

ECO-EFFICIENCY: IMPROVING ENVIRONMENTAL MANAGEMENT STRATEGY IN THE PRIMARY EXTRACTION INDUSTRY

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ABSTRACT

This article examines the application of “eco-efficiency” in the primary extraction industry, defined here as mining and allied operations. This concept, which has been popularized by the World Business Council for Sustainable Development (WBCSD), has become the subject of important documents, discussions, and conferences in recent years. To facilitate the implementation of eco-efficiency, the WBCSD has crafted a seven-principle framework for businesses keen on doing “more with less.” This framework, however, is almost entirely prescriptive for manufacturing and service sector firms, and highly inappropriate for the primary extraction industry. Promoting eco-efficient management in the primary extraction industry requires only partial implementation of the WBCSD framework, as well as the adoption of sector-specific strategies.

INTRODUCTION

Many have proposed that the corporate environmental management paradigm has shifted from a reactive to a “pro-active” mode in recent years. Several firms, in response to increased legislative and stakeholder pressures, appear to be taking a more preventative stance toward environmental issues. However, in the wake of this alleged heightened global environmental awareness, a number of highly ambiguous environmental management terms—“buzzwords”—have evolved. There is now considerable debate over the exact application of terms such

as *pollution prevention*, *cleaner production*, and *sustainable development* in industry.

The difficulty in translating and interpreting particular environmental management concepts underscores what is perhaps a more pressing problem: how does the terminology apply in different industrial contexts? In the case of the primary extraction industry, defined here as mining operations, mineral processing activities, and smelting complexes, producing a convincing interpretation of newly minted environmental management language has often proven onerous. In fact, outside of a series of brief case studies, few investigations have been undertaken to explore the potential functions and applications of environmental management concepts in the sector.

The purpose of this article is to examine the application of one such environmental management term, “eco-efficiency,” in the primary extraction industry. The article quintessentially highlights the limitations of the concept in this context, and, in the process, aims to show how complications can arise if industrial environmental management terminology is interpreted in an excessively cavalier manner. It begins with a broad literature review of eco-efficiency, which profiles its evolution and principles. The article then examines the role of eco-efficiency in primary extractive operations, illustrating the shortcomings of the current working definition and accompanying framework being promoted by the World Business Council for Sustainable Development (WBCSD). The article concludes with a series of case studies, which show how this sector of industry can embrace the concept of eco-efficiency.

AN OVERVIEW OF ECO-EFFICIENCY AND ITS PRINCIPLES

Since publication of the Brundtland Commission’s landmark report *Our Common Future* [1], governments and stakeholder parties have increasingly pressured industry to account for sustainable development, i.e., to account for the needs of the present without jeopardizing the needs of future generations. Certain businesses have since restructured operations and undertaken a series of voluntary initiatives. Addressing key issues of sustainability, however, can be both costly and overwhelming for the management of any business, key challenges identified by the Business Council for Sustainable Development (BCSD).¹ The BCSD proposed that environmentally, industry could address the challenge of sustainable development through eco-efficiency—by emphasizing *pollution reduction through process change* as opposed to reactionary “end-of-pipe” approaches [2]. Eco-efficient operations seek to

¹ In 1995, the BCSD and the World Industry Council for the Environment (WICE) merged and became the World Business Council for Sustainable Development (WBCSD).

produce “more with less,” and create economic value while continuously reducing ecological impacts and the use of resources. This section of the article provides a detailed overview of eco-efficiency, its principles, and its applicability in business operations.

Eco-Efficiency Defined

The BCSD initially defined eco-efficiency as follows:

The delivery of competitively priced goods that satisfy human needs and bring quality-of-life, while progressively reducing ecological impacts and resource intensity throughout the lifecycle, to a level at least in line with Earth’s carrying capacity [9].

Many have since argued that eco-efficiency, which essentially combines economic and ecological efficiency, is an effective strategy for those businesses keen on improving both their bottom line and environmental performance. As Hukkinen [3] explains, eco-efficiency has “inspired environmental policy makers worldwide as a concept that continuously articulates their ongoing concerns in environmental management,” in effect, reflecting a “transition from pollution control to product-oriented solutions.”

Eco-efficient management was first widely publicized by the World Business Council for Sustainable Development (WBCSD), an organization that aims to “provide leadership as a catalyst for change in the achievement of sustainable development” and promote “the attainment of eco-efficiency through high standards of environmental management in business” [4]. The environmental benefits of eco-efficiency include: the conservation of energy and raw materials; substitution of toxic material inputs with nontoxic substances; a reduction in noxious emissions; and the use of less ecologically damaging products. Economically, the firm not only achieves higher profit levels as a result of improved resource and energy efficiency, but also benefits as a result of improved public and governmental perception.

Helminen [5] contends that the definition of eco-efficiency as a corporate (sustainable development) strategy is “problematic” because it fails to include the ethical dimension of sustainability. It is not the intention of this article, however, to evaluate the effectiveness of eco-efficiency as a tool for sustainability; rather, it supports eco-efficiency as an environmental management strategy because it emphasizes continuous improvements in both the ecological and economic arenas. Generally, integrating eco-efficiency into production processes requires industry to consider decreasing inputs to waste streams, reducing throughput and output streams, and minimizing health, safety, and environmental risks [6]. It is a well known fact that several firms have a poorly developed environmental management structure—policies, personnel, auditing schemes, etc.—which has worked against management, who, in turn, have failed to realize the merits of eco-efficient

business practices. As a result, a number of suggestive remedies have emerged in the literature, in an attempt to help guide companies along a path of improved eco-efficiency.

Attempts have been made to provide a scheme for measuring levels of eco-efficiency in business operations. No standardized system has been developed to date, although it is worth noting that the Canadian National Round Table on Environment and Economy (NRTEE) has proposed in a recent report, *Measuring Eco-Efficiency in Business* [7], that a material productivity index, energy intensity index, and toxic release index be used as eco-efficiency indicators for environmental evaluation purposes. Different industries are confronted with different challenges, however, and have different characteristics when it comes to pollution and production processes, therefore rendering it near impossible to have a single universal eco-efficiency indicator set for industry.

In spite of these challenges, Schaltegger et al. [8] has developed a simplistic, yet useful, formula for measuring eco-efficiency. It is as follows:

$$\text{Eco-efficiency} = \text{Value Added} / \text{Environmental Impact Added}$$

The premise behind the formula is that higher levels of eco-efficiency are attained when environmental impact is minimized. To reiterate, the challenge in crafting an industry-wide formula of eco-efficiency is that different industries have markedly different environmental characteristics. Therefore, in the process of developing universal environmental evaluation procedures, tools lose their robustness, and often become too weak and basic for effective analysis and assessment.

Nevertheless, many are still in support of crafting a more complex formula for measuring eco-efficiency. However, realistically, can the pollution aspects of one industry be compared to those of another? For instance, is the environmental performance of a mine comparative to that of a dry cleaning shop? Moreover, if a universal formula is developed for measuring eco-efficiency on a per unit basis, is it realistic to argue, for example, that a mine with newly implemented state-of-the-art environmental management practices is performing more “eco-efficiently” than the most heavily polluting dry cleaning shop? A mine that features the most advanced of environmental technologies and managerial practices is still significantly more environmentally damaging than any dry cleaning business.

It is therefore recommended that the above formula be used but adapted to different industry scenarios; eco-efficiency should be assessed strictly on a sector-by-sector basis.

Principles of Eco-Efficiency

Several strategies have been proposed to promote eco-efficiency in industry. The most widely referenced guidelines, however, are those of the WBCSD. As the

true pioneer of the concept of eco-efficiency, the WBCSD deemed it appropriate to provide an accompanying framework for achieving economic and environmental improvement. It is imperative that a firm makes a number of key changes before adopting a framework of eco-efficiency. The successful integration of *any* environmental management tool, practice, or strategy is contingent upon a change in corporate culture—namely, a company-wide change in attitude toward environmental issues.

First, it is imperative that management restructures corporate environmental management agendas. Eco-efficient firms, which strategize to “stay ahead of the curve,” increasingly address regulatory requirements and the needs of stakeholders in corporate environmental policies. The top priority of a firm claiming to be eco-efficient is environmental management and performance, which requires setting targets and devising methods for facilitating improvement, and identifying strategies for dealing with both anticipated and unanticipated problems with pollution and waste. Secondly, management must express a willingness to abandon all *ad hoc* pollution control systems and replace each with state-of-the-art preventative apparatuses. A similar approach must be taken with toxic material handling—committing to ensure, that wherever possible, hazardous materials will be substituted for, and, whenever necessary, employees will be provided with requisite training. Finally, a company keen on adopting an eco-efficient management strategy must be willing to undertake thorough evaluation. Remaining environmentally pro-active requires continuous analysis to determine how well the firm is performing in light of legislative requirements and stakeholder expectations. Moreover, because eco-efficient management mandates that a firm be anticipatory, continuous evaluation enables a company to respond appropriately to important legislative changes, and to initiate internally the necessary procedures for addressing these changes. These recommendations, although generic, nevertheless signify that environmentally, a company is ready to ascend to the next step: eco-efficient management.

Once these important changes have been made, a firm is in an improved position to adopt a framework of eco-efficiency. As indicated earlier, the most comprehensive, widely referenced guidelines devised to date are those of the WBCSD. After months of extensive research, the WBCSD developed the framework and released its details in its highly influential report, *Eco-Efficient Leadership for Improved Economic and Environmental Performance* [9]. They are as follows:

1. Reduce material intensity: since mass inputs of materials occur at each and every stage of a product’s lifecycle, a substantial quantity of waste is produced. The resulting costs of pollution are passed down the industrial chain and are eventually absorbed by the consumer. Thus, using raw materials more efficiently reduces environmental stress and creates fewer expenses for all parties involved.

2. Reduce energy intensity: as with material inputs, energy inputs are necessary at each stage of the lifecycle. In short, the lower the energy intensity of a material, the more environmentally and economically efficient it is.
3. Reduce the dispersion of toxic agents: industrial processes use harmful toxic chemicals that can either break down rapidly in the biosphere or can bioaccumulate. Minimizing the use and production of these agents, in turn, reduces the probability of costly chemical accidents occurring, and, at the same time, improves environmental protection.
4. Increase recyclability: this includes anything from industrial material inputs to decommissioned products. Reusing materials reduces both the consumption of resources and energy, and the environmental impacts of waste disposal.
5. Maximize the sustainable use of renewable: using renewable and potentially replenishable sources instead of exhaustible resources reduces environmental impacts and pollution costs for firms.
6. Extend the durability of products: the notion of redesigning products into more durable states creates a more efficient good and results in the use of fewer material and energy inputs.
7. Increase the service intensity of goods and services: efforts should be made to increase the value of products for customers.

This seven-principle framework has been used as a reference point in most of the eco-efficiency analyses undertaken to date.

A major complication with this framework is that each of these principles has been proclaimed to be broad in scope, and perhaps more importantly, has been advertised as a universal environmental management tool ideally suitable for all businesses; however, few specific procedures and guidelines have been developed to illustrate how firms can achieve improvements in each of the aforementioned areas. This puts into perspective the overarching problem: does this framework apply differently to different industrial sectors? More specifically, in view of the objectives of this article, how does this framework apply to the primary extraction industry, and how can firms within the sector become more eco-efficient?

ECO-EFFICIENCY AND ITS APPLICATION IN THE PRIMARY EXTRACTION INDUSTRY

The exact scope of application of eco-efficiency in the primary extraction industry is somewhat undetermined. The difficulty with conforming to the eco-efficiency guidelines established by the WBCSD is that the final two principles, “extending the durability of products” and “increasing the service intensity of goods and services,” seem almost entirely prescriptive for manufacturing and service sector firms. The WBCSD has long contended that eco-efficiency “encourages business to search for environmental improvements that yield

parallel economic benefits,” and “focuses on business opportunities and allows companies to become environmentally responsible and more profitable” [10]. Its claim, however, of eco-efficiency being achieved “by the delivery of competitively-priced goods and services” while progressively reducing “resource intensity throughout the lifecycle,” is a fitting environment management mandate for firms residing within the secondary and tertiary sectors but at the same time, highly inappropriate for primary extractive operations. For example, improving the durability of nickel ore is beyond the scope of any smelting complex. Moreover, a mine cannot increase the intensity of its goods, i.e., ore and refined mineral, because it feeds manufacturing firms, and does not provide a “direct” service to the public. In short, the WBCSD, despite its contention that eco-efficiency is an “environmental management philosophy which encourages business to search for environmental improvements that yield parallel economic benefits” [11], has designed an eco-efficiency framework incapable of promoting improvements equally throughout all sectors of industry.

It is imperative, however, that the WBCSD not be seen as ineffective, and that the efforts of the organization not being taken out of context and perceived as fruitless, for the very reason that it has long proven difficult to adopt environmental management terminology in the primary extraction industry. In fact, a series of buzzwords have emerged in recent years that are increasingly being incorporated into government and industry policy-making, the precise functions of which have generated considerable debate in the primary extraction industry. The application of *sustainable development* in mining, for example, has generated mass discussion in the past decade. Many researchers (e.g., [12, 13]) discuss mine sustainability in the context of the resource, whereas others (e.g., [14-16]) overlook the finite nature of minerals altogether and make reference to operating conditions, performance, and surrounding communities, suggesting that mine sustainability should take into account other important environmental and socioeconomic entities outside of mineral production and availability. In another example, the concept of *pollution prevention* has emerged to mean the elimination of wastes at the source, and the avoidance of environmental problems from the outset. During mineral excavation processes, however, a number of unavoidable environmental impacts occur—namely vegetation removal, erosion, sedimentation, and deforestation. These problems *cannot* be fully prevented, and can only be remedied at the time of mine decommissioning and reclamation.

In a study by Hilson [17], it was shown that only five of the seven principles of the WBCSD framework of eco-efficiency apply to mining and allied industries. The following strategies were deemed suitable:

- Reduce material intensity (i.e., decrease water consumption, reuse mine wastes, and implement an environmental management system)
- Reduce energy intensity (e.g., reuse waste heat, use energy-efficient technologies, and maximize the use of “waste” energies)

- Reduce the dispersion of toxic materials (e.g., improve treatment of acid mine drainage, install improved scrubbing apparatuses at smelting complexes, and improve the management and treatment of toxic agents)
- Enhance the recyclability of materials (e.g., chemical recycling, and recover and reprocess waste metals from streams)
- Maximize the sustainable use of renewables (e.g., exploit “passive” energies, substitute renewable energy sources for coal, and use low sulphur coals)

The final two principles, “extending the durability of products” and “increasing the service intensity of goods and services” were determined to be inappropriate for firms of the primary extraction sector.

To help put into perspective how the primary extraction industry can embrace the concept of eco-efficiency, the next section of the article provides case study analyses of methane usage, sulphuric acid recapture, and tailings reuse. Each of these examples illustrates clearly how mining and allied firms have undertaken a series of initiatives resulting in both economic and environmental improvement, or, in a word, eco-efficiency.

CASE STUDIES OF ECO-EFFICIENCY IN THE PRIMARY EXTRACTION INDUSTRY

The primary extraction industry is renowned for being “dirty,” which is why it commonly operates under a stringent web of legislation. Companies have been pressured into being proactive, and have responded by adopting a number of highly effective environmental management tools and strategies—namely, audits, environmental management systems, monitoring practices, and reporting systems. They have also undertaken a number of specific initiatives, involving equipment substitution and technological installation, which have resulted in both economic rewards and environmental improvement. This section of the article presents examples of eco-efficient initiatives undertaken in the primary extraction industry.

Case Study I: Flash Smelting and Sulphuric Acid Recapture

Several base metals such as nickel and copper, when smelted, produce significant quantities of sulphur dioxide (SO₂), which can be captured using flash smelting techniques: unique pyrometallurgical processes for smelting metal sulphide concentrates. In flash smelters, metals and sulphur are oxidized from concentrate, and the SO₂ off-gas produced can be readily fixed into sulphuric acid. Globally, sulphuric acid has a wide range of applications, playing a part in the production of nearly all manufactured goods, including food and drink, general chemicals, steel, fertilizers, petrochemicals, pigments, agricultural fertilizers, and batteries. Several companies, such as Britannia Zinc of the United Kingdom and

INCO Ltd., have invested in flash smelting technology, are now mass producers of sulphuric acid, and heavily market the product.

As Davenport and Partelpoeg [18] note, INCO, in fact, is the pioneer of flash furnaces, and has used the technology effectively for nearly 25 years. The company was formerly one of North America's biggest environmental polluters, largely because of inefficient reverberatory furnace smelters at its complex in Sudbury, Ontario, Canada. As Warhurst and Bridge [19] explain, having reached the limits of efficiency improvements and unable to meet increasingly stringent regulations as part of the acid rain abatement program implemented by the Ontario Ministry of Environment, the company invested some CAN\$3 billion to design an oxygen flash smelter capable of producing an SO₂ off-gas stream that could be readily fixed into sulphuric acid. Environmentally, this change has enabled INCO to reduce its annual emissions of SO₂ by some 100,000 t, and economically, it has helped transformed it into one of the world's lowest cost producers of nickel [20].

Similar improvements have been achieved at the Bingham Canyon Mine in Garfield, Utah, where the Kennecott and Outokumpo flash smelter was installed. Now heralded as the "cleanest smelter in the world," this \$880 million system, which is capable of handling 100 percent of concentrates at the Mine, replaced a facility that was capable of handling only 60 percent of concentrates [21]. As Warhurst [20] explains, to meet increasingly stringent air quality regulations, the company was faced with the choice of investing \$150 million to retrofit existing systems or financing the implementation of the new process; it opted for the latter. The new smelter is capable of capturing 99.9 percent of input sulphur, and it is estimated that the complex, overall, will reduce operating costs by 53 percent.

In short, flash smelting enables smelting complexes to reduce emissions of SO₂, improve operational efficiency, and generate additional revenues for companies as a result of sulphuric acid recapture.

Case Study II: Tailings Reuse

The principal solid waste produced at mines, rock tailings, has significant recycling and reuse potential. Before devising methods for their use, however, gangue should first be identified as waste, as several tailings piles contain valuable base and precious metals. For example, as Ghose and Sen [22] note, iron ore tailings contain iron concentrations of around 45 percent or more that could be economically viable to remove in situations where land and environmental costs are high. In another case, nickel refining, wastes are often loaded with nickel sediments, the successful recovery of which reduces emissions of flue dust and other waste streams, and economically, contributes to raw metal output [23].

Once metal residuals are reprocessed from waste tailings, the remaining piles of sediment can be used for other applications. One practical use is as

paste backfill, a pumpable, flowable fluid consisting of mine tailings and cement that is prepared from dilute slurries of tailings using conventional dewatering systems. Its use helps reduce mine dewatering, minimize tailings impoundment requirements, improve support properties at sites, and minimize spills underground [24]. Paste backfill systems are more practical than traditional rockfill systems because material transport is cheaper (pipeline vs. rail and truck), impoundment costs are less, and labor requirements are fewer [25]. Several mines, including many in Quebec, Alberta, and South Africa, have already demonstrated that paste backfill is a viable alternative to hydraulic backfill [26-28].

Colliery spoils, the by-products of coal mining, can also be used as mine fill. As Sleeman [29] notes, colliery spoils, which are derived from the rocks lying above, below, and sometimes within coal seams, can be grouped into three separate categories. The first, burnt mine stone, is a suitable material for use as common fill, and can be used as “special fill material” in road works in and around a mine. The second, mine stone, can also be used as material for temporary road construction, and as backfill material for disused quarries and clay pits. The final category, modified colliery spoil, can be used for more specialized purposes, such as a reinforcement agent and as an aggregate.

It has been suggested by a number of scientists that waste tailings could also serve as practical construction and building material. Early researchers [30, 31] identified that small amounts of tailings could be used for a number of applications, including as an input to road-making, as a soil additive, as mineral filler material, in the manufacture of bricks, as lightweight aggregate, and as autoclaved blocks. For example, as Dean et al. [32] explain, tests were conducted using tailings from the TVX Mineral Hill Gold Mine in Jardine, Montana, to determine if the waste could be used as an aggregate in concrete bricks and blocks. Laboratory work determined that the tailings concrete, if proportioned to provide the workability and strength necessary for such an application, and if issues of absorption, shrinkage, and durability are fully addressed, could, in fact, be used for aggregating purposes.

Furthermore, as Sleeman [29] explains, unburned colliery spoil or mine stone is also a suitable building material that can be used for raising low-lying recreational sites, in the covering of municipal tips, and as filling in disused canals and docks. Further, mine stone from disused spoil heaps, if properly handled, could provide highway earthworks and stable ground for building construction that could be easily trenched for services. Whitbread et al. [33] indicate that a number of highway projects and railway embankments in the Midlands, England, used unburned colliery spoil, and that overall, the material performed well, the only minor drawback being the difficulty in maintaining its consistency. Ancillary uses of colliery spoil include fill material in road embankments, infill for disused limestone mines, and input material in cement manufacture.

Case Study III: Methane Gas Recapture

The biochemical decay and metamorphic transformation of original vegetable matter—a process called “coalification”—produces large quantities of by-product gases, one of which is methane (CH_4). Higher ranks of coal emit greater volumes of CH_4 , which is released when reserves are removed from pressurized coal beds and crushed. The persistence of CH_4 in coalmines is an issue of utmost importance, particularly for underground, ventilated operations. The gas is highly flammable and, to avoid possibility of an explosion or fire, must be mixed with mine air and channeled to a “gob” or “goaf” area, where it can be released into the atmosphere through boreholes [34].

There is great potential for utilizing this CH_4 gas for heating and energy purposes, and a vast supply is available for use. In China, for example, the world’s largest coal producer, an estimated six million tons of methane is emitted from coal and oil mining operations each year [35]. At coalfields in India, the fourth largest coal producer in the world, an estimated 0.37 million tons of CH_4 is produced annually. The viability in recovering the gas from operations in these and other coal-producing countries is obviously contingent upon achieving a general consensus on utilizing coalbed CH_4 . If the issue is approached properly, however, and the necessary pipelines, compression and treatment facilities are constructed, CH_4 could be collected effectively and used as an alternative to natural gas, as chemical feedstock, as a power source in utility plants, and as combustion air for turbines and boilers [34, 36].

Presently, the biggest barrier preventing utilization of CH_4 emitted from coalmines is the capital costs of pipeline systems. In the United States, for example, costs can range from \$500,000 to \$1 million per mile of pipeline in remote areas [34]. In the more heavily populated areas of coal-producing countries, however, there is no reason why costs for utilizing coalbed methane cannot be substantially less. Countries like India and China, which have heavily agglomerated urban centers situated in close proximity to one another, have already experienced large success with renewable energy sources, in particular, biofuels. Wide-scale utilization of CH_4 gas from coalbeds for equivalent purposes involves implementing similar technologies to those used in renewable energy setups. In short, if properly researched and planned, wide-scale utilization of CH_4 from coalmines could very much become a reality.

The above-mentioned case studies illustrate how the primary extraction industry, by undertaking a series of environmental initiatives, can improve its environmental and economic performance: the basis of eco-efficient management.

CONCLUSION

The present article has attempted to clarify the application of eco-efficiency in primary extractive operations, and has, in the process, effectively illustrated the

difficulty in adopting environmental management terminology in certain industrial contexts. Although the basis of eco-efficient management is “doing more with less,” the eco-efficiency framework developed by the highly influential WBCSD its limitations in this sector of industry. The framework appears to be geared toward service sector and manufacturing firms—operations that are in direct contact with the public.

It has been shown, however, that primary extractive operations *can* become more eco-efficient. It is recommended that the forward thinking companies in the sector use the aforementioned Schaltegger formula as guidance, but not to fully adopt the misleading WBCSD framework. Rather, it is suggested that the first five principles of the framework—reduce material intensity; reduce energy intensity; reduce the dispersion of toxic agents; increase recyclability; and maximize the use of renewables—be followed. The final two principles—extend the durability of products, and increase the intensity of goods and services—should be ignored, as both are ideally suited for manufacturing and service sector firms, but not directly relevant to those operations of the primary extraction industry. As the case studies of sulphuric acid recapture, tailings reuse and coalbed methane usage illustrate, the primary extractive industry can achieve higher levels of eco-efficiency by making optimal changes that result in both environmental improvements and financial gains.

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