MINING AND THE ENVIRONMENT

INTERNATIONAL PERSPECTIVES ON PUBLIC POLICY

edited by
RODERICK G. EGGERT

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John M. Olin
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in Mineral Economics

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Preface

The time-honored saying, "You can't make an omelet without breaking eggs," translates easily into "You can't mine orebodies without insulting the environment." For many generations, this was not a problem. Instead, the problem was to find the richest ore, extract what was valuable, and go on to the next site. The miner was a semiromantic figure in the way of the Chicago stockyards or industrial smokestacks, which were glorified by Walt Whitman.

The attitude toward mining has changed in the industrialized countries and is in the process of changing in the developing ones. Government everywhere has attempted, with varying degrees of success, to lay down rules intended to keep environmentally adverse developments in check without stymieing an activity—mining—that makes an indispensable contribution to economic growth.

The hopeful view is that government and business will be sufficiently enlightened to realize that they must cooperate in the search for the common good. The skeptical view is that each side will cling to what it perceives to be in its own best interest and that the path toward reconciliation is bound to be rocky.

The five lectures presented in this volume address the current relationships between mining and government in different ways but always with the perspective of conflict and reconciliation. The lectures were originally offered at the Mineral Economics Department of the Colorado School of Mines in late 1992, under the auspices of the John M. Olin Distinguished Lectures in Mineral Economics. Each lecturer was invited to present a topic of his or her choosing and, in addition, to spend one or more days in residence on campus, giving both students and faculty added time to delve more thoroughly into the many aspects of the lecturers' chosen topics.

The reader will look in vain for comprehensiveness—the scope of the subject prevents it. Indeed, the value of this collection lies not in its comprehensiveness but rather in its variety of problems and case studies. Each contribution fits within the broad topic reflected in the title, but also illuminates a different facet of that topic. The volume thus has the potential to clarify concepts, illuminate viewpoints, and suggest policy remedies, making it of direct interest to those intimately involved in the management of mining enterprises and in its analysis.

Thanks are due to the John M. Olin Foundation for providing funding for the undertaking, to Resources for the Future for reviewing and publishing the volume, and to Roderick Eggert for his efforts as organizer, editor, and author of a most useful introduction.

Earlier publications in this series, which were also funded by the Olin Foundation and published by Resources for the Future, are *Mineral Wealth and Economic Development*, edited by John E. Tilton, and *Making National Energy Policy*, edited by me. All three publications have profited from a long-standing cooperation between the Colorado School of Mines and Resources for the Future. This program is formally designated as the Mineral Economics and Policy Program and is jointly chaired by John E. Tilton and myself.

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Mining and the Environment: An Introduction and Overview

RODERICK G. EGGERT

Mining, by its nature, poses major environmental challenges. It creates large volumes of, for example, overburden, waste rock, tailings, acid mine drainage, airborne dust, and other contaminants. These by-products are deposited on land and in the air and water, in some cases harming human health, damaging property, and affecting fish and wildlife. Mining in remote and undeveloped areas may reduce the aesthetic value of natural environments. Most wastes from mining are nonhazardous, but some are hazardous.

That mining affects the environment has long been recognized. Georgius Agricola, writing in the 1500s in the book considered to be the first scientific and technical text on mining and metallurgy, noted:

> The strongest argument of the detractors [of mining] is that the fields are devastated by mining operations... They argue that the woods and groves are cut down, for there is need of an endless amount of wood for timbers, machines, and the smelting of metals. And when the woods and groves are felled, then are exterminated the beasts and birds, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions, on account of the devas-

> tation of their fields, woods, groves, brooks and rivers, find great difficulty in procuring the necessaries of life, and by reason of the destruction of the timber they are forced to greater expense in erecting buildings. (Agricola 1950, 8)

For centuries, denuded landscapes, fouled streams, and dirty air were considered part of the price that had to be paid for mineral production. Even most early environmental legislation in the United States, Europe, Japan, and other industrialized countries, dating back to the 1960s and 1970s, was not designed with mining in mind. Rather such legislation was aimed at large industrial sources of water and air pollution. Many developing countries had little in the way of environmental policy.

Times have changed. The 1990s have witnessed a renewed concern worldwide about the environment. The unifying theme has become *sustainability*: development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987, 8). There is no consensus on exactly what is to be sustained and by what means sustainability is to be achieved. But there is general agreement that fairness to future generations requires that economic development today not come at the expense of environmental damage that leaves future generations worse off than the current generation.[1]

As part of this renewed environmental concern, mining is the focus of greater environmental scrutiny today than in the past. In the United States, for example, the desire for greater protection of the environment is a central concern of those advocating revision of the Mining Law of 1872, which has governed mining on federal lands for more than a century. In Australia and other countries, mining has come into conflict with desires for preservation. In Poland, the former East Germany, and elsewhere, it has become apparent that mining took place in many centrally planned economies with little regard for its environmental consequences. Many developing countries are designing environmental policies where none existed previously, and these surely will affect future mining activities.

[1]For an introduction to the issues surrounding sustainable development, see Darmstadter 1992.

As a consequence, the mining industry is understandably more concerned now than even five or ten years ago about the possible effects of environmental policy on its business activities. In 1991, a group of mining companies formed the International Council on Metals and the Environment to represent them in discussions on environmental issues. Most major mining companies have senior managers, often reporting directly to chief executive officers, in charge of corporate environmental affairs—something unheard of a decade ago. As Sir Derek Birkin, chairman of the mining company RTZ, notes: "For many years, the basic disciplines of the minerals industry have been separated along the four basic lines of geology, mining, mineral processing, and metallurgy but now a major new field has emerged—that of the environment" (Fifth Discipline 1993, 290).

Another indicator of this increased interest is the large and growing number of proceedings volumes from professional conferences on environmental management in mining (see, for example, Lootens, Greenslade, and Barker 1991; Van Syl, Koval, and Li 1992; and Yegulalp and Kim 1990). Other recent books serve as handbooks for mine managers (see, for example, Australian Mining Industry Council 1991; Hutchison and Ellison 1992; and Sengupta 1993).

Environmental aspects of mining, therefore, have become critical concerns both for mining companies, as they make investment and production decisions, and for governments, as they design and implement new environmental policies.

Concerns such as these about mining and the environment motivated the lectures collected here. Each lecturer seeks to contribute to the ongoing debate about public policy by highlighting a particular issue or policy area. With one exception, each provides the perspective of a specific country or group of countries. There is no attempt to be comprehensive. For the most part, the talks confine themselves to exploration, development, and mining; later stages of processing, such as smelting and refining, which produce raw and semifabricated metal, are not emphasized. The addresses focus largely on metal mining, although coal and industrial minerals appear several times in the discussion.

This collection contains the revised texts of invited lectures. The speakers have drawn upon their own unique perspectives and experiences, and no attempt has been made editorially to standardize terminology or denotation. Nor, given the public venue of their initial presentation, do the lecturers necessarily provide the extensive documentation that characterizes scholarly essays.

The lectures in this collection have been written to be accessible to nonspecialists. Reading them requires no more than general familiarity with economics, environmental policy, and the mineral industries. The presentations should be of interest not only to environmental economists, mineral economists, public policy analysts, and mining industry executives, but also to students and others wanting an introduction to many of the important public policy issues in the area of mining and the environment. For readers unfamiliar with the mining industry, the following section provides some necessary background information about mineral production and its environmental consequences.

Mining, the Environment, and Public Policy

Mineral production takes place in stages. Both the principal effects of mining on the environment and the important issues for public policy in this area are perhaps best introduced within the context of these production stages.

Mineral Exploration and Mine Development

Before a mineral deposit can be mined, it must be discovered and its economic and technical viability demonstrated; this is the *exploration* stage. The environmental disruption caused by exploration tends to be localized and minor. Most damage that does occur can be remediated relatively easily. During initial assessment of a region's geologic potential, explorationists rely heavily on satellite images, airborne geophysical surveys, and large-scale geologic maps to study large areas of land—hundreds or even thousands of square kilometers. Environmental impacts are essentially nil.

Explorationists then narrow the focus of their search to smaller, more promising areas, involving perhaps several hundred square kilometers. Typical activities include geologic mapping, geochemical sampling, and surface geophysical surveying, which are carried out on the ground without large-scale equipment. Although the environment is affected by these activities, the impacts are minor.

Only in the subsequent, subsurface examination of still smaller areas is there any appreciable environmental impact—from drilling, trenching (bulldozing a trench to examine near-surface rocks), and the associated road building to provide access for drill rigs and bulldozers. Such impacts can be mitigated, albeit at a cost, by reclaiming drill sites and trenches and by revegetating roads. In some instances, the need for roads in remote areas has been eliminated by using helicopters to deliver drilling equipment.

For every one hundred or so mineral deposits that are discovered and evaluated in detail during exploration, fewer than ten on average will be prepared for production during the second stage of mineral production, *mine development.* During development, mining companies design and construct mining and beneficiation facilities, arrange for financing, provide for infrastructure, and develop marketing strategies, among other activities. The environmental impacts of these activities are more significant than those resulting from exploration but much less than those of mineral production itself.

Two types of public policy are critical during mineral exploration and mine development. The first type of public policy consists of land-use rules governing whether land is available for exploration and development. The second type, applicable on those lands available for mineral activities, consists of environmental rules governing permits, environmental impact assessments, and other preproduction activities and approvals that are necessary to proceed from exploration to mine development and mining—in short, the process of environmental compliance prior to mining.

Land-use rules are important because, before mining companies can undertake mineral exploration and development, they need access to prospective mineralized lands. To be sure, in situations where mineral rights are privately held, land access is gained through negotiation between interested private parties. But for most lands worldwide, mineral rights are held by governments.[2]

Explorationists or miners typically gain access to these lands in one of three ways: negotiation with a government agency, competitive bidding, and—in a few cases, such as in the United States—claim staking (that is, claiming the right to explore on a first-come, first-served basis

[2]Governments may hold mineral rights for one of two reasons. First, in most countries, mineral rights are held by the government regardless of who owns the surface rights. Second, in a relatively small number of countries, surface and subsurface rights are not separated, and mineral rights belong to whoever owns the surface. In these countries (which include the United States), the government holds significant mineral rights only when it is also the owner of significant quantities of land.

when lands are considered open for exploration unless they are specifically declared off-limits, such as for national parks or wilderness areas). Existing land-use policies have placed large tracts of land off-limits to mineral exploration and development in a number of countries, including Australia, Canada, and the United States. The desire to avoid the environmental damages of mining is an important reason behind these withdrawals of land from mineral activities.

Public policies in the second category, rules governing the preproduction process of complying with environmental rules, take a number of forms. The most common are environmental permits and environmental impact assessments. Mining companies typically are required to obtain environmental permits signifying government approval of various aspects of their mine plans, including those for reclamation, waste disposal, sewage treatment, drinking water, and construction of dams and other impoundments. Companies also often have to carry out detailed assessments of the environmental impacts of proposed mineral development, which in turn are used by governments in deciding whether to permit mine development at all.

Environmental permits and assessments are important to mining companies because they increase the time, costs, and risks associated with bringing a mine into production. Costs may rise because of expenditures on permitting and environmental assessment and on implementing changes in project design that the compliance process may require. Risks rise, from the perspective of the firm prior to mining, in the sense that governments may decide not to allow mine development after companies have spent significant sums of money on exploration.

Mining and Beneficiation

Once a mineral deposit has been discovered and developed, it is ready for the next stages in the production process: mining and beneficiation. During *mining*, metal-bearing rock called *ore* is extracted from underground or surface mines. Metal concentrations in ore vary greatly, from less than 1 percent by weight for most gold deposits to over 60 percent for some iron ore deposits; most metallic mineral deposits have ore grades in the range of 1–5 percent by weight. *Beneficiation*, sometimes called milling, usually occurs at the mine site. During this stage, ore is processed (or upgraded) into concentrates, which will be processed still further, usually in a smelter or refinery.

Mining and beneficiation can have a variety of environmental effects.[3] The most visible effect probably is the sight of land disturbed by mining and waste disposal. The environmental damage is largely aesthetic.

To put the problem of potentially unsightly land into perspective, consider the study by Johnson and Paone (1982). They estimated that over the fifty-year period 1930–1980, only 0.25 percent of the total land area of the United States was used for surface mining, disposal of wastes from surface and underground mines, and disposal of wastes from mineral beneficiation and further processing. Coal mining represented about half of this land, with mining of nonmetallic minerals accounting for about two-fifths and of metallic minerals about one-tenth. Some 47 percent of the land affected by mining and waste disposal had been reclaimed. The figures of course would vary considerably from country to country, but the essential point is that only a relatively small amount of land is involved in mining and associated waste disposal. Mining activities use much less land than agricultural production, urban development, logging and forestry, and national parks and wilderness areas.

Mining and beneficiation account for significant fractions of the total amount of solid waste generated each year. Very crude estimates compiled by the United Nations Environment Programme (1991b) indicate that mining activities, apparently in this case including oil and gas production and coal mining, account for about three-quarters of the solid wastes generated annually in Canada, one-third in the United States, one-tenth in the European Community, and one-twentieth in Japan. The substantial differences reflect differences in the size of the extractive industries relative to the total economies in these countries. More detailed data for the United States suggest that non–coal mining accounts for about one-seventh of the solid waste generated annually that is considered nonhazardous, while coal mining accounts for less than a hundredth of such wastes. Manufacturing, on the other hand, generates more than half of nonhazardous solid wastes (Office of Technology Assessment 1992).

These volumes of waste, however, are not good proxies for the amount of actual environmental damage caused by mining and benefici-

[3]For a more extensive overview of the environmental effects of metal mining and mineral processing, see United Nations Environment Programme (1991a).

ation. For this point to be clear, it is necessary to know more about the three important types of solid waste generated by mining and beneficiation. *Overburden* is soil and rock removed to gain access to a mineral deposit prior to surface mining. *Waste rock* is separated from ore during mining. Overburden and waste rock typically are deposited adjacent to a mine (or in a mine, in the case of waste rock from underground mining). *Tailings* are the fine waste particles that are produced during the beneficiation of ore and typically suspended in water. Tailings from surface mines usually are deposited in a tailings (or settling) pond, while those from underground mines are deposited in the mine itself. (In a few countries, tailings can be deposited directly into the environment.)

The amount of solid waste generated during mining and beneficiation essentially is determined by, first, the type of mine and, second, the ore grade, or concentration of metal in the rock that will be beneficiated. The type of mine is important because underground mines generate no overburden, and mining techniques are selective enough to extract ore with only small amounts of waste rock. Surface mines, on the other hand, usually generate more than twice as much overburden and waste rock as ore.

As an example, for underground copper, gold, silver, and uranium mines in the United States, the ratio, (overburden + waste rock):ore, is on the order of 0.1:1 to 0.3:1. For surface mines, the ratios range from 2:1 to 10:1 on average (EPA 1985; based on data from the U.S. Bureau of Mines).

Ore grade, the second determinant, governs the quantity of tailings generated by a beneficiation plant. An operation with ore grading 1 percent by weight, for example, will generate ninety-nine pounds of tailings for every pound of metal, assuming complete metal recovery. Actual recovery rates usually range between 90 and 100 percent, resulting in somewhat larger volumes of tailings.

By themselves, the solid wastes of metal mining and beneficiation would cause little environmental damage, except aesthetically. But when surface and ground waters interact with these wastes, acid mine drainage can be created, and this is probably the most serious environmental problem of metal mining and beneficiation. When water interacts in an oxidizing environment with the sulfide minerals typical of most metal mines, sulfuric acid is created. Metals then are dissolved in the resulting acidic water. Acid mine drainage can contaminate drinking water and affect aquatic and plant life if it gets into surface or ground waters.

The nature and extent of actual environmental damage caused by solid mine wastes and, in turn, acid mine drainage vary enormously from case to case, depending on several factors. The type of mineral deposit being mined is important: sulfide-poor deposits, for example, generate less of the sulfur needed to create sulfuric acid than sulfide-rich deposits, and high-grade deposits will have fewer tailings per unit of recovered metal than low-grade deposits. Mining and beneficiation techniques are important: underground mining, as noted above, creates much smaller volumes of waste per unit of metal than does surface mining, and the higher the recovery rate during beneficiation, the smaller the amount of tailings created. Climate is important: in arid regions, there is little of the water necessary to create acid mine drainage. Location and population density are important: acid mine drainage that enters streams feeding into sources of human drinking water not only destroys fish and wildlife habitats, but also damages human health. Finally, the environmental management practices of mining companies are important: waste piles that are revegetated or in some other way sealed, for example, are much less likely to be accessible to the water necessary to create sulfuric acid.

Other environmental problems may be associated with metal mining and beneficiation. Another type of water contamination is wastewater from beneficiation plants, which may contain ore material, heavy metals, thiosalts, and chemical reagents used in beneficiation. Air pollution is limited largely to airborne dust. Underground mining may lead to subsidence. (A major area not dealt with in this volume is the working environment, that is, worker health and safety; readers interested in this issue are referred to Section 11 of Hartman 1992).

The key issues for environmental policy affecting ongoing mining and beneficiation are for the most part the same as those affecting other economic activities: What should be the standards for environmental quality and how should they be determined? What policy tools—for example, direct regulation or economic incentives—are best suited for meeting these standards? How should rules be enforced?

Two aspects of mining and beneficiation noted above, however, bear on these more general questions. First, the extent to which the amount of solid waste generated from mining and beneficiation can be reduced has significant limits. Low-grade ores by their very nature are going to generate large volumes of tailings, and surface mines are going to generate overburden because miners have to remove overlying soil and rock to get to the ore. This is not a call for complacency; rather, it suggests that efforts and policies should be aimed at those aspects of environmental degradation over which miners have some control. Examples include efforts to recycle chemical reagents used in beneficiation, to place or seal waste piles so they are less exposed to the water necessary for acid formation, and to reduce the chances that tailings ponds will leak into surrounding soil and groundwater. Moreover, incremental improvements are to be encouraged, both in beneficiation techniques to increase rates of metal recovery and in mining techniques to reduce the amount of overburden and waste rock extracted along with metallic ores.

Second, the amount of solid waste generated during mining and beneficiation is not a good indicator of the actual amount of environmental damage caused by these activities. The same mineral deposit or mine in different circumstances may generate the same amount of waste but cause substantially different amounts of environmental damage because of differences in climate, population density, or one of the other factors noted earlier. The implication for public policy is that rules need to be flexible enough to account for site-specific differences among mines and beneficiation facilities.

Mine Closure and Rehabilitation

A mine eventually reaches the end of its useful life, either because it physically depletes its ore or because economic conditions become unfavorable (costs rise or mineral prices fall). When this happens, *mine closure* and *rehabilitation* (or reclamation) occur. Underground mines typically are sealed or plugged. Surface mines, as well as waste sites for both underground and surface mines, are rehabilitated. Pits and waste piles have their slopes stabilized and may be revegetated. In some cases, acid mine drainage continues even after mining stops, requiring some type of drainage control.

The precise nature of mine closure and rehabilitation varies from place to place because of different public policies and accepted industry practices. More fundamentally, closure and rehabilitation activities vary because potential damages from closed mines vary considerably for all the reasons cited earlier, such as type of mine, climate, and proximity to population centers.

Key issues for public policy in this area are: the rehabilitation requirements; the mechanism for ensuring that appropriate closure and rehabilitation procedures are followed; and the nature of postmining liability. The rehabilitation requirements often are only vaguely or qualitatively defined: for example, mined land must be returned to a "'usable condition,' to a 'stable condition,' to the 'greatest degree,' or 'equal to the level of highest previous use'" (Intarapravich and Clark, forthcoming). Moreover, economic considerations often seem to get short shrift when rehabilitation standards are being determined; the result can be standards levels for which the costs of rehabilitation exceed the associated benefits. Barnes and Cox (1992), for example, discuss the apparent "goldplating" of rehabilitation requirements in Australia.

The most common mechanism for ensuring that appropriate procedures are followed is a reclamation bond or fund. With a reclamation bond, mining companies put money into an escrow account or in some other way set aside money as a guarantee that they will perform the required reclamation work. The only way for a company to get the money back is to perform the required work. A critical issue for public policy is the size of the bond: high enough to ensure that mine operators actually perform the required work rather than simply forfeit the bonded money, but not so high as to discourage mining.

The nature of postmining liability is perhaps the most controversial issue affecting mine closure and rehabilitation. Subsidence and contaminated mine water are the most common sources of postmining damages for which companies may be required to pay fines or compensation. That companies should be liable for damages caused by nonprudent, negligent, and illegal activities is not controversial. But public policies sometimes define liabilities more broadly. In some cases, a company can be held responsible for damages caused by subsidence and polluted mine water, even if it acted prudently and within existing laws and regulations or was only partially responsible for the damages. A company sometimes can be held responsible for damages retroactively, following changes in laws and regulations. These broader aspects of liability are designed to encourage companies to go beyond simple compliance with existing regulations. But such broad liability has been criticized for being unfair and for discouraging investment in mining activities.

The Lecturers and the Lectures

Against this backdrop of the stages in the life of a mine, the five lectures in this volume assess public policies toward mining and the environment.

Anthony Cox is a senior economist in the Minerals and Energy Group of the Australian Bureau of Agricultural and Resource Economics. He has written extensively on key aspects of the mining industry in Australia. He has been deeply involved in the development and analysis of government policy affecting the mining industry, particularly with respect to environmental issues, taxation, industry assistance, and minerals trade. He undertook his postgraduate training in economics and econometrics at the Australian National University.

In his lecture, Cox focuses on the issue of land access for mineral exploration and mine development. A major source of controversy is the means by which alternative uses of land are valued and compared. (The range of alternative uses includes mining, grazing, timber production, recreation, and preservation, although only rarely would all of these be potential uses for a particular tract of land.) Cox evaluates the appropriateness of using a benefit-cost framework for comparing alternative uses of land, especially when mining and environmental preservation are being considered. Cox uses as an example the recent debate over mineral development at Coronation Hill in the former Kakadu Conservation Zone of the Northern Territory, Australia (the Conservation Zone was incorporated into the larger surrounding Kakadu National Park in 1991).

A benefit-cost framework, as Cox discusses, requires estimating the benefits and costs associated with each alternative use (or combination of uses) and then discounting these values to the present to account for time value. The land use with the highest positive net present value should, in theory, be selected.[4]

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[4]For many activities, including developing a mine and preserving an environment, we receive benefits and incur costs over a period of time. Benefits and costs in this context include not only monetary values but also nonmonetary values, such as damage to human health from dirty air or water and the pleasure we get from a scenic vista. Discounting is a process for reducing future values (benefits and costs) to make them directly comparable with present values. We tend to value the future less than the present because we are impatient—for example, we would rather receive a dollar today than next year. More specifically, receipts received today are worth more than similar future receipts because they can be invested today and grow in value between now and the future period. Some observers, however, question the appropriateness of discounting, especially when environmental values and long time frames are involved; see Toman (in Darmstadter 1992, 17–18).

Net present value is the difference between total benefits and total costs, appropriately discounted to account for time value.

This sounds simple enough, but in practice it is difficult to implement. Cox discusses the problems associated with valuing goods for which there are no markets (such as clean air or water) and valuing environmental damage that may be irreversible. He notes the problems of dealing with both uncertainty about the future and lack of information on mineral potential and the value of conservation in areas under dispute. More fundamentally, he acknowledges that some people question the appropriateness of the process of discounting in the first place. The Coronation Hill example is noteworthy, among other reasons, for its use of the contingent valuation method to estimate the value people place on preserving environmental quality.[5] The example shows that Australians place significant values on preservation. These values, Cox contends, should not be ignored just because they are difficult to quantify.

Cox concludes that, despite its many problems, benefit-cost analysis is an appropriate—even indispensable—tool for focusing public debate about land use. Those designing public policies need to place greater emphasis on the collection of information about benefits and costs and then on the use of this information in a review process that is open and transparent to all interested parties. He argues that the process by which land-use decisions are made is critically important. Balancing desires for mineral development with those for preservation and conservation will never be easy, but a decision-making process that is open and transparent will promote better decisions.

John Tilton is the William J. Coulter Professor of Mineral Economics at the Colorado School of Mines and a University Fellow of Resources for the Future Over the past twenty years, he has written widely on various economic and policy issues confronting the metal industries, including cyclical instability, material substitution, long-run trends in metal demand, and mining and the environment. He received his Ph.D. degree in economics from Yale University.

Tilton focuses on the later stages of mining and beneficiation and of mine closure and reclamation—specifically the issue of who should pay

[5]Contingent valuation methods involve the use of surveys to estimate the value that people place on environmental quality. A survey might, for example, focus on how much people would be willing to pay to preserve a natural environment or to reduce the health risks associated with some type of industrial activity. For an overview of contingent valuation and other methods for valuing environmental damages, see Cummings, Brookshire, and Schulze 1986; Kopp and Smith 1993.

for cleaning up mine wastes—with a perspective from the United States. He notes that what has become known as the polluter-pays principle is the starting point for most discussions in this area, not just in mining but for most polluting activities. Requiring that polluters pay for cleanup encourages efficiency: it requires producers to acknowledge and bear the environmental costs of production, along with the costs they normally bear for capital, labor, raw materials, and other factors of production. It provides incentives for producers to develop and adopt new and cheaper technologies for protecting environmental resources. Requiring that polluters pay is also arguably equitable or fair: those who pollute the environment and benefit from pollution should pay for cleanup.

For ongoing mining, Tilton argues that the polluter-pays principle is quite reasonable as a basis for public policy. But he contends that the principle is inappropriate for dealing with the problems associated with past mining. Many former polluters no longer exist, and others are not financially able to pay for cleanup. Many sites have changed ownership several times over the years, and apportioning blame among the various owners is difficult, if not impossible. Ultimately, Tilton contends, the consumers of goods whose production generated the pollution are responsible for the pollution.

Despite these problems, U.S. policy toward cleaning up hazardous old mining sites relies on the polluter-pays principle. The result, Tilton contends, has been inefficiency in the remediation of sites. Probably between one-fifth and one-third of the total amount spent on remediation has gone toward litigation and other transaction costs associated with determining who is responsible for cleanup (that is, in assigning responsibility for blame). The nature of legal liability in U.S. policy—strict, joint-and-several, and retroactive—discourages remining of old mining and milling sites, often the least expensive method of cleanup. (The three forms of legal liability are defined and their implications are discussed in Tilton's lecture.)

The remaining three lectures do not concentrate on specific stages of production, but instead provide perspectives that cut across all three stages. Gustavo Lagos is a professor of mining engineering at the Pontificia Universidad Catolica de Chile and former executive director of the Center for Copper and Mining Studies, a research organization in Santiago, Chile. He is a member of the Board of Directors of the Center for Environmental Research and Planning and has been a consultant for the government Commission on Mining and the Environment. He received his Ph.D. degree from Leeds University, United Kingdom.

Lagos concentrates on formulating national environmental policies in the developing world, using Chile as an example. In the United States and other industrialized countries, the recent discussions about public policy toward mining and the environment have taken place in the context of existing national policies and regulatory mechanisms dating back in many instances to the 1960s and 1970s. Many mineral-rich developing countries have had little in the way of national environmental policies. In other such developing countries, environmental laws are on the books, but are not effective because of conflicting objectives in different policies, bureaucratic confusion, and weak enforcement; Chile is an example.

Lagos notes that, until very recently, Chile did not require environmental impact studies prior to issuing permits for large projects, had no requirements for land reclamation following mining, and had no standards regulating liquid and solid effluent or soil quality. But this is changing. In less than a decade, public awareness about the environment has grown significantly, and public policy is racing to catch up. A national framework for environmental policy, proposed in 1992, rests on three principles: legal liability for environmental damages, absent previously; environmental impact studies for large new projects affecting the environment; and polluters paying for cleanup. With these principles as a framework, Lagos expects that national legislation will be developed by the end of the 1990s governing, for example, water quality, soil quality, abandoned mines, and tailings dams.

Despite the infancy of environmental policy in Chile, environmental practice is in some cases ahead of national requirements. This is especially true for new projects. In the absence of environmental policies or standards, foreign investors typically design and construct facilities to meet the standards of their home countries (such as the United States or Japan), both in anticipation of the development of stricter standards in Chile and to avoid shareholder accusations of exporting pollution to the developing world. If true not only in Chile but elsewhere in the developing world, the proposition that industrial activity in general and mining in particular will migrate to countries with less strict environmental regulation is weaker than often argued.

The environmental practices agreed upon in ad hoc discussions between foreign investors and local Chileans are likely to significantly shape later legislation and regulations. Thus environmental policies of countries like Australia, Japan, and the United States are likely to have an important influence on future policies in developing countries through their "demonstration" effect. But Lagos argues that it would not be wise for Chile to blindly mimic the environmental policies of the United States and other countries with several decades of experience with environmental policy. Chilean policies should be developed gradually, learning from the experiences of other countries and adapting existing policies elsewhere to the Chilean situation.

David Humphreys is deputy chief economist at the RTZ Corporation, an international mining company based in London. He has written extensively on the metals and minerals industry. Prior to joining RTZ, he worked in U.K. government service for nine years. He is vice president of the Brussels-based industry federation, Euromines, and associate editor of the journal *Resources Policy*. He received his Ph.D. degree in economics from the University of Wales.

Humphreys assesses Europe and its attempt to elaborate supranational policies toward the environment. Supranational organizations and multinational agreements have become increasingly important in environmental policy; consider, for example, the 1987 Montreal protocol on chlorofluorocarbons; the biodiversity convention and other agreements of the 1992 U.N. Conference on Environment and Development (known as the Earth Summit); efforts by multilateral development banks (such as the World Bank) to promote improved environmental practices; and inclusion of (very general) environmental provisions in the North American Free Trade Agreement.

Humphreys observes that, to date, European Community (EC) legislation on the environment has had little effect on the mineral industries; national policies have been more important. He nevertheless concludes that EC influence on environmental matters is bound to increase. For mining, greater EC influence is likely to mean tougher requirements for environmental impact assessments as part of preproduction planning and permitting. Mine wastes, from both ongoing operations and from the past, also are likely to be targets of EC policy.

Humphreys notes the tension between supranational and national interests—EC desires for common environmental standards and regulations versus national desires to tailor rules to fit individual circumstances. The European solution to this tension is the principle of subsidiarity, by which action is taken at the EC level only if it cannot be achieved by the member nations themselves. The principle seems simple enough but has been prone to controversy in interpretation. The principle and its interpretation lie at the heart of the ongoing debate over European union. The approach emerging, in particular the growing acceptance that the achievement of environmental objectives at a supranational level requires policies to have some flexibility to accommodate differing national development aspirations and constraints, potentially has implications for other attempts at supranational policymaking.

Humphreys observes a gradual change in the tone and philosophy underlying the development of environmental policy in Europe. Most early environmental rules relied heavily on direct regulation, especially technology-based standards and performance standards that defined maximum allowable emissions. Governments developed these rules in a largely piecemeal fashion, in response to specific incidents or problems. The process of policy development was confrontational—government versus business. More recently, Humphreys argues, the process has become less reactive and more proactive, what Humphreys calls an integrated approach to policy development. Although direct regulation still is alive and well, more attention is being paid to the potential offered by economic instruments such as emission taxes. Emerging from the political reality of trying to forge agreement amongst twelve sovereign states is a recognition that government, industry, and society as a whole benefit from an approach to environmental matters that is less confrontational and legalistic and more cooperative in tone.

Alyson Warhurst directs the international Mining and Environment Research Network, which brings together interdisciplinary research teams from around the world to study and disseminate policy analysis about environmental regulation, technical change, and international competitiveness. She also is a senior fellow at the Science Policy Research Unit of the University of Sussex in the United Kingdom. She received her Ph.D. degree in industrial policy studies from the University of Sussex. Warhurst has worked extensively in South America, and her research career has focused on technical change in the extractive industries, including offshore oil and mining, with special emphasis on developing countries.

In the final lecture, Warhurst focuses on the roles of technological innovation and human resources in environmental management, especially in developing countries. Much existing environmental policy emphasizes the modification of existing facilities to reduce emissions (add-on solutions to end-of-pipe problems); companies direct their efforts toward complying with specific regulations and meeting specific standards for emissions or pollution-control equipment. There is little incentive to innovate and develop new and less costly means of

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