

ENVIRONMENTAL ENGINEERING IN THE DESIGN OF MINING PROJECTS

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Abstract—The application of environmental engineering (including pollution control) from the inception of a project's study phase through final completion has a significant effect on the project outcome. Good environmental practices, federal and local regulations and laws, international agreements, owner policies, and requirements of financial institutions are applied from the conceptualization of a project through its subsequent design phases. In practice, this means that the environmental engineering discipline works closely with the other engineering disciplines in preparing engineering designs that mitigate environmental impacts. In their team roles, the environmental engineers exchange project information during the owner's environmental impact assessment (EIA) process, wherein the environmental impacts are assessed, evaluated, and submitted to the local authorities.

However, common misunderstandings and confusion over the distinctions between an EIA and environmental engineering design can have a detrimental effect on the development of mining projects. While some universities have been developing environmental engineering programs within the last two decades, the training is mostly aimed toward EIA and environmental management and not toward the actual practice of environmental engineering design. The uncertainty regarding the differences between these functions can confuse the engineers responsible for delivering a successful project outcome.

Keywords—engineering design, environmental engineering, environmental impact, environmental impact assessment (EIA), mining projects

INTRODUCTION

General

Rachel Carson's book, *Silent Spring* (Houghton Mifflin, 1962), was widely credited with launching the environmental movement in the US. Before 1962, pollution control regulations were enforced under a number of programs administered by various agencies, and most regulations covered worker industrial hygiene or a few special pollution control districts (boards created to enforce local, state, and federal regulations); otherwise, citizen complaints were handled under general nuisance control regulations, i.e., pollution control complaints fell under the same regulations as complaints about a neighbor's barking dog! The US Environmental Protection Agency (EPA) was created in 1970 to establish a national environmental policy, replacing the smaller programs. At approximately the same time, many other countries or jurisdictions within countries were developing pollution control regulations, with different agencies or departments within agencies independently

responsible for regulations pertaining to air, water, solid, or hazardous wastes.

In the US, environmental impact assessments (EIAs) originated under the National Environmental Policy Act (NEPA) 1969 to predict the combined effect of a project on the environment. (Different jurisdictions require similar documents such as environmental impact statements, environmental impact reports, or *estudios de impacto ambiental*. These documents are noted here for environmental specialists, who often concentrate on the differences among the documents instead of the considerable similarities.) By the mid-1980s, some multinational mining companies and/or financial institutions were preparing EIAs for projects even if such documentation was not required by the host country. However, following the United Nations Conference on the Environment and Development (UNCED) (known as the Earth Summit), held in Rio de Janeiro, Brazil, in 1992, and with growing environmental awareness on the part of the World Bank, EIA requirements and regulations have been adopted in most countries.

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ABBREVIATIONS, ACRONYMS, AND TERMS

EIA	environmental impact assessment
EPA	(US) Environmental Protection Agency
EPC	engineering, procurement, and construction
GBU	(Bechtel) global business unit
M&M	(Bechtel) Mining & Metals (GBU)
NEPA	National Environmental Policy Act
NGO	nongovernmental organization
O&M	operation and maintenance
TIC	total installed cost
UNCED	United Nations Conference on the Environment and Development

In 1994, Chile established the General Law for the Environment, which was further institutionalized with the promulgation of the Environmental Impact Bylaw in 1997. Argentina's environmental policy developed in a similar manner, starting from the UNCED Treaty of 1992 and culminating in the finalization of the current regulatory framework in 2002. In Peru, the Environmental and Natural Resources Code (1990) established the types of activities that must be performed in an EIA; these are governed by the General Law for the Environment (2005).

Environmental Regulations and the Environmental Engineer

For the purposes of the discussions in this paper, the term Environmental Engineer (as indicated by capitalization) is used to refer to a Bechtel environmental engineer engaged in the Mining & Metals (M&M) Global Business Unit's (GBU's) engineering design activities as described herein. It is likely that the other Bechtel GBU environmental engineers have similar experience.

Environmental regulations that govern the Environmental Engineer's work are somewhat similar to the codes applicable to other disciplines, such as mechanical (boiler), electrical, and seismic. While the environmental requirements contained in other engineering codes incorporated only by reference are equally binding and enforceable, environmental regulations are quite different from traditional engineering codes. The most obvious difference is that the environmental regulations often are

written by legal professionals in a manner that can be difficult for individuals outside the legal profession to understand. In addition, the overall environmental requirements applicable to various projects can differ based on unique site-specific objectives. Even requirements for projects separated by only a few kilometers can vary. Furthermore, compared with other engineering disciplines, environmental engineering is a new field that is changing rapidly, and the applicable regulations can change rapidly at the discretion of elected or appointed political bodies. On the other hand, engineering discipline codes are written by engineers for engineers and may be applied uniformly throughout a country or in a region that consists of multiple countries. These codes may be more than 100 years old and typically can be changed only after a thorough technical peer review.

For most engineering disciplines, a building permit with an associated plan check from the local government department may be required. While this requirement may be waived for major heavy industrial capital projects, the application or checking fees usually are not. However, typically more than 100 separate environmental permits or other documents must be approved by various governmental agencies before construction and/or operations can begin. Public hearings must be held before the EIA is approved or permits are acquired. For most projects, some permits are also on the critical path for the release of funding by the financial institution and/or the owner's board of directors. Depending on the type of project, the pollution control and other mitigation capital costs can range from 3% to more than 50% of the total installed cost (TIC).

An Environmental Engineer on a project has critical schedule and budget duties, only some of which are similar to those of any other engineering discipline. The seamless integration of environmental engineering into the execution of a major capital project is important to the owner's financial and operational success and to the efficiency of an engineering, procurement, and construction (EPC) project's planning and works, as well as the oversight functions of the regulatory agencies. This paper uses the observations, lessons learned, and approaches of the M&M GBU to describe the role of the Environmental Engineer on major projects and to contrast that role with the important work performed by other engineers and scientists with environmental training. This paper also describes the role of formal education and the need for on-the-job training.

BACKGROUND

Before discussing the role of environmental engineering on major EPC projects, it would be useful to briefly describe how M&M Environmental Engineers view an owner’s project.

As seen in **Figure 1**, a typical project undergoes a series of phases: study (conceptual through feasibility) through execution (construction and operation). After the end of the operational phase, the facilities are removed or other closure activities are implemented. Following the operational phase, the property is in the post-closure phase, often with a new beneficial use of

the land. Several items are noted in reference to Figure 1:

- Although the study phase is quite similar from company to company, various organizations define it differently. In Figure 1, the study phase is essentially defined by the type of capital cost estimate being developed for the study. The cost engineer is the internal target customer for the engineering efforts and provides input to the owner’s go or no-go decision(s) about advancing to the next phase, expanding the current phase, or withdrawing from the investment prospect.

An Environmental Engineer on a project has critical schedule and budget duties.

PROJECT PHASE						
OWNER'S PERSPECTIVE	Conceptual	Pre-Feasibility	Feasibility and Financing	Engineering and Construction	Operation	Closure
Overall Project						
Duration, years	1 to 10	1 to 10	1 to 10	1 to 4	5 to 50	100 to 10,000
Nominal Cash Flow *	-2%	-5%	-15%	-200%	1,000%	-2%
• Owner Environmental Needs	• Go/No-Go—A Judgment Call	• Generic Pollution Control Requirements and Costs • Baseline Studies	• Major Equipment and Facility Specifications (for Permit Input) • Capital and Operating Costs • Mitigation Plans • Baseline Documentation • EIA Approvals • Major Permits	• Pollution Control Equipment and Facilities • Monitoring and Reporting • Federal and Local Permits • Engineering and Construction Compliance	• Monitoring, Reporting, Compliance	• Monitoring, Reporting, Compliance, Agency Approval for Abandonment
Environmental Level of Effort	\$10K to \$30K	\$10K to \$400K	\$100K to \$5M	3% to 60% TIC	2% to 10% TIC	0.1% to 5% TIC
* 100% = TIC for typical Bechtel Engineering and Construction scope, excluding Owner's costs (e.g., exploration, property acquisition, process royalties, early staffing, and startup costs)						
BECHTEL'S PERSPECTIVE						
Bechtel Environmental Support (for Execution)	Study	Study	Study to Basic Engineering	Project EPC	O&M	Remediation
• Business Development	• Bid/No-Bid Input	• Bid/No-Bid Input	• Bid/No-Bid Input	• Bid/No-Bid Input	• Bid/No-Bid Input	• Bid/No-Bid Input
• Engineering • Procurement • Project Controls (Estimating Cost and Schedule)	• Go/No-Go Recommendation • Identify Major Pollution Control Requirements	• Generic Pollution Control Requirements and Costs • Define Areas for Baseline Studies	• Prepare Description of Environmental and Pollution Control Facilities • Cost and Schedule Input • Mitigation Planning • Coordination with Environmental Consultants	• Convert EIA Requirements and Bechtel Design Guides to Design Criteria • Input to Pollution Control Equipment/Facilities Material Requisitions • Construction Contracts Technical Data • Input to O&M Procedures		
• Construction	• Go/No-Go Recommendation	• Environmental Compliance During Constructibility Review	• Define Cost and Planning for Construction Environmental Compliance Plan	• Convert EIA Requirements to Construction Environmental Control Plan • Construction Contracts' Field Requirements		
Environmental Level of Effort	\$1K to \$30K	\$10K to \$30K	\$20K to \$50K	1% to 5% TIC		
THIRD-PARTY PERSPECTIVE						
Environmental Consultants (and/or Unbundled Bechtel Services)						
Environmental Level of Effort	None	\$20K to \$400K	\$100K to \$5M	>2% TIC		

Figure 1. Environmental Activities by Project Phase

The Environmental Engineer's role starts at the earliest phases of a project, affects the critical path, and defines a significant portion of the capital expenditures.

- On M&M projects, the owner's involvement in the project life cycle could last from several decades to more than a century. In contrast, Bechtel's involvement may last only a few years when Bechtel's role is limited to the EPC phase. When Bechtel's role includes supporting the owner's project development studies, the total job might continue for a decade. Bechtel has also participated in other types of project scopes that entail facility operation and maintenance (O&M) or the remediation of US Department of Energy sites that are a legacy of the Manhattan (atomic weapons) Project; our involvement in some of these projects has continued for several decades.
- As a consequence of the adoption of more advanced environmental requirements, smaller companies that cannot afford to pay for the baseline studies and environmental approval processes no longer take on these projects. As can be seen from the first gold-colored row in Figure 1, the cost of each successive phase increases significantly. A project might go through several different owner companies because smaller companies cannot afford the cost of a subsequent phase. The smaller companies may need to engage larger companies to provide the financial resources for more extensive drilling efforts to define an ore body, characterize the associated waste rock, and/or initiate the environmental baseline studies that are part of the pre-feasibility study phase. In some cases, only the major, multinational mining houses have the internal resources necessary to assume the financial risks through the feasibility study and reporting phase, until the project can attract financial backing from the international banking community. In addition, the international banking community can require that the selected companies have demonstrated, large-project operating experience that is often not found outside the multinational mining companies.
- The owner's environmental requirements and efforts are shown, by phase, in the green row. These are complemented by the Bechtel Environmental Engineering support shown in the blue row. The red row shows the requirements to perform construction activities while maintaining environmental compliance.
- The owner's typical environmental costs as shown in the first gold-colored row are given as a factor of the TIC. During the pre-feasibility and feasibility study phases, most

of the costs are for the EIA work. During the engineering and construction phase, most costs are for installation of the pollution control equipment and facilities, with a relatively small cost for permit, monitoring, and reporting requirements associated with the construction.

- Bechtel's typical services costs for environmental support are shown in the second gold-colored row. Finally, the third gold-colored row shows typical services by outside (third-party) consultants that prepare the EIA baseline study and impact evaluation documents; most of the environmental-related services costs expended on a project are shown in this row.

The main point to be taken from Figure 1 is that the Environmental Engineer's role starts at the earliest phases of a project, affects the critical path, and defines a significant portion of the capital expenditures.

THE ENVIRONMENTAL ENGINEER'S ROLE

Conceptual Design Phase

During the conceptual design phase, the overall engineering role includes providing practical definitions for the mining, production, and waste-handling facilities, as well as practical definitions of the infrastructure requirements. There is little need to optimize the designs because the purpose is to develop the rough capital and operating cost estimates that are the basis from which to start defining the minimum net income needed to pay for the infrastructure and the operating facilities versus the size of the ore body needed to support a production rate necessary to generate the required income. The cost estimate accuracy required to make these initial determinations is low, the contingency is high, and the cost estimates are often factored. Therefore, little engineering detail is required. Since Bechtel has a rather extensive library of cost information for M&M projects, the individual cost estimates needed to develop the overall capital cost estimate to the requisite degree of accuracy for the conceptual design phase can be produced with a relatively small amount of engineering effort. In general, most of the basic production facility capital costs can be factored from previous projects, while the mine, waste rock, and tailings disposal areas; camps; access corridors for road, rail, and utilities; and ports require only a limited engineered definition to obtain the degree of accuracy required for the capital cost estimate.

The Environmental Engineer's role can be quite limited in this phase. A primary role can be to assist the owner with the early identification of potential environmental issues and/or fatal flaws. The Environmental Engineer works with the owner's environmental team to suggest EIA and permit acquisition strategies. Internally, the Environmental Engineer details to the cost engineers how the subject plant might differ from the plants in the historical database and how the factored costs can be adjusted accordingly. For example, if several previous concentrator projects were sited in remote areas of Chile's Atacama Desert, a concentrator project located in the Santiago Metropolitan Region or agricultural areas would require more extensive air and water pollution control facilities. Depending on the experience of the Environmental Engineer, these adjustments might be handled as an additional percentage allowance, or one or more of the critical facilities might require that some preliminary engineering be performed. The same is true for the project infrastructure.

The Environmental Engineer prepares the pollution control sections of the conceptual design report. These sections include Bechtel's assumptions about the environmental setting, the extent of pollution control facilities, and the costs of any special control equipment.

Pre-Feasibility Study Phase

During the pre-feasibility study phase, an engineering study is usually prepared to examine alternative approaches for developing the resources and to provide the associated capital and operating costs for these alternatives. Some projects cover more than a hundred alternatives for improving rates of return and containing risks. Some pilot testing is performed to determine mineral recovery efficiencies. Additional exploration drilling is used to acquire detailed information on the ore body and its extent. The objective of this phase is to eliminate several of the alternatives and then define the scope of one or a few of the alternatives to be carried forward to the next study phase.

Again, the Environmental Engineer's input to the engineered facilities in this phase of a project might be rather limited, with most efforts consisting of assisting the cost estimating engineers with factoring in information from previous projects and the historical database.

Frequently, to prepare the overall project schedule, the long-lead-time activities for the EIA and permit acquisition processes have to

be started in this phase. The Environmental Engineer needs to prepare project and pollution control descriptions so that the EIA scientists can start or advance their baseline studies before all of the project information is known, let alone finalized. These descriptions often have to include several of the alternatives before the final project is defined. The project footprint has to be defined broadly enough to include variations among the alternatives, but be narrow enough to preclude excessive baseline study costs and/or perception of impacts. Emission and effluent inventories are estimated based on a preliminary screening of alternatives and partially completed metallurgical process information. Also, the Environmental Engineer continues to work with the owner's environmental team on the EIA and permit acquisition strategies. In most cases, the EIA scientists are employed by a third-party contractor engaged by the owner.

The Environmental Engineer prepares the pollution control sections of the pre-feasibility design report(s). These sections include Bechtel's assumptions about the environmental setting, extent of pollution control facilities, costs for any special control equipment, status of EIA and major permit acquisition activities, and recommendations for addressing future environmental items that might affect schedule or capital costs during the next phase.

Feasibility Study Phase

During the feasibility study phase, the engineering study is prepared to assist the cost engineers responsible for developing capital and operating costs for the study report. In addition, the engineering study is specifically directed toward providing information, drawings, and discussions for those individuals tasked with preparing a bankable document to be used by an international financial institution (or other funding source) in determining whether to invest in the project. The bankable document outlines project risks, delineates methods to eliminate those risks, and measures potential economic returns. It includes a certified evaluation of the project ore reserves; evaluation of pertinent commodity market(s) and factors related to the project revenue stream; capital costs; operating costs; pro forma contracts for the reagents, utilities, and transportation costs; information regarding ownership of the land, mineral rights, and process patents; and environmental approvals. In most cases, Bechtel prepares the capital cost estimate and frequently prepares operating cost estimates.

The Environmental Engineer needs to prepare project and pollution control descriptions so that the EIA scientists can start or advance their baseline studies before all of the project information is known.

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However, Bechtel is seldom responsible for the overall bankable document submitted to the financing institution.

The Environmental Engineer issues an environmental engineering design criteria document that, in conjunction with a process design criteria document, constitutes the performance basis for the other disciplines' designs. The Environmental Engineer often prepares the environmental sections of the bankable document. Although the baseline studies and impact evaluations are usually performed by third-party specialty contractors hired by the owner, the Environmental Engineer reviews the EIA documents for consistency among (a) various baseline studies and the facility footprints, (b) the engineered pollution control and other mitigations measures, and (c) the engineered features and the capital or operating cost sections. The Environmental Engineer also reviews alternative design concepts proposed and/or evaluated by the parties conducting the EIAs, the adequacy of the project's proposed pollution control measures (to verify that they comply with project alternatives suggested by agency personnel or commissioners), and the technical or economic feasibility of alternative concepts proposed by nongovernmental organizations (NGOs).

The purpose of the environmental section of the feasibility study is to summarize the environmental aspects of the project; identify risks that could materially and adversely affect the technical, environmental, and financial success of the project; and describe the mitigation provisions that have been included in the estimated cost basis.

Detailed Engineering and Construction Phase

During the detailed engineering and construction phase, engineers prepare criteria, specifications, calculations, drawings, etc., for use in purchasing equipment and bulk material. Construction forces also use these documents to execute the project. These duties constitute the traditional role of engineers on an EPC project.

The Environmental Engineer supplements the environmental engineering design criteria issued during the feasibility phase, adding data on new conditions imposed by the EIA and permit approvals, and prepares a project environmental compliance matrix. Both of these documents are technical interpretations of commitments made by the owner during the EIA and associated processes. Written primarily for

internal use by the other engineering disciplines, they are prepared in a manner that precludes these disciplines from having to conduct their own respective investigations into the EIA/regulations or references thereto.

The Environmental Engineer also prepares the technical documentation for the owner's submittal to the pollution control agencies. To maintain the schedule, such documents often have to be prepared before the designs are complete; therefore, the Environmental Engineer has to understand the pollution control system and the agency review process well enough to make an approvable application. Special conditions resulting from the approval process have to be incorporated into the design criteria and the compliance matrix.

On M&M projects, the engineering discipline tasked with designing a specific facility is also responsible for designing the pollution control measures for that facility. For example, the mechanical discipline designs a belt conveyor transfer station in accordance with the metallurgical/process engineering discipline's flow requirements and the environmental engineering discipline's pollution control requirements. If the air regulations require a baghouse, the environmental design criteria delineate the grams-per-second limits of dust emitted and the concentration of dust, the specific instrumentation, and the sampling points. Next, the mechanical engineer uses the discipline's guidelines to calculate the air flow and coordinates with the layout/plant design discipline to route the ductwork between the platework at the transfer point and the baghouse. In this manner, the work is divided so that each engineering discipline is responsible for the work that it traditionally performs.

In another example involving the civil engineering discipline's responsibility for sedimentation ponds and site drainage, the environmental design criteria establish the minimum sizing requirements for the ponds. These requirements are usually defined by a storm event and freeboard and the discharge concentration and turbidity limitations. Using this information, the civil engineer plans the diversion and/or interception channels and determines the locations and number of ponds.

In both of these examples, the pollution control designs are integrated into the overall design and are not just a pollution control unit operation added on at the end of the process by the environmental engineering discipline.

Of course, the Environmental Engineer has to understand the other disciplines' work practices well enough to be able to clearly inform those disciplines of the engineering requirements without using the legalistic writing style of the EIAs or environmental regulations. Furthermore, an Environmental Engineer has to have sufficient knowledge of the other engineering disciplines' technical design details to be able to assist with preparing the design, technical specification, data sheets, and guarantee clauses, if requested, and to participate in the design coordination and checking to maintain the quality of both processes.

Environmental Engineers also assist with startup and commissioning of the pollution control equipment because they know how this equipment works and how the overall plant production system functions and are knowledgeable about the commissioning testing and reporting requirements of the governing agencies.

Operation and Closure Phases

During the operation and closure phases, the Environmental Engineer prepares brief descriptions of the EIA and other documents, including an operating plan for the mine and plant pollution control systems and facilities. These descriptions may also include feasible closure and post-closure plans for the project. The Environmental Engineer also helps the cost engineers estimate the closure costs. Since the project might operate 25 to 100 years into the future, there could be capital or operating cost implications if these costs must be secured through lines of credit or bonding by a third party.

These descriptions may not be the actual plans; they could constitute representative plans acceptable to the respective agencies and may remain in effect until the owner's plant environmental personnel come onto the project. At this time, final closure plans can be prepared based on plant environmental personnel staffing levels and more current knowledge of the plant.

DEVELOPING THE ENVIRONMENTAL ENGINEER

Imprecisely Understood Role

The Environmental Engineer's role on a major capital project is often imprecisely understood by the general public as well as by project management. Quite often, the role comes to

encompass responsibility for regulations that are not managed by other engineering disciplines or project functions, e.g., impact evaluation, pollution control, sustainability, land use planning, socioeconomic mitigation, plan approvals, code checking, industrial hygiene, operations monitoring and reporting, plant closure, and site remediation.

Differing Educational Philosophies

In educational institutions in North America, Australia, and Europe, an environmental engineering degree is usually awarded by the Civil Engineering department because large public works (water supply and sewerage) programs were traditionally run by civil engineers. A degree in environmental sciences is usually awarded by another university department (often dealing with natural sciences or resources), typically under the leadership or grantsmanship of individual professors within those departments, possibly reflecting the interests of those individuals. Obviously, the scope is not the same from university to university. Whereas individuals graduating with degrees in electrical, mechanical, or civil engineering (as well as fellow graduates in other disciplines or fields) have a general sense about their prospects after graduation, Environmental Engineers tend to be far less certain about their post-graduation plans.

In Chile, Argentina, and Peru, Environmental Engineering and Environmental Science are separate, standalone departments established to meet the demand for engineers in these disciplines coming from the industry and the environmental regulators and policy makers. These graduates are very knowledgeable about how to evaluate, guide, plan, and control environmental policies and regulations, with the goal of creating a sustainable development program.

Needless to say, these two divergent educational philosophies can lead to a culture clash when engineers from the different traditions are brought together in a single, multinational design office.

Divergent Demands

In the Western Hemisphere, Europe, and Australia, the educational programs for Environmental Engineers are very similar. They cover a wide variety of environmental subjects, with emphasis on the basic sciences, technology, natural resources management, environmental laws, and regulations. This foundation prepares

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the graduates to work with consultants and agencies to evaluate, guide, plan, and control environmental policies and regulations. However, this training does not cover EPC work processes or the budget and schedule information needed to prepare the studies required to develop and finance projects. This can lead to a different type of culture clash between the reflective, analytical environmental graduates and the intense, budget/schedule-driven EPC team.

The emphasis given by the universities is largely understandable. Compared with the number of engineers engaged in environmental design, a larger number of environmental scientists evaluate project impacts on the flora and fauna, the habitat of endangered species, ground-level air pollutant concentrations and visibility, groundwater and surface water pollutant travel and attenuation, soil remediation, etc. As a result, university curricula emphasize the need for graduates to be able to monitor, analyze, and report impacts to community planners, enforcement agencies, and regulatory policy makers. Also, there is a significant demand for engineers to design, construct, and operate the world's water supply and sewerage systems.

Conversely, only a relatively small number of companies throughout the world (including Bechtel M&M and its competitors) undertake large EPC efforts such as mining, beneficiation, and smelting projects. As a consequence, there is little demand for the type of Environmental Engineer described in this paper. Therefore, universities do not emphasize formal curricula for such engineers. This means that on-the-job training is required to prepare graduate Environmental Engineers to perform EPC work processes, or that an EPC engineer's specialty must be modified to ensure that he or she understands the environmental compliance issues.

CONCLUSIONS

Environmental considerations and activities form a substantial portion of work performed on M&M projects worldwide. More than 100 separate environmental permits and other documents must be approved by various governmental agencies before the construction and/or operations can begin. Essentially, all projects must have an approved EIA before release of funds. On most projects, some of the permits are also on the critical path for the release of funding by the financial institution

and/or board of directors. Depending on the type of project, the pollution control and other mitigation capital costs can range from 3% to more than 50% of the TIC. While many scientists and engineers who are highly skilled in the environmental arena contribute to a project's environmental documentation, only one or two Environmental Engineers within a project EPC organization work with their counterparts in the owner's organization to define what will actually be constructed.

There are two key conclusions from the discussions in this paper:

- First, there is the lack of environmental engineering graduates who can perform EPC design work because most of the engineers graduating from universities have been trained to do environmental assessments. Some of these graduates can be trained in the EPC work processes. However, to compensate for the lack of Environmental Engineers, Bechtel M&M's approach has been to train engineers who have expertise in a certain area (dust control, water and air contamination, etc.) in the legal requirements applicable to their field. This approach has been successful but time consuming, and, more often than not, cyclical engineering backlogs make developing and retaining trained personnel problematic.
- Second, to ensure that an Environmental Engineer is able to work as effectively as possible, proper communication tools need to be in place to inform all the engineering disciplines working on a project of the environmental requirements. The primary tools are the environmental engineering design criteria and the environmental compliance matrix. These documents present the requirements in a manner that can be integrated into each discipline's work process. The benefits of this approach are that fewer Environmental Engineers are needed and, more importantly, that engineers, regardless of discipline, can and will take ownership of the pollution control equipment and facilities instead of passing the problem to an Environmental Engineering group to handle. ■

BIOGRAPHIES



Mónica Villafañe Hormazábal is the chief representative Environmental Engineer for Bechtel's Mining & Metals business based in Santiago, Chile. She is functionally responsible for environmental engineering executed from this office and provides environmental expertise to major copper projects. Mónica develops environmental design criteria and verifies that projects being developed in the Santiago office comply with environmental regulations (compliance matrix) and client environmental requirements.

Mónica has 26 years of experience, including 3 years with Bechtel Chile. She specializes in environmental regulations and permitting; water treatment; recovery and discharge permitting; hazardous waste treatment, storage, and disposal; solid waste treatment; and mine closure/post-closure management/procedures. She is also very knowledgeable about the environmental legislation of Chile, Peru, and Argentina, and, to a lesser extent, the legal regulations of Mexico.

Mónica has presented and published more than 18 technical papers on a wide variety of environmental topics, such as technological alternatives for wastewater management, environmental impact procedure and its use in the mining industry, and solid waste management in northern Chile. She assisted the local authorities in Antofagasta, Chile, after the high-magnitude earthquake that affected the city in 1995 and was recognized by its mayor for her contributions.

Mónica holds a degree in engineering sciences and is a Civil Engineer from the University of Concepción, Chile. She has completed specialization courses and internships in environment, safety, and occupational health; audit; and quality.



James A. Murray retired in 2008 from Bechtel's Mining & Metals Global Business Unit after serving as the GBU's chief environmental engineer for approximately 25 years. He continues with M&M as a senior principal engineer in an in-house consulting role supporting pollution control engineering and environmental permit acquisition programs for a range of commodities and technologies. Jim has performed environmental engineering activities in connection with the mining, beneficiation, and smelting of light, heavy, precious, and base metals; tailings dams; cement; coal; coke (metallurgical and petroleum); fossil power; fertilizer; industrial minerals; petroleum and petrochemical; pipelines; ports; and subway and railroad tunnel ventilation.

Jim authored Chapter 15, "Economic Impact of Current Environmental Regulations on Mining," in *Mining Environmental Handbook: Effects of Mining on the Environment and American Environmental Controls on Mining*. He also authored or co-authored 16 technical papers. Jim holds four US patents and six related foreign patents.

Before joining Bechtel, Jim was manager for air pollution control at Kaiser Engineers.

Jim earned his MS and BS, both in Mechanical Engineering, from Stanford University, in California. He is a licensed Professional Mechanical Engineer in California and a Diplomat of the American Academy of Environmental Engineers.

