sales _____
- 4) production volume - units/tons in 1995 _____;
1996 volume (units/tons) _____;
expected 1997 volume (units/tons) _____
- 5) number of employees _____; annual employee turnover rate _____ %
- 6) parent company: nationality _____;
location _____
- 7) geographic markets: regional _____ %; national _____ %; international _____ %
- 8) how does the facility compare with other facilities of the parent company in terms of:
financial performance _____;
environmental performance _____

Environmental Management

- 1) environmental license: does the facility have a license from IPAAM (formerly IMA-AM) _____;
 - a) constituents reported to IPAAM as part of facility's self-monitoring _____

 - b) average number of times each year that limits in the environmental license are exceeded _____;
please provide background _____
- 2) environmental philosophy: does facility seek: regulatory compliance _____; or
continuous improvement of environmental performance _____;
 - a) has the facility addressed environmental issues beyond those required by law _____;
please give example _____
 - b) does top management at corporate level actively support environmental efforts _____;
with their time _____; with corporate resources _____
 - c) is environmental performance a factor in determining management compensation at facility _____

- 3) environmental concerns: a) environmental risks from facility operations _____;
b) future environmental challenges at the facility _____
- 4) environmental protection investments: major systems installed _____;
year installed _____; cost _____;
portion of total investment spent on environmental protection _____
- 5) policy: does the company have an official written policy on environmental protection _____;
a) when was the policy established _____;
b) does the policy emphasize preventing the generation of pollutants rather than managing them once created _____;
c) does the policy call for continuous improvement of environmental performance _____
- 6) environmental goals: has the facility established specific environmental goals and targets _____;
a) are these goals quantified _____;
b) are target completion dates set _____;
c) is progress toward achieving goals tracked _____
- 7) dedicated staff: does the facility have dedicated solely to: environmental concerns _____;
quality management concerns _____;
do these individuals work closely with production engineering staff _____
- 8) environmental responsibility: does primary responsibility for environmental performance lie with: line management _____;
environmental staff _____; others _____
- 9) employee involvement: are efforts made to involve all employees in environmental efforts _____;
- does the facility: a) use interdisciplinary teams _____;
b) employee training _____;
c) employee suggestion programs _____;
d) other approaches _____, please specify _____

- 10) environmental review: a) do facility staff perform periodic environmental self-evaluations _____;
 b) does the facility undergo periodic environmental reviews by corporate staff _____;
 c) do customers review the environmental performance of the facility _____;
 d) does the facility review the environmental performance of its suppliers/subcontractors _____
- 11) opportunities identification: a) are records from self monitoring analyzed regularly _____;
 b) does the facility gather information on the release or transfer of hazardous materials _____;
 c) is materials accounting used to identify potential environmental releases _____;
 d) does the facility's accounting system relate the costs of environmental protection (e.g., waste management costs, insurance costs) back to specific products or processes _____;
 e) does the facility use benchmarking with facilities of other companies _____;
 - what companies _____
- 12) pollution prevention (PP): number of PP activities undertaken in the last 3 years _____
- 13) international standards: does the facility plan to seek ISO 14001 certification _____

Motivation for pollution prevention activities (please check all factors that apply to the facility)

(please star those factors that are the primary drivers of decisionmaking)

- | | |
|---|---|
| _____ problems/costs of waste disposal | _____ liability issues |
| _____ regulations that limit disposal options | _____ a pollutant release and transfer registry |
| _____ the expectation of more stringent environmental regulations | |
| _____ corporate policy | _____ requirements of a corporate customer |
| _____ self-evaluations by facility staff | _____ consumer/public expectations |
| _____ facility reviews by corporate staff | _____ potential loss of financial incentives |
| | _____ loan requirements (e.g., green protocol) |
| _____ operational efficiencies | _____ enhanced product output |
| _____ lowered energy costs | _____ other motivating factors (please specify) |

Techniques used to prevent pollution (please check all approaches that have been used at the facility)

Note: these techniques are defined on the following page.

- | | | |
|-----------------------|------------------------------|-------------------------|
| _____ process changes | _____ operational changes | _____ equipment changes |
| _____ product changes | _____ chemical substitutions | |

Defintions of Techniques used to prevent pollution

Process changes

- refinements or alterations in the process itself
(e.g., in a chemical process, this would be a change in the chemical reaction process itself)

Operational changes

- improving plant operations
may include:
 - material handling,
 - the manner in which activities within the process are conducted
 - maintenance

Equipment changes

- modifications and additions to equipment that is in use

Chemical changes

- using different raw materials that will create fewer toxic and hazardous wastes during the production process, without changing the process itself

Product changes

- redesigning the end product so that its manufacture creates less toxic and hazardous waste

Appendix D

Protocol Used During Facility Visits

CASE #

Facility identification

Facility name	facility ownership
facility address	facility telephone
Contact person	title
contact's telephone	email
Industry Type	SIC/ISIC Code

I CORPORATE LEVEL - MANAGEMENT

Environmental Policy

- 1) a) Does the company have an official written policy on environmental protection?
 - when was it established?
 - may I have a copy?
 - b) Does that policy cover all company facilities worldwide?
 - is general policy set by corporation or are facilities fully independent?
 - c) Does that policy call for:
 - efforts that go beyond compliance with environmental laws and regulations?
 - evaluating source reduction approaches before waste management techniques are applied?
 - routinely considering source reduction during the engineering phase for new products and processes?
 - involving employees?
 - involving suppliers and customers in addressing environmental concerns
(e.g., Philips monitors the environmental programs of its preferred suppliers)?
 - continuous improvement in environmental performance?
 - routine environmental self-evaluations by facility staff?
 - routine environmental audits by corporate personnel?
 - what are the environmental performance standards that are used?
 - source reduction information to be shared with:
 - suppliers?
 - customers?
 - other industries?
 - d) What individual serves as a point of contact for the corporation regarding the policy?
- 2) Is the focus of the policy (and any associated guidelines) on preventing the generation of pollutants rather than on managing them once created (e.g., Kodak)?
 - a) how does the company define source reduction/pollution prevention/waste minimization?
 - b) does the policy cover all media (i.e., air, water, land)?

Environmental Leadership

- 1) Do environmental protection efforts have high-level leadership?
 - at what level (e.g., board of directors committee)?
- 2) Where does responsibility for implementation of the environmental policy lie?
(line management, environmental staff, or both)
- 3) Is environmental performance a factor in determining management compensation at the corporate level?
- 4) Is there a formal environmental management program?
 - are corporate environmental action plans established?
 - Is there an environmental department?
 - Is the company seeking to comply with ISO 14001 (and similar codes)?
- 5) In industries where "codes of management practice" have been established (e.g., CMA), do company management systems conform with best practice?
- 6) Does the company collect "TRI-like" data at its facilities (even where this is not required)?

Openness on Environmental Issues

- 1) Does the company publicly disclose the state of environmental management activities?
- 2) Does the industry trade association or company have a public advisory council (e.g., CMA)?

II FACILITY LEVEL MANAGEMENT

General

- 1) Current production technology at plant?
 - equipment type, age, value?
- 2) Overall environmental strategy at facility?
- 3) Vision for facilities future environmental performance?
- 4) How does facility compare with other plants of the parent company?
 - in terms of economic performance?
 - in terms of environmental performance?

- 2) Is information on potential pollutants collected at the process-level?
 - a) does information collection include a process by process comparison of material inputs and outputs?
 - 1) methods used in materials comparisons:

- materials accounting	- on what processes?
- materials balance (+/- 5%)	- on what processes?
- statistical process control	- on what processes?
 - 2) how frequently are data collected?
 - 3) is the information collected computerized?
 - 4) who collects the materials accounting/balancing information?
 - what is their background?
 - b) in addition to analyses of material quantities, does this analysis include a detailed review of employee activities that may generate waste (e.g., materials handling, maintenance)?
- 3) Are environmental costs applied to the individual processes that are responsible for waste generation rather than being treated as overhead (i.e., is there a full cost accounting system)?

e.g.,

 - cost of wasted starting materials and lost product,
 - is this done by specific chemical or chemical category?
 - waste handling (such as capital and operating expenses for on-site recycling, treatment, storage or disposal facilities),
 - transportation and other expenses for wastes sent off-site,
 - regulatory compliance (such as staff time and other resources used for compliance with environmental regulations),
 - insurance premiums,
 - future liability due to waste site cleanup, accidents, worker illness,
 - public/customer relations costs related to waste issues,
 - diminution of the value/level of "corporate goodwill".

Data Use target group: management; production, environmental and accounting staff

- 1) Who sees the data?
 - upper management
 - process managers
 - source reduction teams?
- 2) How is the data used?
- 3) How is the data factored into decisions about source reduction efforts?

4) Is a source reduction plan developed?

Using information from the process-level inventory of potential pollutants and from pollution cost analyses does the facility develop specific source reduction plans (environmental action plans)?

a) do facility source reduction plans:

- prioritize production processes and waste streams for source reduction efforts?
- identify appropriate techniques?
- set source reduction targets and schedules?
 - are targets based on specific chemicals, chemical categories, or waste categories?
 - are targets established for individual processes or for the plant as a whole?
 - has a base year been established from which progress is measured?
 - how is baseline data modified to reflect changes in products and production levels?
 - what are the current target substances?
 - what are the target dates?

b) is progress toward achieving targeted performance tracked?

- have targets been achieved?

c) when was the plan established?

d) when was the plan last revised?

e) are new targets set as old targets are achieved

- (i.e., is source reduction pursued on a continuous basis)?

Other Aspects of Facility Management target group: facility management

1) What is the source of environmental priorities?

- corporate policy
- facility management
- local regulatory pressure

2) How much flexibility do local managers have regarding environmental issues?

3) What are the principle factors motivating environmental efforts?

4) Who, within the plant, has ultimate responsibility for reducing the generation of wastes?

- title:
- who do they report to?
- who reports to them?

- 5) Is there an environmental department at the facility?
 - size of staff?
- 6) What is the role of the plant manager?
- 7) Is it clear from policy that employees are encouraged and expected to propose source reduction ideas (e.g., Kodak)?
- 8) Are efforts made to involve employees and management in finding means to reduce waste generation?
 - a) source reduction training programs ; please describe:
 - b) active solicitation of ideas
 - c) recognition, reward and incentive programs ; please give example:
 - d) is environmental performance of the facility a factor in determining management compensation at the facility level?
- 9) How is information about source reduction progress transmitted throughout the facility?]
- 10) Major environmental issues and concerns according to:
 - facility management?
 - environmental staff?
 - corporate representatives?
- 11) Have environmental programs at the facility been modeled after some other facility/organization?
 - If so, what facility or organization?
- 12) Does the facility use benchmarking in the environmental area?
 - with whom do they compare themselves?
- 13) Does facility work to maintain a dialogue with neighbors (e.g., CMA)?
(this could include establishing an external advisory body for the facility's environmental matters?)

III FACILITY LEVEL - PROCESS BACKGROUND

1) Output & employment

- a) annual sales
- b) annual production volume
- c) number of employees
 - administrative
 - production

Labor profile:

- age
- gender
- average company service (yrs)

- d) management (nationality)
- e) date operations began
- f) total investment in facility
- g) major changes in output in last 10 years
- h) major changes in product in last 10 years

2) Product type

- a) Product(s) produced at plant (SIC codes)
- b) Production process used - continuous or batch; batch size, time period between runs
- c) Production changes planned

3) Market

- local, regional, national or international

4) Environmental profile

- a) permits held
- b) permits applied for
- c) permits needed, but not yet applied for
- d) current permit violations
- e) on-site releases/disposal (TRI)

1) Water discharges

- a) chemicals and quantities released by production processes
- b) chemicals and quantities released by one-time events (accidental releases)
- c) receiving water body

- 2) Air emissions
 - a) chemicals and quantities released by production processes
 - stack emissions
 - fugitive emissions
 - b) chemicals and quantities released by one-time events (accidental releases)
- 3) land releases and disposal
 - a) chemical
 - b) type of disposal (landfill, land treatment, surface impoundment, underground injection)
- f) off-site transfers (TRI)
 - 1) for disposal
 - chemical(s)
 - quantity transferred
 - 2) for treatment
 - chemical(s)
 - quantity transferred
 - 3) to publicly owed treatment works (POTW)
 - chemical(s)
 - quantity transferred
- g) on-site storage (TRI)
 - 1) product storage (MSDSs)
 - chemical inventory
 - type of storage
 - 2) waste storage
 - waste inventory
 - type of storage
- h) recycling, energy recovery, and treatment (TRI)
 - 1) quantity recycled on-site ; off-site
 - 2) quantity used for energy recovery on-site ; off-site
 - 3) quantity treated on-site ; off-site

IV PROCESS LEVEL - MODIFICATIONS

- 1) Production process description (including waste information) - before and after modification
(in narrative and/or diagrammatic form)

a) Source Reduction

- 1) source of the idea for modification
- 2) motivating factors
- 3) source reduction method used:
 - operational changes (improved housekeeping, maintenance, inventory control, training)
 - chemical substitution
 - equipment and technology changes
 - process and procedure changes (includes in-process recycling)
 - product redesign or reformulation
- 4) What factors influenced the choice of source reduction method?

b) Other pollution management

- 1) source of the idea for modification
- 2) motivating factors
- 3) pollution management method used:
 - out-of-process recycling
 - treatment
 - disposal
- 4) What factors influenced the choice of pollution management method?

c) Scale/size of operation/process

d) Process change - stage of development

2) Date implemented

3) Time to implement (including R&D, if required)

4) Physical effects (material accounting)

a) materials affected

increase/decrease in raw material use

- per unit production
- annually
- % change

b) increase/decrease in waste generation

- per unit production
- annually
- % change

c) increase/decrease in energy use

- per unit production
- annually
- % change

d) increase/decrease in water use

- per unit production
- annually
- % change

e) increase/decrease in productivity/product yield

f) effect on product characteristics and quality

5) Economic factors

a) change in:

- | | |
|------------------|------------------|
| - material use | ; effect on cost |
| - energy use | ; effect on cost |
| - water use | ; effect on cost |
| - waste disposal | ; effect on cost |

b) facilities

- modifications made
- capital cost

equipment

- modifications made
- capital cost
- operating cost effect

c) other waste management costs

- | | | |
|------------------|-----------------------|------------------|
| - personnel | - person-hour demands | ; effect on cost |
| | - skill level demands | ; effect on cost |
| - transportation | | ; effect on cost |

- maintenance of pollution control equipment
 - changed maintenance requirements (e.g., frequency, complexity of maintenance)
 - effect on cost
 - change in normal maintenance downtime
 - effect on cost

6) Effects/benefits:

a) Economic measures

- Annual cost savings (annual production cost savings, annual disposal cost savings)
- Payback period
- Improvements to product quality
- Transferability (commercialization potential)

b) Environmental and health effects

c) Other effects (e.g., improved regulator relationships)

7) Obstacles, problems, known constraints

8) assumptions

9) frequency, reproducibility

10) applicability to other firms or other circumstances in the same firm

Vita

William Schramm was born in Albany, New York on June 8, 1955. He entered Rensselaer Polytechnic Institute in Troy, New York in August, 1973 and received a Bachelor of Science in Geology in June, 1977. He entered a Master's program at Louisiana State University in Baton Rouge, Louisiana in August, 1977 and received a Master of Science in Geology in May, 1981. After working as a petroleum geologist for six years, he entered The University of Texas at Austin Business School in August, 1986 and received a Master's in Business Administration in December, 1987. In August, 1989, he entered the University of Tennessee to pursue a doctoral degree. He participated in the doctoral program while working as a project manager with the Department of Energy's Hazardous Waste Remedial Actions Program in Oak Ridge, Tennessee, and later as a research scientist with the Environmental Sciences Division of Oak Ridge National Laboratory. The Doctorate in Ecology was received in May 1998.