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Sustainable Mining: Trends and Opportunities

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CHAPTER 5

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ABSTRACT

Sustainable development integrates economic, environmental and social considerations in order to improve the lives of the current generation and ensure that future generations will have adequate resources and opportunities. Sustainable mining is not a new approach or concept in resource consumption. It is a holistic approach for dealing with a complex, interlinked set of factors that determine the net societal worth of a project.

A holistic approach to phosphate beneficiation gives us opportunities for the improvement of economic results through reactant and waste minimization. It also gives direction for continued research thrusts to solve the problems associated with the clay ponds and the reduction of potentially hazardous wastes.

SUSTAINABLE DEVELOPMENT

Sustainable development is a growing concern expressed by many businesses, organizations and individuals. Yet, no workable quantifiable definition of sustainability is available for evaluation of specific projects or operations. The lack of such a definition inherently gives engineers difficulty. Sustainability of human activities (predominantly production and consumption) is a growing concern among businesses, customers, governments, international bodies and nongovernmental organizations. These concerns are often linked to energy efficiency, reduction of environmentally harmful emissions, ecosystem preservation and other "save the Earth" efforts (Hemanowicz, 2004). They are becoming a part of the "triple bottom line" for business accounting: financial, social and environmental (EBF, 2002). Despite its increasing importance, current definitions of "sustainability" are somewhat vacuous. The most commonly accepted description was provided by the World Commission on Environment and Development (1987) in the "Brundtland Report." According to this report, the goal of sustainability is to "meet the needs of the present generation without compromising the ability of future generations to meet their own needs."

SUSTAINABLE MINING

Obviously, sustainable mining is part of the more general notion of sustainable development. But what is it? The definitions and the perceived concepts associated with the term, "sustainable mining" are as diverse and numerous as the special interest groups that use the terminology.

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How do we recognize sustainable development and mining? When the concepts of sustainable development are applied to mineral resources, there is little agreement on what is to be sustained, and by what means. Without such agreement, sustainable development will remain little more than a slogan of little practical value to public-policy makers. Part of what is missing from most discussions is an understanding of the nature of mineral resources and the dynamics of their development (National Academy of Sciences, 1996). Without this understanding, the use of the sustainable development and mining sustainability becomes phrases that often confuse sustainability with environmental protection and other lofty goals that, strictly speaking, are not required for sustainable operations.

In the search for an answer to the question of what is sustainable mining we will review two groups' perspectives of sustainable mining and development. The two largest United States public landholders, the US Bureau of Land Management and the USDA Forest Service, have produced a joint proclamation setting forth their applications and implementation. Contained in the bulletin, *Sustainable Development and Its Influence on Mining Operations Federal Lands—A Conversation in Plain Language* (Clarke and Bosworth, 2003), Kathleen Clarke, director of the Bureau of Land Management, and Dale Bosworth, chief of the USDA Forest Service, proclaim, "Mining, minerals and metals are important to the economic and social development of many countries. Minerals are essential for modern living. Enhancing the contribution of mining, minerals and metals to sustainable development includes actions at all levels to:

(a) Support efforts to address the environmental, economic, health, and social impacts and benefits of mining, minerals and metals throughout their life cycle, including workers' health and safety, and use a range of partnerships, furthering existing activities at the national and international levels among interested Governments, intergovernmental organizations, mining companies and workers and other stakeholders to promote transparency and accountability for sustainable mining and minerals development;

(b) Enhance the participation of stakeholders, including local and indigenous communities and women, to play an active role in minerals, metals and mining development throughout the life cycles of mining operations, including after closure for rehabilitation purposes, in accordance with national regulations and taking into account significant transboundary impacts;

(c) Foster sustainable mining practices through the provision of financial, technical and capacity-building support to developing countries and countries with economies in transition, for the mining and processing of minerals, including small-scale mining, and, where possible and appropriate, improve value-added processing, upgrade scientific and technological information and reclaim and rehabilitate degraded sites."

The corporate leaders of the minerals industry have responded to the call for sustainable development. The best source of their response is found in the report of the Mining, Minerals and Sustainable Development Project (MMSD, 2002). In the report they state, "One of the greatest challenges facing the world today is integrating economic activity with environmental integrity, social concerns, and effective governance systems. The goal of that integration can be seen as 'sustainable development.' In the context of the minerals sector, the goal should be to maximize the contribution to the well-being of the current generation in a way that ensures an equitable distribution of its costs and benefits, without reducing the potential for future generations to meet their own needs."

Sustainable development and mining sustainability are supported by four pillars: economic sphere, social sphere, environmental sphere and governance sphere. Each sphere has a set of guiding principles as indicated in Table 1.

The minerals industry stakeholders and leaders have described nine key challenges facing

Table 1 Sustainable development principles (from MMSD, 2002)

Sphere	Principles
Economic Sphere	• Maximize human well-being • Ensure efficient use of all resources by maximizing rents • Seek to identify and internalize environmental and social costs • Maintain and enhance the conditions for viable enterprise
Social Sphere	• Ensure a fair distribution of the costs and benefits of development for all those alive today • Respect and reinforce the fundamental rights of human beings, including civil and political liberties, cultural autonomy, social and economic freedoms, and personal security • See to sustain improvements over time; ensure that depletion of natural resources will not deprive future generations through replacement with other forms of capital
Environmental Sphere	• Promote responsible stewardship of natural resources and the environment, including remediation of past damage • Minimize waste and environmental damage along the supply chain • Exercise prudence where impacts are unknown or uncertain • Operate within ecological limits and protect critical natural capital
Governance Sphere	• Support representative democracy, including participatory decision-making • Encourage free enterprise within a system of fair rules and incentives • Avoid excessive concentration of power through checks and balances • Ensure transparency through providing all stakeholders with access to relevant and accurate information • Ensure Accountability for decisions and actions, which are based on comprehensive and reliable analysis • Encourage cooperation to build trust and shared goals and values • Ensure that decisions are made at the appropriate level, adhering to the principle of subsidiarity where possible.

the minerals industry in the quest for mining sustainability. These challenges are

1. Visibility of the minerals industry
2. The control, use and management of land
3. Minerals and economic development
4. Local communities and mines
5. Mining, minerals, and the environment
6. An integrated approach to using minerals
7. Access to information
8. Artisanal and small-scale mining
9. Sector governance: roles, responsibilities, and instruments for change

Indeed, the mining industry is making more than a good gesture effort in embracing the sustainability initiatives. The leaders of the mining industry believe they will benefit by at least one or more of the following:

- Enhancing public reputation
- Establishing a business leadership position

- Building competitive advantage
- Securing public license to operate
- Attracting and retaining quality employees
- Attracting investment capital
- Driving internal behavior change
- Initiating efficiency improvement
- Attracting better quality business partners
- Maintaining strong shareholder support
- Minimizing business risk
- Avoiding, or at least delaying, onerous statutory regulation;
- Increasing capacity for innovation
- Maintaining access to land
- Believing it is simply the right thing to do

The principles of sustainable mining are well-defined by various groups, but the challenges for meeting the principles are great and complex. Many of the challenges facing sustainable mining are challenges that public opinion makers and government officials will have major roles in overcoming them. As technical leaders and educators we do have influence on how the challenge of mining and minerals beneficiation can be less threatening to the local environment and ecology. We can certainly aid in meeting the challenge of developing an integrated approach to using minerals.

One of the challenges is the large amounts of material involved in large-scale mining and minerals extraction. Although Korte and others (2000) have written about the effects of the cyanide leaching gold recovery process on the environment and the ramifications of it in terms of sustainable mining, some of their conclusions can be easily extrapolated to all large mining operations. Without question their point that the problems arising from the change of the chemistry of million of tons of natural ore during the grinding procedure, producing changes in the bioavailabilities of metals and other substances are not well understood. In the case of phosphate production not only are there large quantities of ore, but large quantities of mineral product that is chemically treated. Their conclusion is that when living in a time where the word "sustainability" has a certain weight, can such operations ever be considered sustainable.

Another is challenge of the significant altering of material by the use of chemicals in the treatment of the ores. The American Chemical Society (ACS) supports the use of the twelve Green Chemistry Principles (Anastas, P. T., Warner, J. C., 1998). Bucknam (2004) points out that four of these principles: prevention, atom economy, safer auxiliaries, and real-time analysis for pollution prevention provide guidance for sustainable use of chemicals in metallurgical processing.

Mining produces very large volumes of waste, so decisions about where and how to dispose of it are often virtually irreversible. Because decisions about waste handling and other aspects of operations are often so difficult and expensive to reverse, they need to be made correctly in the first place through mine closure planning.

A third challenge is the environmental legacy left by mining. The environmental issues of current mining operations are daunting enough. But in many ways far more troubling are some of the continuing effects of past mining and smelting. The development of an environmental management system (EMS) in which an environmental impact assessment (EIA) is an integral part would permit the mining company and the regulating authority a structure method for having an awareness and control of the performance of a project that could be applied at all stages of the mining life cycle. In the times of sustainable development, the EIA is insufficient. Now and in the future there is a greater need for integrated impact assessments. The minimum loss of biodiversity is the other great challenge of mining sustainability. The loss of biodiversity is an irreversible loss. Conservation practices that guarantee a minimum impact on biodiversity must be adopted and implemented.

As important as the methods of mining and beneficiation is how the minerals are used in efforts to develop sustainable development. An integrated approach for the use of minerals must be utilized. The use and downstream supply of mineral products has implications for sustainable development and must be considered along with mining and processing of minerals. Current patterns of minerals use raise concerns about efficiency and the need for more equitable access to resources world-wide. The environmental and health impacts of different mineral products in use need to be carefully managed. Where the risks associated with use are deemed unacceptable or are not known, the costs associated with using certain minerals may outweigh the benefits.

PHOSPHATE MINING

Each mineral/metals commodity that is produced through mining and metallurgical activities has a nearly unique set of conditions that need to be considered when studying sustainable mining issues. As mentioned before, three challenges, in one form or another, accompany any mining and beneficiation activity if it is large. Certainly, phosphate production has sustainability challenges including large amounts of material, use of chemicals to aid beneficiation and the improvement of the use and downstream supply.

The large scale of the phosphate produced and the location of the production facilities create one of the greater challenges for achieving sustainable phosphate rock production. The scale of the phosphate operations makes some of the ideals of sustainable mining difficult to approach. Jasinski (2004) reports that the U.S. production of marketable phosphate rock increased slightly to 36.1 million metric tons (Mt) in Crop Year 2004 compared with 35.6 Mt in Crop Year 2003. The manufacturing wet-process phosphoric acid for fertilizers and animal feed supplements was estimated to have accounted for more than 95% of the phosphate rock consumption.

Millions of tons of material are produced within the United States. But only four states have production and two states produce the bulk of it: Florida and North Carolina. The production of phosphate rock in the United States, by region, is given in Table 2 (Jasinski 2004).

Florida, alone, accounts for approximately 75% of domestic production and approximately 20% of world production, which is greater than any other country in the world (Florida Phosphate Council, 2003).

The relative magnitude of the worldwide mining and mineral processing of phosphate rock is illustrated by the compilation of the world production of some bulk minerals in 1998/1999 that was prepared by the United Nations Environment Programme (2001). The compilation is given in Table 3.

The United Nations and the International Fertilizer Commission have sponsored an excellent report (UNEP, 2001) on the mining sustainability of the minerals used for fertilizers. In the report it is claimed that the phosphate mining industry has had a significant improvement in the environmental performance. Improved performance has been caused by the following:

- Growing public awareness of environmental issues
- Greater appreciation by companies of the environmental issues
- Increasing regulation
- Scientific and technical progress that permits resolution of some of the issues
- Technological developments that improve environmental performance as a by-product of better efficiency

A number of emerging issues and trends may affect the industry in coming years, including the following:

- Consumers as a political and economic force
- The public's demand for accountability and transparency across the board, for both businesses and government
- Sensitivities about globalization
- A multidisciplinary approach to resolving issues

Table 2 Phosphate rock production (×1,000 metric tons) in the United States, by region

Period	Florida and North Carolina				Idaho and Utah			
	Crude Ore		Marketable Rock		Crude Ore		Marketable Rock	
	Tonnage	P_2O_5	Tonnage	P_2O_5	Tonnage	P_2O_5	Tonnage	P_2O_5
Crop year 2003	149,000	13,600	30,400	9,130	6,850	1,489	5,150	1,430
Crop year 2004	144,200	13,430	31,100	9,190	6,840	1,487	4,980	1,292

Table 3 World production of some bulk in minerals in 1998/1999

Product	Tonnage
Coal	4,655,000,000
Iron	1,020,000,000
Salt	186,000,000
Phosphate Rock	144,000,000
Bauxite	126,000,000
Gypsum	107,000,000
Potach Ore	45,000,000

- Ongoing public debate on what constitutes sustainability and good environmental performance
- Increasingly stringent expectations of environmental performance
- Scrutiny of business at a local and international level

In the future, community concerns may shift away from a focus on environmental damage at the mine site to the need to balance competing demands for limited natural resources such as fresh water and agricultural land. The mining industry, as a consumer of natural resources, will not be isolated from these pressures. Foresight and the adoption of adequate and effective solutions to arising issues will assist the industry's response.

Because of the magnitude of the operations used for the production of phosphate, the impacts are significant for the local area. The potential environmental effects can be delineated by the various phases of the production. In the mining phase in which there is overburden removal and the mining of the ore the potential environmental effects are land surface disturbance, water contamination, water table lowering, air emissions, topsoil degradation, vegetation and wildlife disruption, and possible noise and vibration problems. The second phase is the material handling from the mine to the beneficiation plant. Potential environmental effects in handling include air emissions, water contamination and noise.

Mineral beneficiation certainly is not without potential adverse environmental effects. Beneficiation of the phosphate rock includes the traditional steps of size reduction, separation, concentration, contaminant removal, drying, compaction and other product preparation steps. Waste generation is potentially one of the greatest adverse environmental effects. A variety of wastes is generated from the beneficiation of phosphate rock and may include following:

- Oversize low-grade rock from screening
- Coarse tailings composed of sand
- Fine tailings composed of clays and similar size materials
- Process water contaminated with fines and process reagents

The beneficiation of phosphate produces large volumes of waste that may cause a variety of adverse environmental effects if not managed and disposed of properly. The major environmental concerns related to waste disposal and management include the following:

- Land surface disturbance from the construction and operation of large waste disposal impoundments such as dams, ponds and stacks
- Surface and ground water contamination by wastes such as fines, tailings effluents and brines
- The safety and stability of the storage facility

Failure can result in extensive and widespread offsite effects.

Mine closure is now an integral part of any mine plan. During the past decade more and more public and government attention has been devoted to the potentially adverse environmental effects developed after the cessation of active mining operations. The goals and objectives of the attention and the appropriate legislation are to leave the mine site in a stable and safe condition. The concepts of mine sustainability and sustainable development have made mine closure more complicated than it has been in the past. It now involves the following objectives:

- Finalizing rehabilitation that commenced earlier in the mine life
- Rehabilitation and other activities such as sealing shafts and removing plant and equipment that could not be removed until after mining and beneficiation were completed
- Monitoring the keep of rehabilitation and closure activities in the long term

Rehabilitation is generally conducted progressively throughout the mine life. Social impacts on the workforce and on the community, associated with the closure of an operation, may be complex. The obviation of these impacts is certainly within the spirit of mining sustainability.

How much has the concepts of mining sustainability been accepted by the public and private sectors? One needs to study no more than the 2003–2008 Strategic Plan of the Florida Institute of Phosphate Research (FPIR, 2003). The FIPR research priorities mirror the potential environmental and sociological effects of phosphate mining and processing described in the United Nations Report, a report co-sponsored by the International Fertilizer Industry Association. The goals for chemical processing are directly aimed at solving the mine sustainability issues created by large processing wastes. They are (1) to develop procedures for reducing the magnitude of the process water problem, and (2) to reduce the accumulation of phosphogypsum in the stacks.

The goals in the strategic plan for mining and beneficiation also are crafted to fit the needs of sustainable mining. And once again, the issue of large quantities of material drives the goals, which are listed below:

- Develop methods for reducing or eliminating clay settling ponds
- Find environmentally acceptable uses for phosphatic clays
- Find environmentally acceptable uses for clay settling ponds
- Develop technologies for solving the dolomite problem
- Improve mining and transportation efficiency
- Improve flotation efficiency

One important aspect of sustainable mining is taking into account the whole mining venture. During and after the life of the mining operation environmental considerations must be evaluated along with sound reclamation practices. The strategic plan addresses goals for the environment and reclamations:

- Evaluate the effects of phosphate mining, processing and reclamation on the environment and develop methods for minimizing and ameliorating impacts
- Develop reclamation technology
- Increase knowledge of the functioning of hydrologic systems in mining areas and develop methods for enhancing them

The last thrust of the strategic plan is public and environmental health. This focus area also fits nicely into the goals of mining sustainability, which include the following:

- Evaluate the occupational, public, and environmental health aspects of phosphate industry emissions and by-products
- Evaluate the occupational, public, and environmental health aspects of exposure to technologically enhanced naturally occurring radioactive materials (TENORM)
- Develop procedures or technology to reduce risks of occupational-related illness or injury to persons employed within the Florida phosphate industry
- Evaluate the occupational, public, and environmental health aspects of technologies, procedures, and practices developed by FIPR through the mining and beneficiation, chemical processing, reclamation, and public and environmental health research programs
- Respond to new occupational, public, and environmental health concerns raised by the public, the phosphate industry, and governmental agencies

The Florida phosphate industry is an example of why the philosophy of sustainable mining must be adopted and implemented. After review of some of the articles published by local press agencies and transmitted on action groups web sites, it is obvious the industry has some political problems. For instance, one of the latest reports is the coverage of the failed retention dam that held an estimated 150 million gallons of phosphogypsum wastewater (MSNBC, 2004).

The true test of how the phosphate mining industry has done relative to mining sustainability is how potential new mining activities are received by the local public and government officials. The questions asked indicate what significant issues must be addressed. Nearly all are centered on local environment and natural habitat impacts based on the size of the operations. In the forefront is probably the use of ground water and its eventual return to the watershed for human and wildlife use. Because of the scale of the mines and their beneficiation plants the magnitude of the waste problem is enormous. One waste, phosphogypsum is a particularly difficult one to dispose or store without some habitat impact (Call, 2003).

Another possible long-term impact is the possible destruction of topsoil over a large area. It has been alleged that the long-term effect of overburden removal and the subsequent replacement with mine and mill wastes will be the long-term effect of the reduction in the quality and quantity of plants and animals on reclaimed mine sites. Questions have been raised regarding the reclamation and restoration plans for proposed new mining sites (Erwin, 2004). It is argued that the cost to meet the Florida Department of Environmental Protection's measures of success is prohibitive. Those measures of success include the following:

- All applicable water quality standards are met
- The mitigation area achieves viable and sustainable ecological and hydrological functions
- Specific success criteria contained in the permit are met

Most of the criticism leveled at the phosphate industry stems with the problems generated by the large-scale mining and processing required for the phosphate production needed for agriculture. Of course having the deposits in close proximity to both fragile ecosystems and large urban population centers doesn't help.

THE AGRICULTURE CONNECTION

Phosphate mining and beneficiation is not only impacted by the concerns regarding mining sustainability, but it is also impacted by those of sustainable agriculture. Any trend in phosphate usage in agriculture has a direct impact on phosphate rock production. Ninetyfive percent of the national production of phosphate rock is consumed in the manufacture of phosphoric acid, the basic material for producing most phosphatic fertilizers. The most common phosphatic fertilizers are diammonium phosphate (DAP) and monoammonium phosphate (MAP). The United States supplies most of the phosphate fertilizers in the world. Overall, more than 50 percent of the phosphoric acid produced in the United States is exported as finished fertilizers or commercial acid.

One misconception is that sustainable agriculture will have most of its impacts in the developing nations of the world. The acceptance of sustainable agriculture and development practices will have major impacts in the Corn Belt of the United States and it will be felt well beyond the Belt's boundaries. Two significant trends will impact the use of inorganic fertilizer.

The Florida Institute of Phosphate Research (FPIR, 2002) has given an answer to the question of why use chemical fertilizer instead of organic fertilizers. The response to the question includes, "The key to growing crops that are plentiful and that contain the nutrients we need is assuring that the local soil has the nutrients it needs. Manure and compost for example, typically have, and provide, relatively low nutrient content in comparison to commercial fertilizer. If enough is spread, it may provide adequate nitrogen, but likely will not provide enough phosphate."

Two relatively new variables may alter the phosphate balance between organic phosphorous and phosphorous from chemical fertilizers. The first is the response to the regulations, which go into effect in 2007, regarding Concentrated Animal Feeding Operations (CAFO). The second is the production of ethanol from corn use as a motor fuel. The major byproduct of the production of ethanol from corn is wet distillers grain (WDG). The major use of WDG is cattle feed. Nutritionally, the WDG is a better feed to cattle than corn. One of the positive aspects of WDG is the phosphorous content is significantly greater than that of corn. Fortunately, since the ethanol plants essentially process the starch in the corn into ethanol, the waste and byproducts have higher concentrations of phosphate than the original corn. The WDG supplies more phosphorous than the cow requires so manure produced has a higher content of phosphorous than manure originating from a corn feed.

Animal manure contains more phosphorous than nitrogen relative to plant needs, meaning that less manure can be spread on a given acre under the phosphorous limit than a nitrogen limit (Mullins, 2000). With the adopted phosphorous rules for a CAFO, approximately 2.4 acres of farmland are required for manure spreading for each cow contained in a CAFO. If WDG is used as a feed the amount of land needed for manure disposal is approximately five acres. If the integrated ethanol-cattle production facilities grow as anticipated, the need for inorganic phosphorous fertilizer will be significantly negatively impacted.

Phosphate mining is nearly unique because of the potential impacts of sustainable agriculture on a mining industry and, therefore, sustainable mining. Truly, this is an overarching case of sustainable development.

CONCLUSION

The cost/benefit analysis of phosphate mining, and therefore, the sustainability, is dependent on the geographic system used for the calculation. Because of the magnitude of the material involved in the mining and beneficiation efforts the local impacts can only be minimized, not eliminated. Any potential research effort must be evaluated on the potential for minimization of the impacts. The technical expert's triple bottom line is now technical feasibility, financial feasibility and environmental feasibility. Government and industry demand no less.

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