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BUREAU OF MINES
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The Availability of Primary Lead and Zinc in Market Economy Countries

A Minerals Availability Appraisal

By Carl A. DiFrancesco, Joseph L. Cornellisson,
and Gary R. Peterson

UNITED STATES DEPARTMENT OF THE INTERIOR

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PREFACE

The U.S. Bureau of Mines Minerals Availability Program assesses the worldwide availability of nonfuel minerals. The Bureau identifies, collects, compiles, and evaluates information on active and developing mines, explored deposits, and mineral processing plants worldwide. The program's objectives are to classify domestic and foreign resources, to identify by cost evaluation the resources that are reserves, and to analyze the availability of mineral resources.

This report is a continuation of previous Division of Resource Evaluation reports in which the availability of lead and zinc resources from domestic and foreign sources and the factors affecting availability were evaluated. This report updates and expands upon the first report, published in 1983.

Analyses of other metals and minerals are in progress. Questions about the Minerals Availability Program should be addressed to Chief, Division of Resource Evaluation, U.S. Bureau of Mines, 810 Seventh Street, NW., Washington, DC 20241.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS—Continued

TABLES

THE AVAILABILITY OF PRIMARY LEAD AND ZINC IN MARKET ECONOMY COUNTRIES

A MINERALS AVAILABILITY APPRAISAL

By Carl A. DiFrancesco,[1] Joseph L. Cornellisson,[1] and Gary R. Peterson[2]

ABSTRACT

The U.S. Bureau of Mines estimated the potential availability of lead and zinc from 205 mines and deposits in market economy countries (MEC's) by performing detailed geologic, engineering, and cost evaluations. These evaluated properties had demonstrated resources totaling 57 million metric tons (Mmt) of contained lead and accounted for approximately two-thirds of the Bureau's reserve base for lead in MEC's (almost 96 Mmt). These properties had contained (in situ contained metal) zinc resources totaling 160 Mmt and also accounted for almost two-thirds of the Bureau's reserve base for zinc in MEC's (259 Mmt). Total recoverable (contained metal, milled, smelted, and refined) MEC lead resources from evaluated mines and deposits were 48 Mmt; 27% was from primary lead mines and deposits, and the remaining 73% from primary zinc mines and deposits. Of the primary lead mines, the United States had the lowest estimated weighted-average total cost for producers at $0.25/lb recoverable lead at 0% discounted cash flow rate of return (DCFROR).

Total recoverable MEC zinc resources evaluated were 131 Mmt, 98% of which was from primary zinc mines and deposits. The remainder was from primary lead mines and deposits. The estimated weighted average total cost of production for producing mines in the United States amounted to $0.49/lb zinc in January 1990 dollars at a 0% DCFROR.

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INTRODUCTION

The U.S. Bureau of Mines undertook this study due to the changing status of the worldwide lead and zinc industry. Lead and zinc usually occur together and are beneficiated at the same locations, but they have quite divergent post-milling markets. Severe problems with low metal prices during the period from 1982 to 1987 and oversupply of lead and zinc induced producers worldwide to consolidate plant ownership (rationalization) in the industry and introduce effective measures (new technologies) to lower costs and increase profits.

Major problems for both the lead and zinc industries are the environmental effects of mining, milling, smelting, and refining. Due to the high toxicity of lead, and as both lead and zinc are found together in about three out of four deposits, the mining of lead and zinc poses serious problems for the mining industry. Mine sites contain both solid (waste piles) as well as liquid (surface and ground water drainage from present and past operations) waste sources. These considerations present challenging problems to the development of any new lead or lead-containing zinc deposit in the United States. Those zinc deposits that do not contain lead share the general environmental concerns of land, water, and air disturbances.

As new and more stringent air, water, and solid waste regulations become effective, the survival of primary and secondary lead smelters and refineries is threatened. The effects of these regulations could be serious if government and industry cannot come to terms on their content before their implementation. Environmental issues associated with the lead and zinc industry were not analyzed in terms of cost but were summarized to point out the serious effects that past, present, and future legislation have had or will have on the industries.

This study evaluates the potential availability of lead and zinc from 205 mines and deposits in market economy countries (MEC's), including 144 that were producing in 1989. In addition, 61 properties considered to have potential to produce during the study period were included (tables 1 and 2).

Table 1.—Deposits evaluated primarily for lead

Country	Deposit name	Owner	Status[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities
Brazil	Boquira + Plumbum	Paulista De Metais	P	U	B	Open stope	Pb, Zn, Ag, Au, Cu.
Mexico	Rosario	IMMSA	P	U	A	Filled stopes	Pb, Zn, Ag, Au, Cu.
Morocco	Djebel Aoum	S.M.A.	P	U	D	Combined	Pb, Zn, Ag.
Do.	Sidi Lachen	Brpm/Arabia Mng. Co.	P	U	A	Overhand	Pb, Zn, Ag.
Do.	Touissit Mining Area	Compagnie Miniere De Touissit	P	U	B	Combined	Pb, Zn, Cu.
Namibia	Tsumeb	Tsumeb Corp. Ltd.	P	U	C	Sublevel	Pb, Zn, Ag, Cu.
South Africa, Republic of.	Broken Hill	Black Mountain Mineral Dev. Co.	P	U	D	Horizontal cut and fill	Pb, Zn, Ag, Cu.
Sweden	Laisvall	Boliden Ab	P	U	D	Room and pillar	Pb, Zn, Ag.
United States	Buick	Doe Run	P	U	D	do.	Pb, Zn, Ag.
Do.	Burgin Mine Project	Sunshine Mining Co.	N	U	A	Timbered stopes	Pb, Zn, Ag.
Do.	Casteel	Doe Run	P	U	C	Room and pillar	Pb, Zn, Ag, Cu.
Do.	Clayton Silver Mine	Clayton Silver Mines, Inc.	P	U	A	Shrinkage with caving	Pb, Ag, Au, Cu, Zn.
Do.	Doe Run	Doe Run	P	U	D	Room and pillar	Pb, Au, Cu, Zn.
Do.	Lucky Friday	Hecla Mining Co.	P	U	A	Horizontal cut and fill	Pb, Zn, Ag, Au.
Do.	Magmont	Cominco/Dresser	P	U	C	Room and pillar	Pb, Zn, Cu.
Do.	West Fork	ASARCO	P	U	C	do.	Pb, Zn, Ag.
Do.	Sweetwater	ASARCO	P	U	D	do.	Pb, Zn, Ag.

[1]N:nonproducer; P:producing property.
[2]U:underground.
[3]A:0—250; B:251—500; C:501—1,000; D:1,001—3,000; in kmt/yr ore.

Table 2.—Deposits evaluated primarily for zinc

Country	Deposit name	Owner	Current[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities[4]
Algeria	El Abed	Sonarem	P	U	B	Room and pillar	Zn, Pb, Ag.
Argentina . .	El Aguilar	Comsur	P	U	B	Underhand square-set	Zn, Pb, Ag.
Australia . . .	Beltana	Pasminco Ltd.	P	S	A	Open pit	Zn.
Do.	Cadjebut	BHP-Utah Minerals/ Billiton	P	U	B	Room and pillar	Zn, Pb.
Do.	Elura	Pasminco Ltd.	P	U	D	Open stope	Zn, Pb, Ag.
Do.	Golden Grove	Murchison Zinc/ Esso/Aztec	P	U	C	Sublevel	Zn, Ag, Au, Cu.
Do.	Hellyer	Aberfoyle Ltd.	P	U	C	Open stope	Zn, Pb, Ag, Au, Cu.
Do.	Hilton	MIM Holding Ltd.	P	U	D	do.	Zn, Pb, Ag.
Do.	Lady Loretta	Pancontinental/ Outokompu	D	U	B	Sublevel	Zn, Pb, Ag.
Do.	Mt. Isa	MIM Holdings Ltd.	P	U	E	Combined	Zn, Pb, Ag.
Do.	North Broken Hill	No. Broken Hill Ltd./Pasminco	P	U	B	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Que River	Aberfoyle Ltd.	P	U	B	Caving	Zn, Pb, Ag, Au, Cu.
Do.	Rosebery Mine	Pasminco Ltd.	P	U	C	Open stope	Zn, Pb, Ag, Au, Cu.
Do.	South Mine Broken Hill	Minerals, Mining, & Metallurgy	P	S	C	Open pit	Zn, Pb, Ag.
Do.	Thalanga	Outokumpu Oy/ Pancontinental	P	U	B	Inclined cut and fill	Zn, Pb, Ag, Au, Cu.
Do.	Woodcutters	Nicron Resources & Others	P	U	A	Open stope	Zn, Pb, Ag.
Do.	Woodlawn	Denehurst Ltd.	P	U	B	Inclined cut and fill	Zn, Pb, Ag, Au, Cu.
Do.	ZC Mine	Pasminco Ltd.	P	U	D	Caving	Zn, Pb, Ag.
Austria	Bleiberg-Kreuth	Bleiberger Bergwerks Union	P	U	B	Combined	Zn, Pb.
Bolivia	Bolivar	Comibol	P	U	A	Horizontal cut and fill	Zn, Pb, Ag, Sn.
Do.	Quechisla	Comsur	P	U	B	Overhand shrinkage	Zn, Pb.
Do.	Quioma	Cia Minera Quioma	P	U	A	Horizontal cut and fill	Zn, Pb, Ag.
Brazil	Morro Agudo	Comp. Miniera De Metais S.A.	P	U	B	Combined	Zn, Pb, Cd.
Do.	Vazante	Companhia Miniera De Metais	P	C	B	do.	Zn.
Burma	Bawdwin	No. 1 Mining Co.	P	C	A	do.	Zn, Pb, Ag, Cu.
Canada . . .	Abcourt-Barvue	Mines Abcourt	P	U	A	Horizontal cut and fill	Zn, Ag.
Do.	Brunswick #12	Brunswick M&S Corp.	P	U	E	do.	Zn, Pb, Ag, Cu.
Do.	Caribou Mine	East West Caribou Mining NI	P	U	B	do.	Zn, Pb, Ag, Au.
Do.	Chisel Lake Mine	Hudson Bay Mining & Smelting	P	U	A	Fill stope	Zn, Pb, Ag, Au, Cu.
Do.	Cirque	Curragh Resources	N	U	D	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Faro Anvil	Curragh Resources/ Boliden	P	S	E	Open pit	Zn, Pb, Ag.
Do.	Geco	Noranda Mines Ltd.	P	U	D	Open stope	Zn, Ag, Cu.
Do.	Goz Creek	Cons. Barrier Reef Resources	N	S	B	Bench (berm)	Zn, Ag.
Do.	Great Slave Reef	Du Pont/Westmin/ Philipp Bros	N	U	B	Room and pillar	Zn, Pb.
Do.	Grum	Curragh Resources	D	C	D	Surface/underground	Zn, Pb, Ag.
Do.	Hackett River	Cominco/Etruscan	N	U	D	Horizontal cut and fill	Zn, Pb, Ag, Au, Cu.
Do.	Half Mile Lake	Conwest Exploration Cl.	N	U	C	do.	Zn, Pb, Ag, Cu.
Do.	Heath Steele	Heath Stl/Noranda/ Brunsk	P	U	D	Open stope	Zn, Pb, Ag, Cu.
Do.	Howard's Pass	Placer Dome/Essex Min'L	N	U	E	Room and pillar	Zn, Pb, Ag.
Do.	Isle Dieu	Noranda	P	U	B	Sublevel	Zn, Ag, Au, Cu.
Do.	Izok Lake	Kidd Creek Mines Ltd.	N	S	C	Open pit	Zn, Pb, Ag, Cu.

See footnotes at end of table.

Table 2.—Deposits evaluated primarily for zinc—Continued

Country	Deposit name	Owner	Current[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities[4]
Canada—Continued	Kidd Creek	Falconbridge, Ltd.	P	U	E	Open stope.	Zn, Pb, Ag, Cu.
Do.	Nanisivik	Mineral Resources International	P	U	C	Room and pillar	Zn, Pb, Ag.
Do.	Midway	Regional Res./Canamax/Procan	N	U	A	Sublevel	Zn, Pb, Ag.
Do.	Myra Falls	Westmin	P	U	D	Room and pillar	Zn, Pb, Ag, Au, Cu.
Do.	Polaris Mine	Cominco	P	U	D	Horizontal cut and fill	Zn, Pb.
Do.	Robb Lake	Texas Gulf/Arrow Int/Barrier	N	U	B	Room and pillar	Zn, Pb, Ag.
Do.	Ruttan	Hudson Bay Mining & Smelting	P	U	C	Open stope	Zn, Ag, Au, Cu.
Do.	Selbaie Mine	Bp-Can/Esso-Can/Tcpl	P	C	D	Surface/underground	Zn, Ag, Au, Cu.
Do.	Sullivan	Cominco	P	U	D	Room and pillar	Zn, Pb, Ag.
Do.	Tom Deposit	Hudson Bay Mining	N	U	C	Horizontal cut and fill	Zn, Pb.
Do.	Trout Lake	Hudson Bay/Granges Manitoba	P	U	C	do.	Zn, Ag, Au, Cu.
Do.	Vangorda	Curragh Resources	N	S	D	Open pit	Zn, Pb, Ag.
Do.	Winston Lake	Minnova Ltd. Subs. Of Kerr Addis	P	U	B	Horizontal cut and fill	Zn, Ag, Au, Cu.
Chile	El Toqui	Lac Minerals	P	U	B	Room and pillar	Zn.
Finland . . .	Pyhasalmi	Outokumpu Oy	P	U	C	Sublevel	Zn, Ag, Au, Cu, Py.
Do.	Vihanti	do.	P	U	D	Combined	Zn, Pb, Ag, Au, Cu.
France	Bodennec	BRGM	N	S	A	Bench (berm)	Zn, Ag, Au, Cu.
Do.	Nohailac-Saint Salvy	Pennaroya	P	U	A	Other fill stope	Zn, Ag, Ge.
Do.	Prt-Aux-Moines	BRGM	N	U	A	Sublevel	Zn, Ag, Au, Cu.
Germany . .	Bad Grund	Preussag Ag Metal	P	U	B	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Meggen	Metallgesellschaft A.G.	P	U	C	Combined	Zn, Pb, Py.
Great Britain	Parys Mountain	Imperial Metal Corp.	D	U	B	Shrinkage	Zn, Pb, Ag, Au, Cu.
Greece	Kassandra	Hellenic Chemical Products	P	U	B	Caving	Zn, Pb, Ag, Au, Py.
Do.	Olympias	do.	P	U	B	do.	Zn, Pb, Ag, Au, Cu, Py.
Honduras . .	El Mochito	Breakwater Resources Ltd.	P	U	C	Combined	Zn, Pb, Ag.
India	Ambamata (Ambaji)	Gujaret Mineral Development	P	C	B	do.	Zn, Pb, Ag, Au, Cu.
Do.	Mochia-Balaria	Hindustan Zinc Ltd.	P	U	C	do.	Zn, Pb.
Do.	Rampura Agucha	do.	N	S	C	Open pit	Zn, Pb, Ag, Cd.
Do.	Rajpura-Dariba	do.	P	C	B	Combined	Zn, Pb, Ag, Cu, Cd.
Do.	Zawarmala-Baroi	do.	P	U	C	Open stope	Zn, Pb, Ag.
Ireland	Galmoy	Conroy Petroleum/Am. Pac. Mng.	D	U	C	Room and pillar	Zn, Pb, Ag, Cd.
Do.	Tara	Tara Mines Ltd.	P	U	D	do.	Zn, Pb.
Italy	Masua	Nuova SAMIM	P	U	C	Caving	Zn, Pb.
Do.	Monteponi	do.	P	U	B	Combined	Zn, Pb, Ag.
Do.	Montevecchio	do.	P	U	A	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Raibl	do.	P	U	B	Combined	Zn, Pb.
Japan	Ezuri Mine	Dowa Mining Co.	P	U	A	Inclined top slicing	Zn, Pb, Ag, Au, Cu, Py, Ba.
Do.	Fukasawa Mine	do.	P	U	A	do.	Zn, Pb, Ag, Au, Cu, Py, Ba.
Do.	Kosaka Mine	do.	P	U	C	Horizontal cut and fill	Zn, Pb, Ag, Au, Cu.
Do.	Matsumine (Hanaoko)	do.	P	U	A	Inclined top slicing	Zn, Pb, Ag, Au, Cu, Py, Ba.
Do.	Mozumi Mine (Kamioka)	Mitsui Mining and Smelting	P	U	B	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Tochibura Mine (Kamioka)	do.	P	U	D	Caving	Zn, Pb, Ag.

See footnotes at end of table.

Table 2.—Deposits evaluated primarily for zinc—Continued

Country	Deposit name	Owner	Current[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities[4]
Japan—Continued	Toycha Mine	Toycha Mining Co. Ltd.	P	U	B	Sublevel	Zn, Pb, Ag, Py.
Korea, Republic of.	Taebek	Young Poong Mining Co.	N	U	B	Horizontal cut and fill	Zn, Pb, Ag.
Mexico	Bismark	Penoles/Cyprus	D	U	C	Filled stopesods	Zn, Pb, Ag.
Do.	Charcas	IMMSA	P	U	C	Combined	Zn, Pb, Ag, Cu.
Do.	El Monte and El Carrizal	Fresnillo	P	U	B	Open pit	Zn, Pb, Ag, Cu.
Do.	La Colorada	Min. Victoria Eugenia S.A.	P	U	A	Horizontal cut and fill	Zn, Pb, Ag, Au.
Do.	La Minita	Industrias Penoles S.A.	P	S	C	Open pit	Zn, Pb, Ag, Ba.
Do.	La Negra	do.	P	U	B	Sublevel caving	Zn, Pb, Ag, Cu.
Do.	Naica	IMMSA	P	U	C	Inclined cut and fill	Zn, Pb, Ag, Au, Cu.
Do.	Real De Angeles	Minera Real De Angeles	P	S	E	Open pit	Zn, Pb, Ag.
Do.	Rey De La Plata	Industrias Penoles S.A.	N	U	B	Horizontal cut and fill	Zn, Pb, Ag, Au.
Do.	San Francisco Del Oro	Empresas Frisco S.A. De C.V.	P	U	C	Shrinkage stoping	Zn, Pb, Ag, Au, Cu.
Do.	San Martin	IMMSA	P	U	D	Horizontal cut and fill	Zn, Pb, Ag, Cu.
Do.	Santa Barbara	IMMSA	P	U	D	Combined	Zn, Pb, Ag, Au, Cu.
Do.	Santa Eulalia	IMMSA	P	U	B	Horizontal cut and fill	Zn, Pb, Ag, Cu.
Do.	Santa Maria De La Paz	Neg. Min. Sta. Maria De La Paz	P	U	D	Shrinkage stoping	Zn, Pb, Ag.
Do.	Taxco	IMMSA	P	U	D	Combined	Zn, Pb, Ag.
Do.	Velardena	Minerales Metalicos Del Norte	P	U	A	Shrinkage with fill	Zn, Pb, Ag.
Morocco . .	Hajar	Cmg	N	U	C	Combined	Zn, Pb, Au, Cu.
Namibia . . .	Rosh Pinah	Imscor Zinc Pty. Ltd.	P	U	B	Sublevel	Zn, Pb, Au, Cu.
Norway . . .	Bleikvassli	A/S Bleikvassli Gruber	P	U	A	Open stope	Zn, Pb, Cu, Py.
Peru	Atacocha-Chieren	Compania Minera Atacocha S.A.	P	U	C	Combined	Zn, Pb, Ag, Au.
Do.	Carahuacra	Volcan Compania Minera S.A.	P	C	B	do.	Zn, Pb, Ag.
Do.	Casapalca	Centromin	P	U	C	do.	Zn, Pb, Ag, Cu.
Do.	Cerro De Pasco	do.	P	U	D	do.	Zn, Pb, Ag.
Do.	Colquijirca	Sociedad Minera El Brocal	P	S	B	Open pit	Zn, Pb, Ag, Cu.
Do.	Contonga	Soc. Minera Gran Bretana	P	U	B	Shrinkage stoping	Zn, Pb, Ag.
Do.	Graciella-Juanita	Perubar S.A.	P	C	A	Combined	Zn, Pb, Ba.
Do.	Huanzala	Cia Minera Santa Luisa S.A.	P	U	B	Horizontal cut and fill	Zn, Pb, Ag, Cu.
Do.	Huaron	Cia Minera Huaron S.A.	P	U	C	Combined	Zn, Ag, Au, Cu.
Do.	Iscaycruz	Empresa Min. Especial Iscay Cruz	D	U	A	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Milpo	Cia. Minera Milpo S.A.	P	U	C	Combined	Zn, Pb, Ag.
Do.	Morococha	Centromin	P	U	B	do.	Zn, Pb, Ag.
Do.	Quiruvilca	Corporacion Minera Nor Peru S.A.	P	U	B	do.	Zn, Ag, Au, Cu.
Do.	Raura	Cia. Raura S.A.	P	U	B	do.	Zn, Ag, Au, Cu.
Do.	San Cristobal	Centromin	P	U	C	Filled stopes	Zn, Ag, Au, Du, W.
Do.	San Vicente	Simsa	P	U	C	Horizontal cut and fill	Zn, Pb.
Do.	Santander	Docarb	P	U	B	Sublevel caving	Zn, Ag, Au, Cu.
Do.	Yauricocha	Centromin	P	U	B	Combined	Zn, Ag, Au, Cu.
Portugal . . .	Aljustrel	Pirites Alentejanas S.A.R.L.	D	U	D	Horizontal cut and fill	Zn, Pb, Ag, Au, Cu, Py.
South Africa, Republic of	Gamsberg	Gamsberg Zinc Corp.	N	U	E	Sublevel	Zn, Pb.
Do.	Pering	Shell South Africa (Pty.)	P	S	D	Open pit	Zn, Pb.
Spain	Aznacollar	Boliden A.B.	P	S	E	do.	Zn, Pb.
Do.	Cartagena	Pennaroya Zinc Ltd.	P	U	D	Bench (berm)	Zn, Pb, Ag, Cu.

See footnotes at end of table.

Table 2.—Deposits evaluated primarily for zinc—Continued

Country	Deposit name	Owner	Current[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities[4]
Spain—Continued	La Troya	Exminesa	P	U	B	Room and pillar	Zn, Pb.
Do	Reocin	Asturiana De Zinc S.A.	P	C	D	Combined	Zn, Pb, Py.
Do	Rubiales	Exminesa	P	U	C	Block caving	Zn, Pb, Ag.
Do	Sotiel	Ermasa	P	U	C	Room and pillar	Zn, Pb, Ag, Au, Cu, Py.
Sweden ...	Boliden Operations	Boliden AB	P	U	D	Horizontal cut and fill	Zn, Pb, Ag, Au, Cu.
Do	Garpenberg and Garpenberg	do.	P	U	A	do.	Zn, Pb, Ag, Au, Cu.
Do.	Kristineberg	do.	P	U	D	do.	Zn, Pb, Ag, Au, Cu.
Do.	Zincgruvan	Vielle-Montagne Sa	P	U	C	do.	Zn, Pb, Ag, Au, Cu.
Thailand ...	Mae Sod	Padaeng Industries, Ltd.	P	S	A	Open pit	Zn, Cd.
Tunisia	Bougrine	Tunisia Office Des Mines	P	U	B	Horizontal cut and fill	Zn, Pb.
Turkey	Aladag	Cinkur Mining and Smelting	P	U	A	Open stope	Zn, Pb.
Do.	Cayeli	Etibank, Metal Mining Corp.	N	U	C	Other fill stope methods	Zn, Cu, Au, Pb, Py.
United States	Arctic Camp	Bear Creek Mining Co./Kennecott	N	S	D	Open pit	Zn, Pb, Ag, Au, Cu.
Do.	Bald Mountain	Bolidenoong Mining Co.	N	S	D	do.	Zn, Ag, Au, Cu.
Do.	Balmat/Pierrepont	Horsehead Industries	P	U	C	Timber w/sublevel fill	Zn, Pb.
Do.	Beaver Creek	ASARCO	N	U	B	Room and pillar	Zn, St.
Do.	Big War Creek	Inspiration Resources Corp.	N	U	A	do.	Zn, St.
Do.	Black Cloud (Leadville Unit)	ASARCO/Ressurection	P	U	A	Horizontal cut and fill	Zn, Pb, Ag, Au.
Do.	Blue Moon Project	Colony Pacific Exploration Ltd.	N	U	B	Open stope	Zn, Pb, Ag, Au, Cu.
Do.	Bunker Hill	Bunker Hill Mining Co. Inc.	P	U	B	Horizontal cut and fill	Zn, Pb, Ag.
Do.	Burkesville Project	Caminco/ASARCO/NL Ind.	N	U	C	Room and pillar	Zn, Pb, St.
Do.	Butte Hill	New Butte Miningngeles	D	U	B	Block caving	Zn, Pb, Ag, Au, Cu.
Do.	Carthage Property	St. Joe Minerals/ Freeport Min.	N	U	B	Combined	Zn, St.
Do.	Crandon	Exxon Minerals Co. A. De C.V.	N	U	E	Open stope	Zn, Pb, Ag, Au, Cu.
Do.	Cub Creek	New Jersey Zinc	N	U	C	Combined	Zn, St.
Do.	Cumberland	Jersey Miniere	N	U	C	Room and pillar	Zn, St.
Do.	Cumberland Deposit	Exxon Minerals	N	U	C	Combined	Zn, Cd.
Do.	Cumberland Property	St. Joe Minerals/ Freeport Min.	N	U	C	Room and pillars	Zn, St, Cd.
Do.	East Gainesboro	Getty Oil/Tenn. Zinc Dev.	N	U	C	Combined	Zn, St.
Do.	Eureka/Calloway/ Cherokee	Cities Service	N	U	B	Sublevel	Zn, Cu, Fe.
Do.	Fountain Run	St. Joe Minerals Corp.	N	U	C	Combined	Zn, St.
Do.	Gainesboro	New Jersey Zinc/ W. R. Grace & Co.	N	U	C	Room and pillar	Zn.
Do.	Gordonsville-Elmwood	Jersey Miniere Zinc	P	U	D	do.	Zn, St.
Do.	Green's Creek	Rio Tinto Zinc	P	U	A	do.	Zn, Pb, Ag, Au.
Do.	Hartsville	Marathon Oil Co./ J. F. Flanders	N	U	C	Combined	Zn, St.

See footnotes at end of table.

Table 2.—Deposits evaluated primarily for zinc—Continued

Country	Deposit name	Owner	Current[1]	Type[2]	Capacity[3]	Mining methods	Mineral commodities[4]
United States—Continued	Hartsville Area	Cominco American/NI Ind.	N	U	A	Combined	Zn, St.
Do.	Idol	Inspiration Resources	N	U	A	Room and pillar	Zn.
Do.	Inspiration Zinc	Inspiration Resourcesocal	N	U	B	Combined	Zn, Pb.
Do.	Lik	General Crude Oil & Others	N	S	C	Open pit	Zn, Pb, Ag.
Do.	Lost Creek	New Jersey Zinc Co.	N	U	A	Shrinkage	Zn, St.
Do.	Montana Tunnels	Pegasus Gold Corporation	P	S	E	Open pit	Zn, Pb, Ag, Au.
Do.	Ozark-Mahoning	Ozark-Mahoning Company	P	U	A	Room and pillar	Zn, Pb, Ag, Fl.
Do.	Pall Mall	Dresser/Toho-Nichimen/ASARCO	N	U	E	Combined	Zn, St.
Do.	Pelican River	Noranda Mines Ltd.	N	U	A	Horizontal cut and fill	Zn, Cu.
Do.	Pend Orielle	Resource Finance	N	U	A	Sublevel	Zn, Pb.
Do.	Pinos Altos	Cyprus Minerals	P	U	A	Combined	Zn, Pb, Ag, Cu.
Do.	Red Dog	Nana Reg. Corp. Caminco Alaska	P	S	D	Open pit	Zn, Pb, Ag.
Do.	Stonewall	Jersey Miniere Zinc Co.	N	U	B	Room and pillar	Zn, St.
Do.	Sunnyside	Alta Bay/Washington Mining	P	C	A	Surface underground	Zn, Pb, Ag, Au, Cu.
Do.	Van Stone/ Boundrydam	Equinox Resources	N	U	C	Room and pillar	Zn, Pb.
Do.	Ward Mountain	Silver King Mines (Alta Gold)	P	U	B	do.	Zn, Pb, Ag, Cu.
Do.	Washington Zinc Unit	Callahan Mining & Others	N	U	C	Sublevel	Zn, Pb.
Do.	Young, Immel, Coy, New Market	ASARCO	P	U	D	Combined	Zn, St.
Do.	Zinc Mine Works	Union Zinc	P	U	B	Room and pillar	Zn, St.
Zaire	Kipushi	Gecamines	P	U	D	Combined	Zn, Ag, Au.
Zambia . . .	Kabwe	ZCCM	P	U	A	Shrinkage with caving	Zn, Pb.

[1]D: developing deposit; N: nonproducer; P: producing property.
[2]C: surface and underground; S: surface; U: underground.
[3]A: 0—250; B: 251—500; C: 501—1,000; D: 1,001—3,000; E: greater than 3,001; in kmt/yr ore.
[4]Fl—fluorspar; Py—pyrite; St—crushed stone.

Based on this study, the United States presently has one-fifth of the demonstrated resources of lead in MEC's, while consuming about 22% of total lead produced in 1989. Lead resources are abundant throughout the world, the largest producers being the United States, Australia, Canada, and the former U.S.S.R. At this time, approximately 90% of the lead ore mined in the United States is found in Missouri. The proximity and relative accessibility of lead mines in Canada and Mexico, and the modern and efficient status of mines, mills, smelters, refineries, and major manufacturing plants, render a relatively low risk of supply disruption for the United States. Because of its status as the world's largest recycler of lead-scrap, the United States has been able to provide over 50% of its demand requirement from scrap in recent years. However, environmental risks also pose a serious threat to the viability of lead-scrap recycling.

Zinc resources are abundant throughout the world, the major producing countries being Canada, the former U.S.S.R., Australia, Peru, and the United States. Based on the properties included in this study, the United States has about one-fourth of the demonstrated resources of zinc in MEC's. Because of the proximity and relative accessibility of zinc metal in Canada and Mexico, the risk of supply disruption to the United States is fairly low.

Most of the information in this report is an updated summary of Bureau of Mines Information Circular 9026 "Primary Lead and Zinc Availability—Market Economy Countries, A Minerals Availability Program Appraisal" (*1*).[3] Additional information on domestic and foreign lead and zinc is available from other Bureau publications (*1-2*).

[3]Italic numbers in parentheses refer to references preceding the appendixes at the end of this report.

ACKNOWLEDGMENTS

Some of the data for the domestic deposits analyzed in this study were developed at Bureau Field Operations Centers in Denver, CO; Juneau, AK; and Spokane, WA. The assistance of William Woodbury and James Jolly, the Bureau lead and zinc specialists, respectively, is appreciated.

WORLD LEAD AND ZINC INDUSTRIES

The major lead and zinc minerals are the sulfides galena (PbS) and sphalerite (ZnS), respectively. Lead and zinc minerals are typically found either individually or in combination with each other, and/or with copper or silver. The final product(s) from the mill is usually a lead and/or zinc concentrate. The concentrate is then processed at a smelter and/or refinery to produce a refined metal product. This study analyzes costs of lead and zinc from ore through the production of refined metal. Transportation costs to the smelter and refinery are included. Secondary lead and zinc recovery were not analyzed, but production was described since it is part of the total supply of refined lead and zinc.

LEAD

The lead industry faces severe environmental challenges. Toxicity of lead, in native and oxide forms, makes its continued use vulnerable to environmental legislation. This concern is one of the major factors resulting in closure and lack of new startups for lead mines, mills, and smelters and or refineries in areas with strong environmental laws.

Uses

Lead is used mainly in the manufacture of storage batteries and in materials for the metalworking and construction industries (*3*). The use in storage batteries makes lead a necessary material for both civilian and military purposes.

Lead is used in a wide variety of industrial and commercial applications in the form of pure metal, alloys,[4] or chemical compounds. Applications are shown by usage in table 3. The properties that make lead an essential commodity include low melting point, ease of casting, high density, low strength, ease of fabrication, acid resistance, and chemical stability (*4*). Material competition between lead and other materials is based on these technical properties, lead's relatively low price in comparison to potential substitutes, and the relatively high availability of lead. However, the inherent environmental hazards associated with lead have been a driving force behind substitution for lead.

Table 3.—Uses of lead

Storage batteries:
- Consumer batteries (power tools, flashlights, etc.).
- Starting-lighting-ignition (SLI) systems.
- Uninterruptible power supply (UPS) systems.
- Standby power supply (SPS) systems.
- Load-leveling/peak-power applications.
- Traction batteries (includes electron-volts, forklifts, mine locos, etc.).
- Industrial batteries, others.

Transportation uses:
- Bearings.
- Terne metal in gasoline tanks.
- Wheel weights.
- Autobody solder and filler for antique car restoration.
- Leaded gasoline additives.

Construction uses (includes sheet, cast, and extruded products):
- Caulking.
- Piping.
- Traps.
- Roofing and flashing.
- Solder.
- Bearing blocks in large-structure foundations for vibration damping.
- Radon barriers under residential housing.
- Soundproofing sheets.
- Radiation barriers for nuclear material.
- Corrosion protection in the chemical industry for storage tanks, process vessels, and transportation equipment.

Power-communication-electronics uses:
- Lead sheathing for cables.
- Casting metals in electrical and electronic equipment.
- Bearings in electrical equipment.
- Solder (electronic components, electrical machinery and equipment).
- Nuclear transportation and storage casques.

Ammunition.

Lead oxide:
- Paints.
- Glass and ceramic products.

Miscellaneous: Boat keels, wire, rope, kane, type, etc.

[4]Alloying agents include copper, antimony, calcium, tin, arsenic, silver, strontium, bismuth, and cadmium.

Production

In 1989, nearly 3.4 Mmt primary lead were mined in 48 countries from 8 major production regions (*5*). Of the total world production, 65% (2.2 Mmt) was produced by MEC's,[5] and 35% (1.2 Mmt) by non-MEC's.[6] The major MEC lead concentrate producers are shown in figure 1, and major worldwide concentrate producing regions are shown in figure 2.

Primary lead refining took place in 34 countries in 1989 in 7 major production regions for a total production of 3.2 Mmt. Production was split between MEC's (2.2 Mmt) and non-MEC's (1.0 Mmt). The major MEC primary lead refining regions are also shown in figure 2.

Environmental concerns have stimulated the growth of the secondary lead refining industry. Many countries are instituting laws regarding recycling of lead products or controlling the disposal of lead-bearing materials. World secondary lead production was reported at 2.2 Mmt (*6*) in 1980, and production had increased to 2.6 Mmt in 1989 (45% of total refined lead production). During 1989, secondary lead refining occurred in 48 countries (14 more than produced primary refined lead), and the percentages of production contributed by each of the major producing nations are shown in figure 1. North America and Europe have the most secondary lead refining due to access to spent automobile batteries. At 30% of total secondary production, the United States has by far the world's largest secondary lead refining industry. While secondary lead refining has grown over the last decade, primary refining has declined in the United States from 675 kmt in 1980 to 397 kmt in 1989. Approximately 55% of total U.S. refined lead in 1980 was from secondary sources, while in 1990, 67% came from secondary sources.

The displacement of primary refining facilities by secondary facilities is beginning to take place as a result of the changing structure of the industry. The Doe Run Company is building a $34 million facility in Boss, MO (developed by ENGITEC IMPIANTI SpA of Milan, Italy), to recycle lead, plastic, and acid from used automobile and industrial batteries. The new plant, being built adjacent to the current Buick lead smelter in an effort to lower construction costs, could use 40% of the presently idled capacity at the smelter (*7*). This conversion would not prevent utilizing the facility as a primary smelter, and technical modifications could allow for an unchanged capacity. This plant would produce less waste than any other plant currently in use in the United States. The new plant, which is expected to produce 60,000 tons of lead per year from 120,000 tons of spent automobile batteries, will also recover sulfate for use in the detergent industry and polypropylene chips to be recycled into new battery cases.

U. S. Consumption Trends

Between 1980 and 1989, total lead consumption in the United States has increased approximately 20%, from 1.07 Mmt to 1.28 Mmt. However, this upward trend is not indicative of the dual nature of the lead market. This dual nature is shown by the increasing consumption in lead-acid storage batteries and by declining use in other applications (fig. 3). In the last 10 years, this increasing use in battery applications has overshadowed the declining use in many other applications.

Between 1980 and 1989, the amount of lead consumed in the battery industry increased 57%, from 645 kmt in 1980 to 1,012 kmt in 1989. Battery usage accounted for 60% of U.S. lead consumption in 1980 and nearly 80% in 1989. Concurrently, research that is improving the characteristics of the lead-acid battery in terms of reliability and capacity is increasing the economics of the lead battery industry. For the short term, battery demand remains strong even with environmental challenges. On the other hand, alternate battery systems such as nickel-iron, nickel-cadmium, sodium-sulfur, lithium-sulfur, and conductive polymers (the so-called plastic batteries) are being intensely investigated. Currently, none of these systems can match both the reliability and capacity of the lead-acid system; however in the future, this research could lead to changes in battery applications that could have a negative impact on the demand for lead.

As shown in table 3, other nonbattery uses encompass a wide variety; however, total nonbattery usage has declined over 36% in the last 10 years, from 425 kmt in 1980 to 271 kmt in 1989 (fig. 3). Only two categories have shown significant growth in this period—ammunition and cable covering. Cable covering is used to protect both power and communication cables from corrosion. Most other categories have shown significant declines in usage

[5]Market economy countries producing lead and zinc include the following: Algeria, Argentina, Australia, Austria, Bolivia, Brazil, Burma, Canada, Chile, Finland, France, Germany, Greece, Honduras, India, Ireland, Italy, Japan, Rep. of Korea, Mexico, Morocco, Namibia, Norway, Peru, Portugal, Spain, Sweden, South Africa, Thailand, Turkey, Tunisia, the United States, Zaire, and Zambia.

[6]Non-market economy countires producing lead and zinc are defined to include the following: Bulgaria, China, Czechoslovakia, Poland, Romania, and the former U.S.S.R., as of January 1990, Vietnam and Yugoslavia (considered to be part of Western World productior and yet still not possessing a market economy).

The Eastern European nations of Bulgaria, Czechoslovakia, Germany D.R., Poland, and Romania are classified as non-MEC at the time of this analysis. However, political changes underway during the 1990's could result in a potentially higher percentage of production from these nations being available for future MEC trade. These countries contributed approximately 8% of world production in 1989.

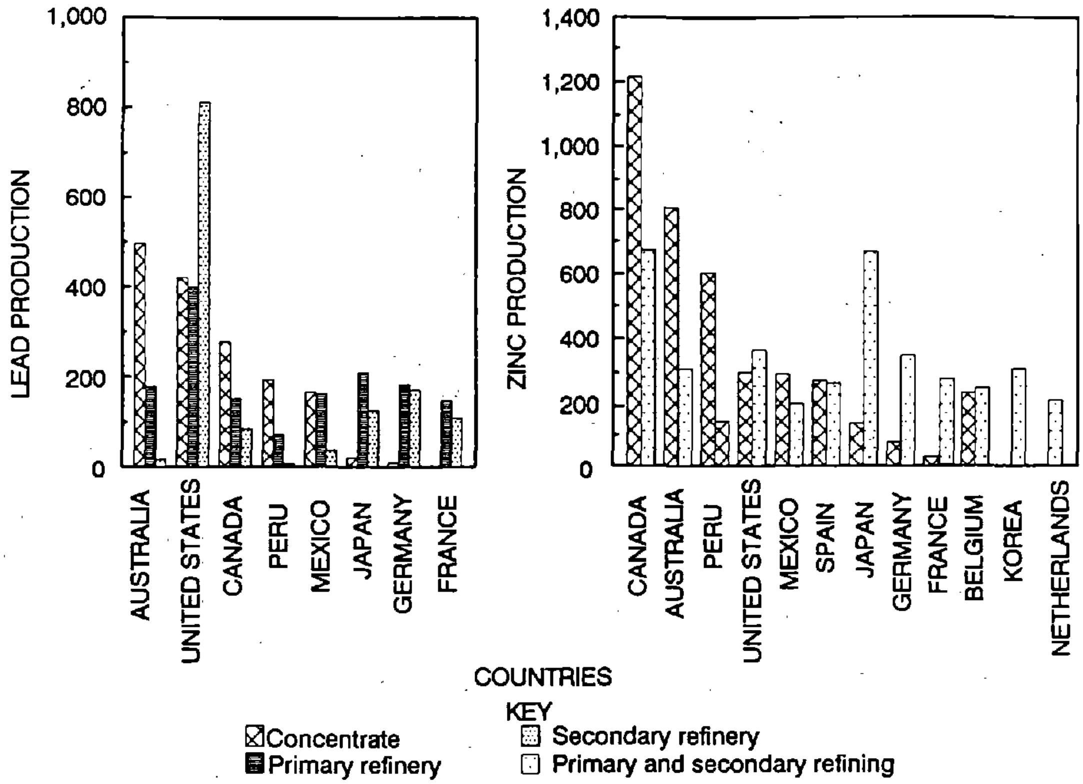

Figure 1.—MEC lead and zinc production by major country, 1989.

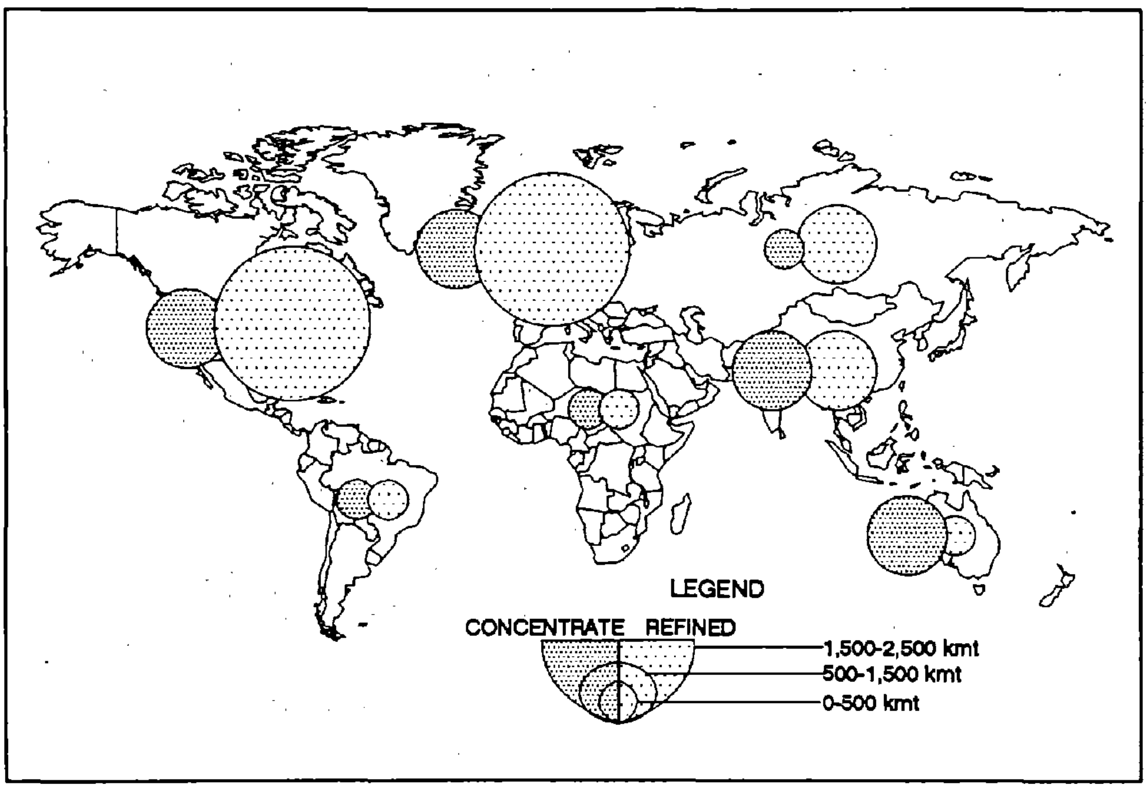

Figure 2.—World lead-concentrate and refined-lead production by region, 1989.

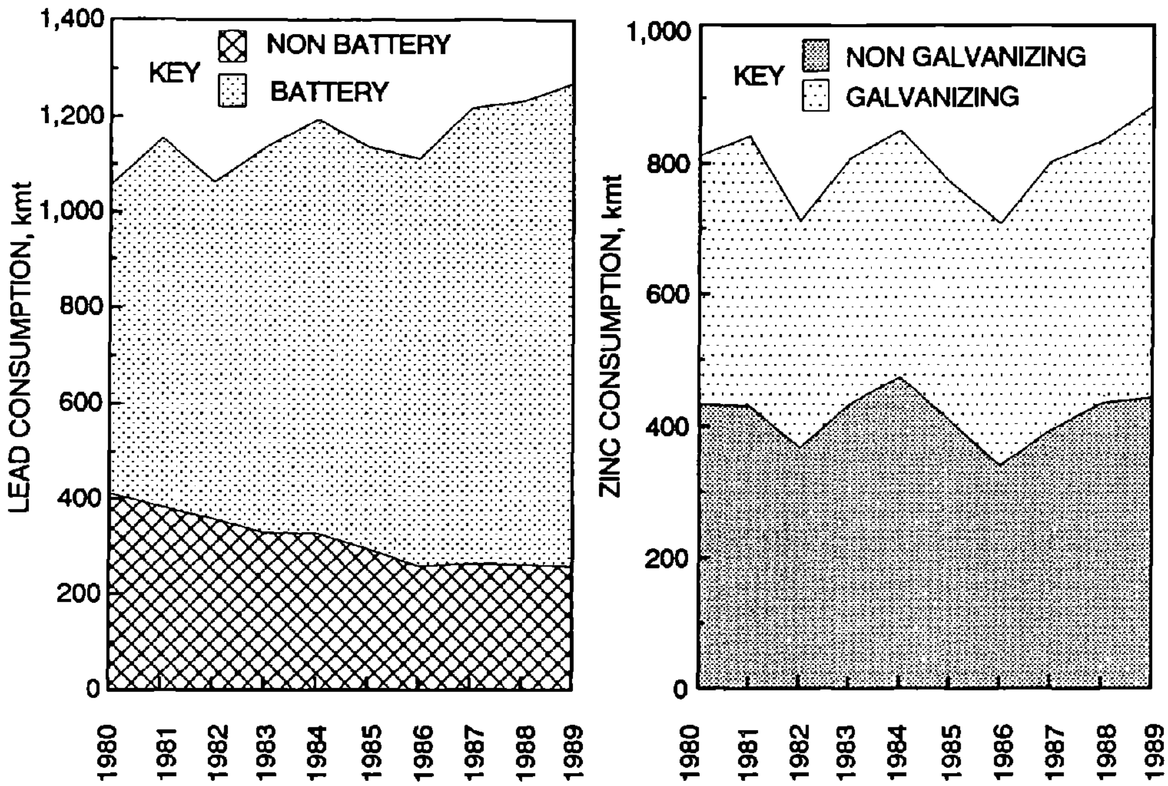

Figure 3.—U.S. consumption trends for lead and zinc.

in the last 10 years. The most significant declines have been environmentally related; the most dramatic has been the virtual elimination of lead as a gasoline additive. In 1980, gasoline additives consumed over 127 kmt of lead. By 1989, this consumption had been reduced to under 20 kmt. Usage in solder has shown a drop of almost 60% in the 10-year period due to the elimination of lead-based solder in potable water systems. Lead has also been eliminated as a pigment in residential paints.

U.S. Trade Patterns

In 1989, the United States exported 57 kmt of lead ores and concentrates to the major MEC's, shown in figure 4. Almost 6.1 kmt of wrought lead and lead alloys were exported to over 39 countries (*5*), while lead scrap was exported to over 28 countries.

Imports of lead ore and concentrates to the United States totaled 5.1 kmt, Peru being the largest supplier (55%) (see figure 4). Base bullion (crude lead containing silver, with or without gold) (*8*) was provided by three countries (6 kmt), Mexico being the largest supplier (93%). Canada, at 77%, was the largest supplier of pigs and bars to the United States, 11 other countries supplying much smaller amounts (total 118 kmt). Imports of reclaimed scrap (including ash and residues) came from two countries (0.8 kmt), with the most coming from Canada.

U.S. Environmental Issues

Lead and its oxides are highly toxic, dangerous substances and have been identified as such by the Environmental Protection Agency (EPA)(*5*). EPA's Lead Pollution Prevention Program is scheduled for acceleration in 1992. The main thrust of this program is a developing policy to minimize or eliminate exposure to lead and its compounds where warranted by medical evidence. Pollution prevention through source reduction, where feasible, is the main objective of the agency's lead strategy; i.e., reduced consumption.

Due to environmental hazards associated with the disposal of lead, many States are banning the disposal of batteries in landfills; as a result, recycling of lead batteries could increase. Battery lead is the largest source of scrap, accounting for about 85% of all scrap recycled.

ZINC

Although the zinc industry does not have the same constraints as the lead industry, those mines recovering byproduct or coproduct lead may face the same environmental problems. Some 86% of producing properties, and 59% of nonproducing properties evaluated as primary zinc, contain byproduct or coproduct lead.

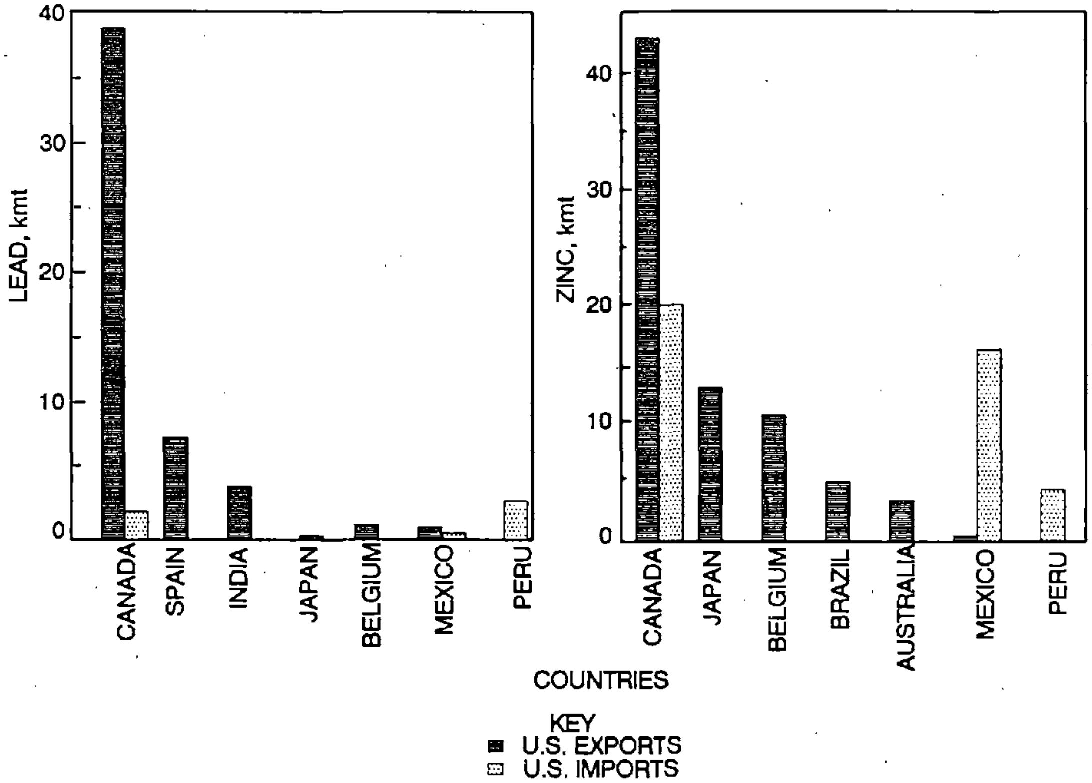

Figure 4.—U.S. lead- and zinc-concentrate exports and imports, 1989.

Uses

Zinc is used in a wide variety of products, usually in the form of coatings, die castings, brass products, or chemical compounds. Because there is no effective zinc substitute for corrosion protection on iron and steel, it is a necessary material to both the civilian and military populations. Zinc usually loses its identity as a solitary metal in the final product. The properties that make zinc an essential commodity include low melting point, high electrochemical activity, ease of alloy[7] formation, and ease of workability. Uses are shown in table 4. The most common use is in galvanizing where steel products are coated with zinc to protect against corrosion. Methods of applying the zinc coating include hot-dip galvanizing, continuous-line galvanizing, electrogalvanizing, zinc plating, zinc spraying, and painting with zinc-bearing paints (*8*). Zinc's physical properties, relatively low price, and high availability are its advantages over other materials considered for substitution.

[7]Alloying agents include copper, aluminum, and magnesium.

Production

In 1989, nearly 7.1 Mmt of primary zinc was mined in 50 countries in 7 production regions (*9*) (see figure 5). Of the total world production, 72% (5.1 Mmt) was produced by MEC's, and 28% by non-MEC's. The major MEC concentrate producers are shown in figure 1.

Primary and secondary refining took place in 36 countries in 7 major production regions in 1989 (also see figure 5). Production was split between MEC's (5.1 Mmt) and non-MEC's (2.1 Mmt). In 1989, the United States produced about 5% of the total primary and secondary metal production. The industry has grown over the last decade, primary and secondary metal production having increased worldwide from 6.5 Mmt in 1980 to 7.2 Mmt in 1989. Approximately 23% of total U.S. refined zinc in all forms was from secondary sources in 1980, and 26% was from secondary sources in 1990.

At least one primary zinc refinery (the Corpus Christi plant in Texas) has been converted into a processor of hazardous wastes. This conversion could be a sign of things to come, should environmental regulations become more severe and the economics of primary zinc smelting turn more costly.

Table 4.—Uses of zinc

- Galvanizing:
  - Sheet and strip.
  - Wire and wire rope.
  - Tube and pipe.
  - Tanks and containers.
  - Structural components.
  - Nails, bolts, and nets.
  - Fencing and netting.
  - Vehicle undercoating.
- Die-casting:
  - Automobile components.
  - Builders hardware.
  - Appliance parts.
  - Construction and builders hardware and tools.
  - Machinery parts.
- Brass and bronze components.
- Zinc-based chemicals:
  - Dyes and inks.
  - Paint pigments.
  - Rubber vulcanization.
  - Wood preservatives.
  - Fungicides.
  - Pharmaceuticals.
  - Electronics.
  - Oil additives.
  - Welding flux.
  - Gold leach recovery.

U.S. Consumption Trends

Between 1982 and 1989, U.S. apparent consumption[8] of slab zinc increased over 30%. Galvanizing utilized approximately 50% of all zinc consumed. In galvanizing, the majority of zinc is used in sheet and strips; this use has grown significantly in the last 4 years, and consumption by galvanizing uses has accelerated at a much higher rate than nongalvanizing uses (*10*) (fig. 3).

As long as new automobile models continue to be produced, the demand for zinc will continue to increase as more and more parts are being galvanized. This increase is limited by the fact that with time there would be fewer parts to coat and by the potential effect of the substitution of plastic and aluminum. Currently, the major application in galvanizing is in anticorrosion coatings; and this usage appears to be increasing since the major automobile manufacturers are increasing their anticorrosion warranties. The trend toward cars utilizing two-sided zinc or zinc alloy precoatings in 90% of the sheet-steel components may

[8]The U.S. Bureau of Mines data are based on apparent consumption that has been estimated from reported consumption. Apparent consumption is defined as production + imports - exports.

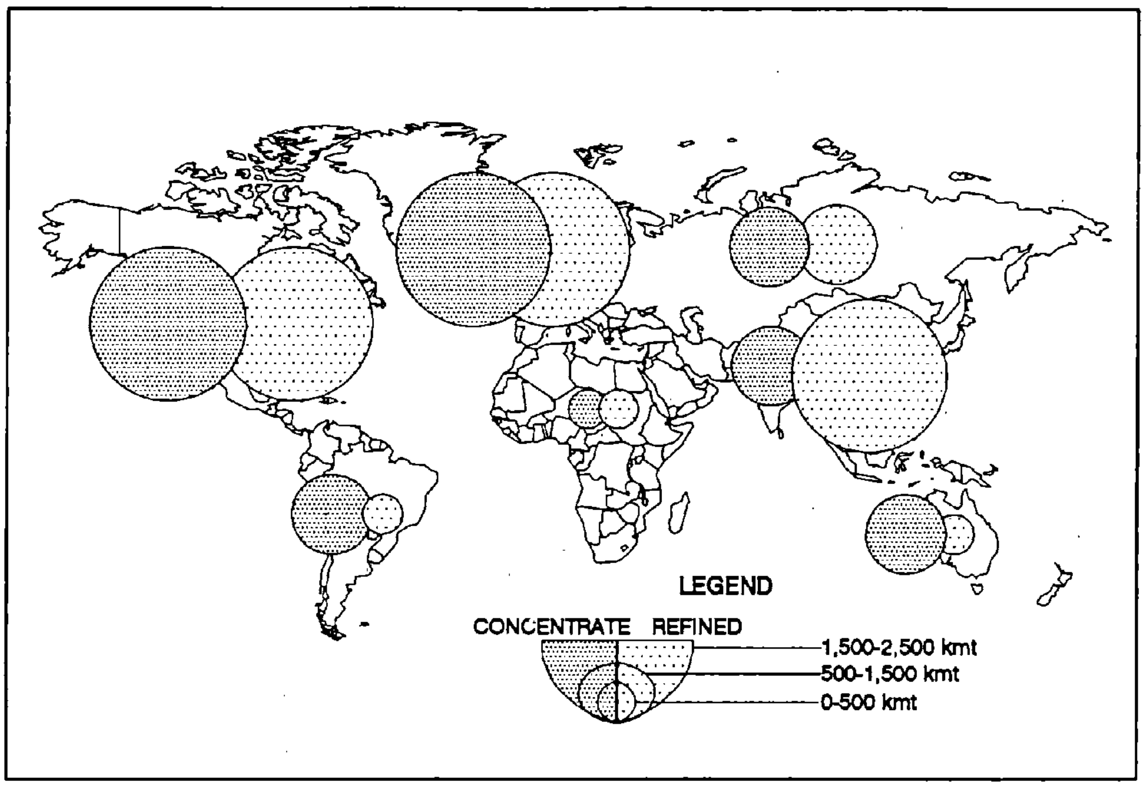

Figure 5.—World zinc-concentrate and refined-zinc production by region, 1989.

eventually change to increased use of hot-dip galvannealed steel as a replacement for both regular hot-dip galvanized and electrogalvanized in new cars and trucks in the middle 1990's. The cost effectiveness of hot-dip galvannealed steel could promote more demand for zinc (*11*). Thermal spraying could prove to be an advantage to the zinc industry as uses for wear resistance, dimensional restoration, corrosion resistance, and shielding should pick up in the near future. Thermal spraying can be defined as a family of coating systems in which any variety of molten materials propelled at sufficient velocity coat a substrate. Materials (used to coat a substrate) include zinc (used mainly on permanent structures like bridges), as well as all types and combinations of ceramics, carbides, plastics, and metals available in powder, wire, or rod form.

Several new technological methods could increase the short term demand for zinc but produce a long-term decrease in production. Zinc-nickel sheet may be utilized in a much higher volume since several Japanese manufacturers were reported to be looking into U.S. suppliers for their needs. Several Japanese firms have developed a zinc vapor deposition system that provides a uniform coating on steel strip. Increased accuracy of coating weight and time, as well as two-sided differential coating ability, are reported to reduce production costs between 20% and 30%. A new hot-dip line in the Netherlands is capable of differential two-sided coating using Galvalume (45% zinc, 55% aluminum). Galvalume is 4-5 times as corrosion resistant as zinc-only galvanized steel.

For nongalvanizing uses of zinc, approximately one-half of the zinc reported consumed is used in the manufacture of zinc-based alloys, primarily used in die-castings (*12*). The next largest use of zinc metal is in brass and bronze, followed by use in the production of zinc oxides. French-process zinc oxide production has almost tripled in the last 10 years due to the closure of Amer-process production facilities. Again, competition from plastics, aluminum, cast iron, and stainless steel in the nongalvanizing uses may impact the amount of zinc used at a future date. The use of zinc in automobile body parts may, at some future date, show a decrease in consumption due to the competition from molded plastics and a trend toward using thinner coatings or zinc alloys.

U.S. Trade Patterns

In 1989, the United States exported 79 kmt of zinc ores and concentrates to over 11 countries, 85% going to Canada, Japan, and Belgium (see figure 4) (*12*). In 1990, exported zinc concentrates are estimated to increase 3% due to the coming on-line of the Red Dog mine and mill. Unwrought zinc and zinc alloys (8 kmt) were exported to over 15 countries with Canada and the Federal Republic of Germany receiving 85%. Wrought zinc and zinc alloy totaling 19 kmt was exported to over 29 countries with Canada, the Federal Republic of Germany, India, and Taiwan receiving 89%.

Imports of zinc ores and concentrates in 1989 totaled 41 kmt (see figure 4). Blocks, pigs, or slabs were supplied by 23 countries (712 kmt); and 78% was supplied by Australia, Canada, Mexico, and Peru.

U.S. Environmental Issues

The Bevill Amendment (exclusion), as applied to solid waste from the extraction, beneficiation, and processing of ores and minerals, retains residues from primary zinc processing as the only zinc-related waste to be regulated under subtitle D of the Resource Conservation and Recovery Act (RCRA) (*12*). This regulation adds the extra burden of a hazardous waste problem to the zinc smelting industry.

Generally, more than 75% of zinc scrap recycling is from new scrap (recovered in the use or fabrication of zinc or zinc-containing materials). This has accounted for slightly over 30% of zinc reported consumed in the United States. Old scrap is recovered in the form of diecastings, steelmaking electric arc furnace (EAF) dusts (50%), and brass and bronze. The increasing use of galvanized steel in automobiles will indirectly lead to an increase in the supply of zinc-bearing EAF dust, as more galvanized automobile steel is recycled. Currently, several new technologies for reclaiming EAF dust using plasma furnaces are being utilized. Regulations have classified EAF dust (>15% Zn) as a hazardous waste, mandating treatment or recycling of >15% zinc EAF dust, and thus have forced a significant increase in the quantity of zinc that is recycled and recovered.

The three areas of lead-zinc mining classified as Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (Superfund) (*12*) sites are the Bunker Hill lead-zinc complex in Idaho, the tri-state district located in parts of Kansas, Missouri, and Oklahoma, and the Leadville-Yak Tunnel Area of Colorado. The Bunker Hill site has problems with contaminated soil and residues in a 21-square-mile area around the former smelter, near the town of Kellogg. In the tri-state district, EPA efforts focused mainly on specific areas to reduce heavy-metal contamination of surface and subsurface waters. About $6 million had been spent up until 1989 to clean up mining sites in the Tar Creek area of Oklahoma. Cleanup efforts involve revegetation, blocking surface water access (mine shafts), mining-operation residue burial, and redirecting surface streams around mineral areas by the recontouring of existing surfaces. The Yak Tunnel, originally developed to drain the mines of the Leadville district, was designated as a Superfund site in 1983 because drainage from the tunnel produces a toxic sludge containing lead, zinc, copper, and other heavy metals. Reclamation plans currently include construction of a surge pond, tunnel rehabilitation, construction of a filtration and/or water treatment plant, monitoring wells, and a tunnel plug (*13*). The total cost will probably be well over $25 million. Proposed plans for processing old dumps and tailings through the Black Cloud operation's mill have been complicated by the potential classification of these dumps as hazardous waste. The new OSHA cadmium Permissible Exposure Limit (PEL's) will also have an effect on U.S. zinc production as smelter-refineries will have to conform with new standards.

The Basel Convention Amendment, designed to ensure that imported waste and scrap are treated in an environmentally safe manner, is expected to be ratified by the U.S. Senate in 1993 (*12*). This regulation would ensure the proper transportation, treatment, and/or disposal by the importing country. The impact could be felt for future U.S. exports of scrap, waste, and residues. This convention could seriously affect exports to countries where environmental controls are not up to current U.S. standards.

METHODOLOGIES

To determine the potential availability and supply of lead and zinc, geologic and engineering data were collected and analyzed for the 205 evaluated mines and deposits. These data include the following: demonstrated resource estimates; actual or estimated mine and mill operating parameters, including future expansions and development plans when reported; and operating costs, taxes, and other pertinent expenditures. Capital expenditures for mining and processing facilities include the cost of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure includes the cost of access and haulage facilities, water facilities, power supply, and personnel accommodations.

Operating costs, estimated for mining, milling, and transportation, are a combination of direct and indirect costs. Direct operating costs include production and maintenance labor, operating supplies, utilities, and payroll overhead. Indirect operating costs include technical and clerical labor, administrative costs, facilities maintenance and supplies, and research. Other costs in the analysis include applicable fixed charges, such as local taxes, insurance, depreciation, deferred expenses, interest payments, and return on investment. Transportation charges either estimated or derived from actual data when available, include the in-country transportation cost required to ship concentrates to the smelter or port, and ocean freight charges for exported concentrates. Smelter-refinery charges were included in the total cost.

Material balances were estimated for each concentrate produced at the mill. Estimates were calculated of smelting and refining charges for each concentrate and the payfors (amount paid to the mine after accounting for the proper credits and deductions for applicable metals, table 5) associated with each commodity treated. For undeveloped deposits, future materials flows were estimated based on historical patterns of similar producers, and estimates of potential smelting and refining costs were made.

Table 5.—Smelter schedule developed for domestic and foreign lead, zinc, and copper concentrates

Concentrate	Domestic[1]					Foreign				
Recoverable metals	Deductions		Paid for	Smelter charge[2]	Refinery charge[2]	Deductions		Paid for	Smelter charge[2]	Refinery charge[2]
Zinc concentrate:										
Zinc	8.0	wt%	85%	240	0	8.0	wt%	85%	203	0
Gold	1.0	gm/mt	70%	0	192,900	1.0	gm/mt	70%	0	161,770
Silver	100.0	gm/mt	75%	0	9,650	103.0	gm/mt	75%	0	9,650
Lead concentrate:										
Lead	1.5	wt%	95%	105	265	3.0	wt%	95%	215	0
Gold	1.0	gm/mt	95%	0	192,900	1.0	gm/mt	90%	0	161,770
Silver	30.0	gm/mt	95%	0	9,867	50.0	gm/mt	95%	0	9,650
Copper concentrate:										
Copper	1.0	wt%	100%	90	220	1.0	wt%	100%	70	320
Gold	1.0	gm/mt	90%	0	192,900	1.0	gm/mt	95%	0	16,770
Silver	30.0	gm/mt	90%	0	9,867	30.0	gm/mt	95%	0	9,650

[1]Includes price participation agreements at $0.68/lb Zn.
[2]All charges are in $/mt metal.

For the purposes of this investigation, all mineral concentrates were treated as if they were shipped to custom smelter-refineries. The cost of smelting and refining includes the treatment charge for processing the concentrates and various deductions and payfors on the metal content of the concentrate. Prices for byproducts are given in figure 6, and typical treatment charges, deductions, and payfors are listed in table 5 for both domestic and foreign operations evaluated in this study. For a more detailed study of minor byproduct recoveries see Foster, 1991 (*14*).

To determine typical revenues generated by a concentrate, the grade deduction is first subtracted from the concentrate grade, and the result is multiplied by the payfor percent in decimal form. The resulting quantity is what the smelter will pay at the current market price minus the deduction. A price deduction, when necessary, covers any further cost to refine the commodity to a finished product. An example is given in table 6.

Working capital is a revolving cash fund required for such operating expenses as labor, supplies, taxes, and insurance. Working capital was estimated as 3 months of operating costs in developing countries and 2 months of operating costs in developed countries.

The costs used in this study were collected or developed using various methodologies. Most costs were developed from January 1986-88 data and based on January 1988 resource estimates. Operating parameters and cost data for producing U.S. operations were collected by the Bureau's Field Operations Centers located in Denver, CO, Spokane, WA, and Juneau, AK. Engineering cost estimates for foreign properties were developed by personnel at the Bureau's Minerals Availability Field Office, based on data collected from a number of sources, company annual reports, published articles and reports, purchased private reports, site visits, engineering evaluations, government contacts, and personal correspondence with companies. A number of significant lead-zinc mines and properties were visited and evaluated by Pincock, Allen & Holt, Inc., under Bureau contract No. J0267002.

Deposits evaluated for lead and zinc usually contain anywhere from one to five different metals. Most commonly, lead and/or zinc is found in combination with silver, copper, or gold. Other metals and industrial minerals associated with lead and zinc that are not so common are as follows: barite, fluorspar, limestone, pyrite, tin, and tungsten. Minor amounts of cadmium, germanium, gallium, indium, and thallium are also found in some deposits. Those operations that had or would have greater than 50% of their revenues generated by lead or zinc are considered primary lead and zinc. Certain properties were not included in the final cost analysis because of high byproduct credits, exceeding all costs of mining, milling, and further processing.

Given the trend in recent years of the price volatility of these metals (fig. 6), it becomes apparent that the profitability of a lead-zinc mine is as much dependent on its byproducts as the primary product. Of producing mines evaluated as primary lead properties, 15 out of 16 had some associated byproducts (table 1). A large portion of lead (79%) is produced from polymetallic sulfide deposits, which are considered as primary zinc in this study.

Revenues for primary lead properties show that most of the revenue came from lead. However, some properties show that byproduct credits are so large that all of the costs of mining and processing the lead is paid for by the byproducts themselves. The amount of byproduct revenue attached to these lead properties points out that even though most revenues are attributed to lead, anywhere from 14% to 66% of the total revenue of the mining venture was attributable to its byproducts. When weighted-average byproduct percentages were analyzed for these deposits, the largest amount came from zinc (fig. 7).

Table 6.—Smelter payment schedules per metric ton of lead concentrate versus contained metal values

	(A) Grade of concentrate, %	(B) Smelter adjustment factor on grade, %	(C) Recovery factor, %	(D) Price		((A-B)*C*D)[1] Total ($/mt)
				Per pound	Per mt	
Smelter schedule:						
Lead	75	1.50	95	$0.40	$882	$615.74
Silver	0.126	1.003	95	$81.65	$179,998	+210.33
Total paid for metals to mine						$826.19
Less treatment charge						-106.51
Total paid to mine from smelter						$719.68
Contained metal value:						
Lead	75	0.00	100	$0.40	$882	$661.50
Silver	0.126	0.00	100	$81.65	$179,998	+226.80
Contained metal value						$888.30
Total paid to mine from smelter						-719.68
						$168.62

[1]Except treatment charge, which is given.

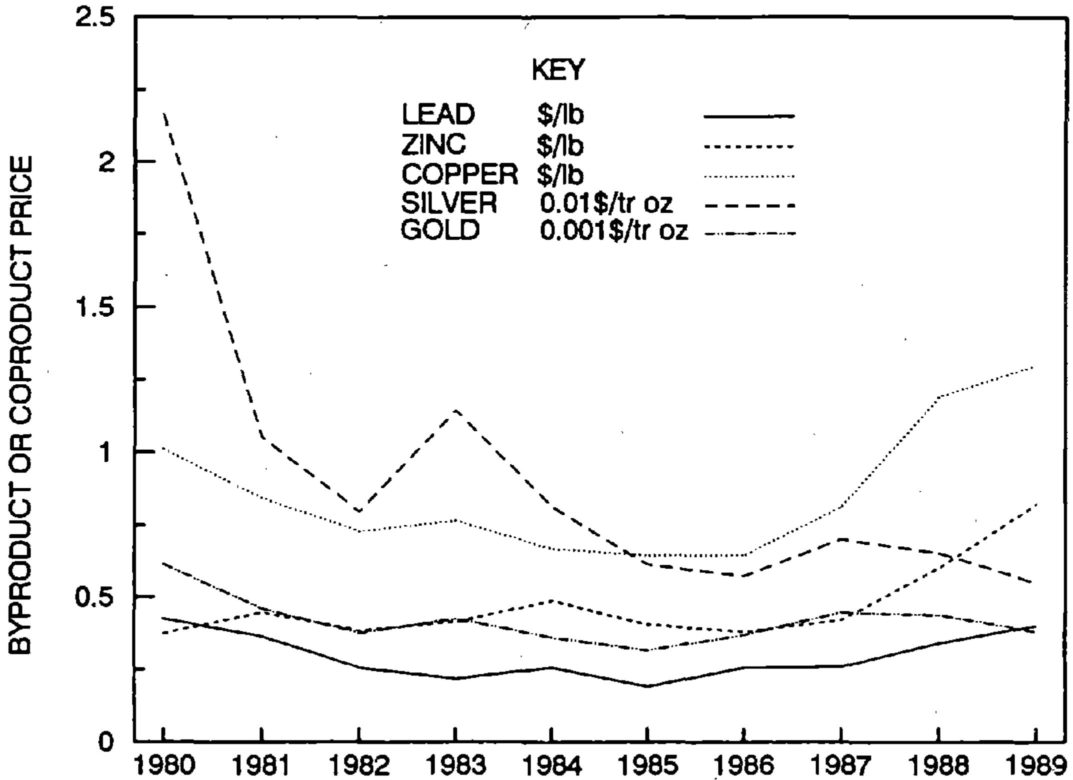

Figure 6.—Byproduct or coproduct prices for lead and zinc.

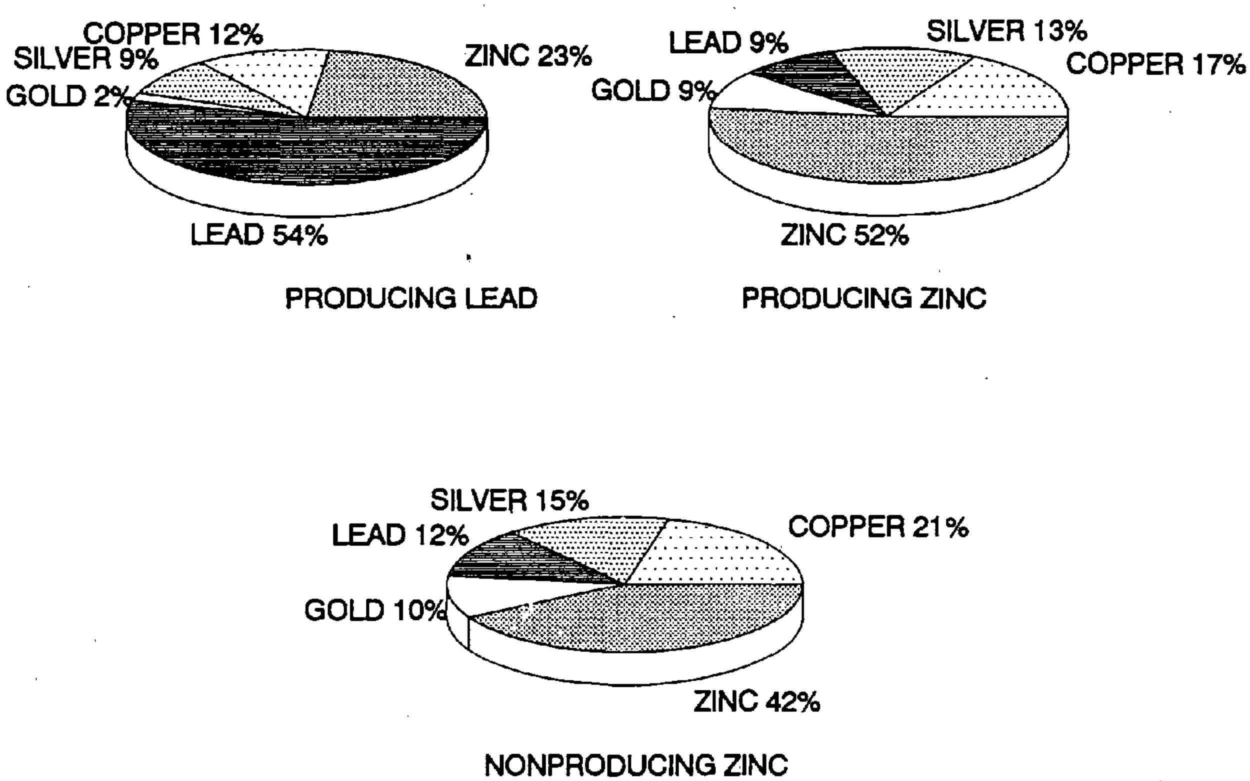

Figure 7.—Percentage of revenues for representative lead and zinc properties in the MEC's.

Out of the 129 primary zinc properties that were in production during 1989 (table 2), only 11 recovered zinc without any major byproducts. Weighted-average byproduct revenues from selected properties are shown on figure 7. Of the 59 nonproducing deposits evaluated, 19 deposits occurred with zinc and some minor byproducts, while the rest had major byproduct associations.

After production parameters and cost estimates were determined for each mining operation and deposit, all of the operating data were entered into the Supply Analysis Model (SAM). The Bureau developed the SAM to perform discounted-cash-flow rate-of-return (DCFROR) analyses to determine the long-run constant dollar price at which the primary commodity must be sold (f.o.b. smelter and/or refinery) to recover all costs of production (not covered by byproduct credits), including a prespecified return on all investments. The DCFROR is commonly defined as the rate of return that makes the present worth of cash-flow from an investment equal the present worth of all aftertax investments (*15*). For this study, a 15% DCFROR was considered the necessary rate of return to provide the incentive to develop a mineral property or to continue producing over the long run. The value for the primary commodity price is equivalent to the average long-run total cost of production for the operation over its producing life under a set of conditions (e.g., mine plan, full-capacity production, and a market for all output) necessary to perform a full economic evaluation.

A DCFROR analysis for each operation was also performed at a 0% rate of return, and both sets of results were analyzed in the costs section. Prices used for byproducts ($0.60/lb Zn; $0.30/lb Pb; $1.00/lb Cu; $5.40/tr oz Ag; $381.20/tr oz Au) were assumed to be the average 1989 market rate modified by long-term price factors. Revenues received for byproducts are credited against the cost of production. The costs and resources were then updated to the January 1990 study date.

The analyses used the Bureau's International Mining Cost Indexation System to update costs to January 1990 U.S. dollar terms. The index system includes updating factors for 12 separate components of mining and milling costs (e.g., mining labor, mining equipment, diesel fuel, steel, and chemicals, etc.) for foreign countries and for 14 factors in the United States. The index values for each component in each country take account of whether the expenditure is in local or foreign currency and what the traditional sources are for needed imports, such as equipment and certain operating and maintenance supplies. A time series of exchange rates is used to translate the cost index values developed in local currencies into values expressed in U.S. dollars. A separate tax records file, maintained for each particular State or country, contains the relevant tax parameters under which a mining firm would operate. Tax parameters include corporate income taxes, property taxes, royalties, severance taxes, or other taxes that pertain to the production of lead and zinc. Deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax-loss carry forwards are also included in the analysis. These tax parameters are applied to each mineral deposit under evaluation, under the assumption that each deposit represents a separate corporate entity.

Upon completion of the individual property analyses, the results for all 205 properties included in the study were aggregated as potential total resource availability curves. These curves show the total amount of material available at any given cost at both 0% and 15% DCFROR for producing properties and 15% DCFROR for nonproducing properties (since it is felt that most nonproducers would need to show a 15% ROR before major investments begin). The 1989 availability curves show the amount of commodity available in 1989 at both the operating cost level (the costs an operation must cover to remain producing) and with a 0% DCFROR. Potential annual availability curves illustrate the amount that is available at selected prices for the period from 1989 to 1994 at a 15% DCFROR because it was assumed that over the long run all costs of production must be recovered, including a 15% DCFROR. It is doubtful that the demonstrated resources of these producing mines will decline at the rates indicated by some of the curves. As has been noted, " ... it is generally true that deposits of lead and zinc do not lend themselves to easy or rapid delineation of large tonnages of ores. The reserves in a deposit or group of deposits are proved progressively over a period of years. In this respect there is a marked analogy between reserves of zinc and proved reserves of petroleum and natural gas" (*16*). Many of the lead and zinc operators report their demonstrated resources for only a few years ahead of their current mining position and increase or maintain their reserves as mining continues. Also, in many cases, demonstrated resources are increased each year as a result of ongoing exploration programs. This gradual expansion is due in the most part to the highly complicated geology (see the appendix) and the tax advantages, since only defined reserves are taxed. Therefore, there is a high probability that additional resources exist that will allow most of the currently producing mines to continue beyond the time frame of reported resources.

Environmental issues associated with the lead and zinc industry were not analyzed but were summarized to point out the serious effects that past, present, and future legislation have had or will have on the industries. Present and future legislation, especially in the United States, could shift total and annual supply curves for lead and possibly even zinc up to a point where much of the currently available lead at competitive prices would shift upward on the curve and become marginally or totally uneconomic. This trend could be caused by serious delays in new lead-producing mine startups as well as lead smelter and refinery shutdowns.

RESOURCES

Demonstrated resources of contained lead were estimated to be approximately 60 Mmt (table 7) for the properties evaluated which contain lead. Seventeen properties were designated as primary lead, while 147 had lead as a byproduct or coproduct. Five countries accounted for just over 75% of MEC lead-contained resources: the United States (25%), Australia (24%), Canada (18%), Peru (5%), and the Republic of South Africa (5%).

Demonstrated resources of contained zinc are estimated to be 166 Mmt for the properties evaluated (table 7). Six countries account for just over 75% of MEC contained resources: the United States (29%), Canada (19%), Australia (14%), India (6%), the Republic of South Africa (4%), and Peru (4%). The distribution of contained lead and zinc demonstrated resources evaluated in this study is shown in figure 8.

Table 7.—Summary of MEC demonstrated lead and zinc resources as of January 1989

Country	Lead			Zinc		
	Demonstrated resources (in situ), kmt	Grade, %	Contained resources, kmt	Demonstrated resources, kmt	Grade, %	Contained resources, kmt
Algeria	3,580	1.20	43	3,580	5.00	179
Argentina	2,975	5.60	167	2,975	7.30	217
Australia	231,750	5.91	14,146	258,809	8.72	22,278
Austria	6,415	.50	18	6,415	6.50	238
Bolivia	3,024	3.39	139	3,024	7.77	266
Brazil	13,043	2.10	232	21,638	11.74	2,337
Burma	1,600	5.00	79	1,600	4.00	64
Canada	394,386	2.64	11,033	454,948	6.62	30,689
Chile	...	...	...	3,000	8.00	402
Finland	3,350	.40	17	16,450	2.70	475
France	11,545	1.03	111	11,545	6.75	856
Great Britain	4,800	3.00	143	4,800	6.00	288
Greece	18,420	3.18	679	18,420	4.07	875
Honduras	4,159	4.00	165	4,159	8.00	333
India	100,627	1.96	1,847	100,627	9.21	8,504
Ireland	26,784	1.91	517	26,784	7.79	2,027
Italy	31,868	1.18	331	31,868	11.83	2,988
Japan	52,498	.92	490	52,498	5.24	2,781
Korea, Republic of	10,000	3.10	317	10,000	6.20	644
Mexico	177,123	1.01	290	177,123	2.69	4,742
Morocco	17,119	4.48	4,391	14,743	7.93	2,358
Namibia	6,242	2.92	760	6,242	2.60	1,093
Norway	2,377	2.40	57	2,377	4.20	100
Peru	77,331	3.29	2,601	77,331	7.44	5,937
Portugal	133,376	1.30	1,211	133,376	3.60	3,360
South Africa	187,530	1.06	2,381	187,530	2.25	10,997
Spain	157,955	1.11	1,394	157,955	3.45	4,346
Sweden	57,077	1.88	1,092	57,077	5.59	3,278
Thailand	...	...	...	3,345	27.85	998
Tunisia	5,443	3.00	163	5,443	12.00	647
Turkey	630	1.20	7	25,630	8.30	2,158
United States	523,412	2.66	13,452	1,054,940	4.30	46,667
West Germany	12,229	1.30	165	12,229	6.53	865
Zaire	...	...	...	11,850	6.55	776
Zambia	1,700	11.10	187	1,700	22.70	382
Total or average	2,280,368	2.45	59,582	2,962,031	5.34	166,146

NOTE.—Data may not add to totals shown because of independent rounding. Leaders (. . .) indicate no production.

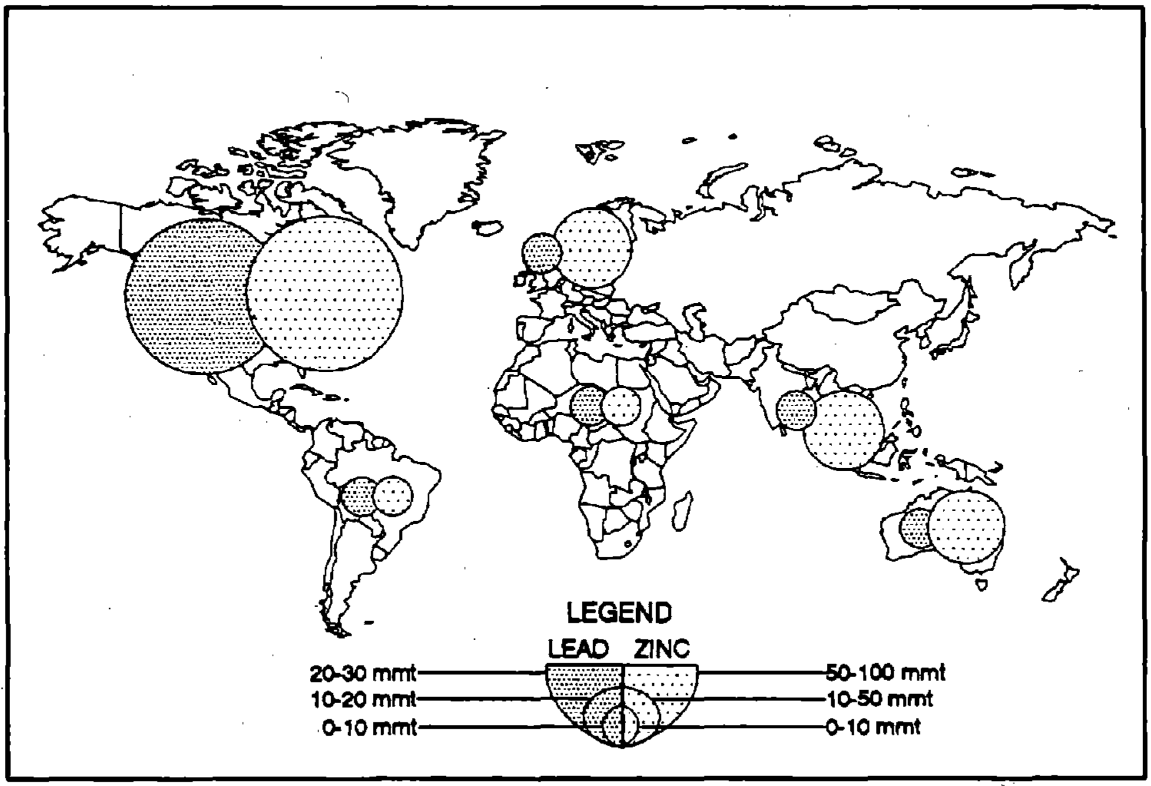

Figure 8.—MEC demonstrated resource distribution by region, 1989.

COSTS

The costs presented in this section are in constant January 1990 U.S. dollars, and average costs are determined over the remaining life of each operation based on current technology. Technological or other productivity improvements as well as environmental constraints are not considered here but could affect the future costs of these operations.

LEAD

Table 8 and figure 9 compare costs/lb of lead for primary lead operations. Properties in the United States had lower net operating costs because U.S. operations benefit from lower mine operating costs and lower transportation costs. This lower cost is a result of highly productive large room-and-pillar methods used in the Missouri lead mines versus a number of small cut-and-fill operations in the other countries studied. Transportation costs are also lower for U.S. operations because producers in other countries export more of their concentrate over longer distances, and many U.S. producers are vertically integrated. Byproduct credits in the MEC's were higher than for the U.S. producers because of higher concentrations of silver and other byproducts and coproducts in the ores. The lower capital recovery, mine operating costs, and mill operating costs found in the U.S. operations are more than enough to offset the larger byproduct credits in the MEC's. Therefore, total production costs at a 15% DCFROR were estimated to be $0.27/lb for U.S. producers, while international producers averaged $0.14/lb more at $0.41/lb.

ZINC

Table 9 and figure 9 illustrate estimated total production costs per pound of zinc for producing and nonproducing primary zinc operations. The relatively high cost of underground mining and milling in Mexico and Peru is due to the complex nature of the deposits and small capacities of the mines. Mill operating costs vary depending upon the zinc grade and the complexity of the ore. A complex ore would require the flotation of several different concentrates and subsequently incur a greater mill operating cost.

For producing operations, the average cost to refine zinc (including the cost of smelting and refining byproducts) varies considerably. Actual refining costs of zinc do not vary appreciably among countries, but other costs, including the smelting and refining of lead and other byproduct commodities, can vary considerably. This wide range results from differences in the number of byproducts and byproduct grades, which results in additional refining charges. The operations with high costs in the smelter-refinery category usually recover much or all of the added cost in the form of byproduct credits.

Total zinc production costs at a 15% DCFROR were estimated to range from $0.48/lb in Australia to $0.78/lb in Peru. Peru was the highest cost producer, while the continents of Africa and Australia were the lowest. Generally, countries that produced complex ore with high zinc grades tended to be the low-cost producers, while areas that produced simple ores with relatively few byproducts and relatively low zinc grades tended to be the highest.

Table 8.—Lead production costs for selected[1] operations in the United States and other MEC's[2]

(All costs are in January 1990 U.S. dollars per pound recoverable lead on a weighted-average basis)

Country	Operating costs		Smelting-refining	Transportation	Less byproduct credits	Net operative cost[3]	Recovery of capital[4]	0% DCFROR		15% DCFROR		
	Mine	Mill						Taxes and royalties[5]	Total cost[6]	Taxes and royalties[7]	Return on investment[8]	Total cost[9]
United States	0.08	0.03	0.21	0.01	0.11	0.22	0.03	0.01	0.26	0.01	0.01	0.27
Other MEC's	.27	.07	.20	.12	.34	.32	.04	.03	.39	.04	.01	.41
Total or average	.17	.05	.21	.07	.22	.28	.03	.02	.33	.02	.01	.34

[1]Properties with high byproduct or coproduct revenues were excluded from this table. In these selected cases, the byproduct revenues exceeded the cost of producing the lead.
[2]Includes all byproduct revenue credits for the operation.
[3]Includes Brazil, Mexico, Morocco, Namibia, South Africa, and Sweden.
[4]Includes cost of recovering remaining undepreciated investments in exploration, acquisition, development, mine and mill plant and equipment, and infrastructure, and reinvestments required over the life of the operation.
[5]Includes property, State, Federal, and severance taxes, and royalties, where applicable, calculated at a 0% DCFROR.
[6]Equal to the sum of net operating costs, taxation, and capital recovery determined at a 0% DCFROR.
[7]Includes property, State, Federal, and severance taxes, and royalties, where applicable, calculated at a 15% DCFROR.
[8]The revenue increase per pound necessary to obtain a 15% DCFROR.
[9]Equal to the sum of net operating costs, taxation generated at a 15% DCFROR, capital recovery, plus the return on investment.

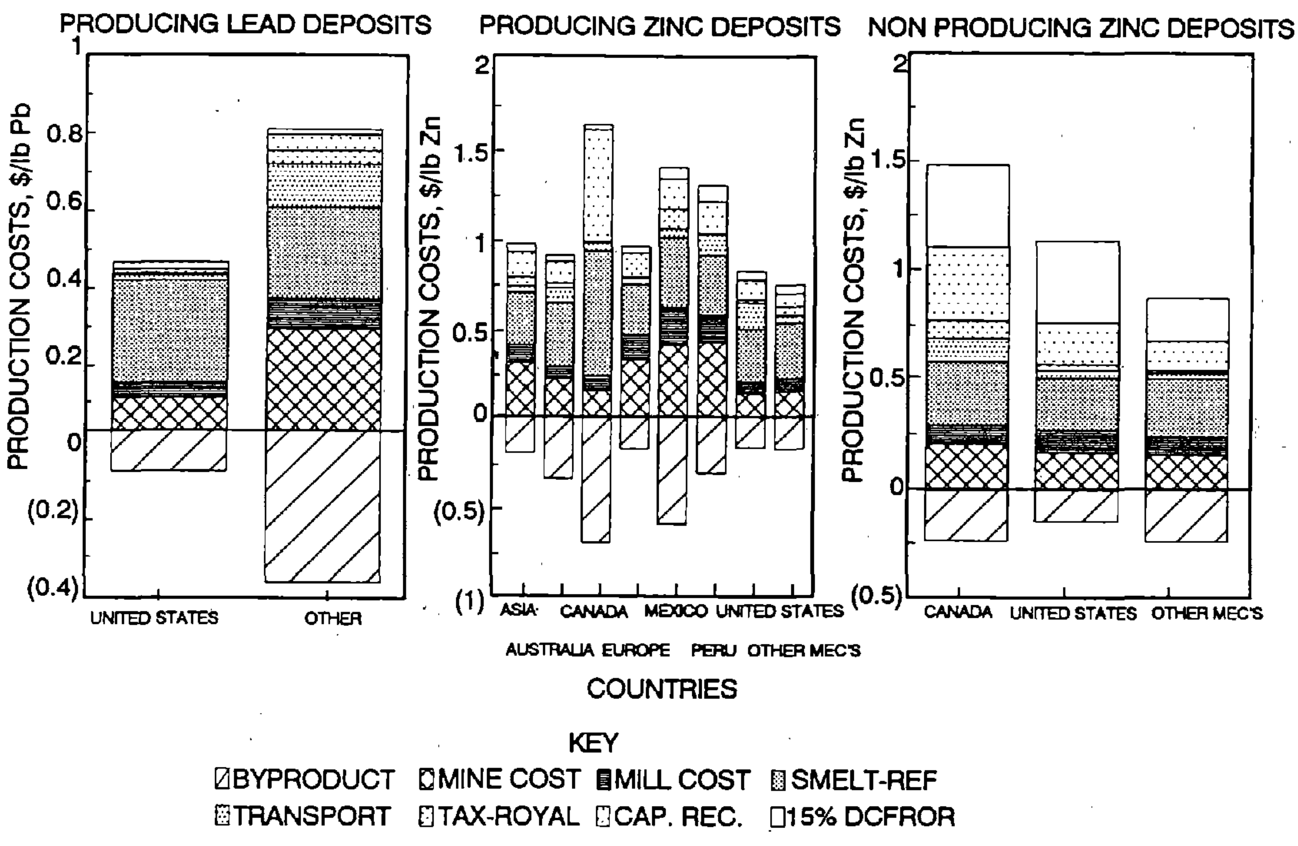

Figure 9.—Production costs in the United States and other MEC's, 1990.

Table 9.—Zinc production costs for selected[1] operations in the United States and other MEC's

(All costs are in January 1990 U.S. dollars per pound recoverable zinc on a weighted-average basis)

Region/Country	No. mines	Operating costs		Smelting-refining	Trans-portation	Less byproduct credits	Net operating costs[2]	Recovery of capital[3]	0% DCFROR		15% DCFROR		
		Mine	Mill						Taxes and royalties[4]	Total cost[5]	Taxes and royalties[6]	Return on investment[7]	Total cost[8]
PRODUCERS													
Asia	13	0.25	0.08	0.24	0.03	0.17	0.43	0.12	0.04	0.59	0.09	0.04	0.68
Australia	14	.17	.06	.30	.07	.29	.31	.10	.02	.43	.04	.03	.48
Canada	13	.12	.07	.58	.04	.60	.21	.52	.01	.74	.01	.02	.76
Europe	24	.26	.11	.23	.03	.16	.47	.11	.01	.59	.02	.03	.66
Mexico	11	.33	.18	.33	.04	.51	.37	.11	.09	.57	.12	.05	.65
Peru	16	.35	.12	.28	.10	.27	.58	.15	.01	.74	.02	.03	.78
United States	14	.11	.06	.25	.12	.15	.39	.09	.02	.50	.05	.08	.61
Other	12	.11	.06	.26	.04	.15	.32	.06	.04	.42	.06	.04	.48
Total or average	117	.18	.08	.32	.07	.28	.37	.18	.02	.57	.04	.04	.63
NONPRODUCERS													
Canada	12	0.21	0.09	0.29	0.11	0.23	0.47	0.34	0.08	0.89	0.26	0.37	1.43
United States	30	.17	.11	.23	.04	.14	.41	.19	.03	.63	.14	.37	1.11
Other	12	.17	.08	.26	.03	.23	.31	.13	.01	.45	.15	.19	.78
Total or average	54	.18	.10	.25	.05	.19	.39	.20	.03	.62	.17	.32	1.08

[1]Properties with high byproduct or coproduct revenues were excluded from this table. In these selected cases, the byproduct revenues exceeded the cost of producing the lead.

[2]Includes all byproduct revenue credits for the operation.

[3]Includes cost of recovering remaining undepreciated investments in exploration, acquisition, development, mine and mill plant and equipment, and infrastructure, and reinvestments required over the life of the operation.

[4]Includes property, State, Federal, and severance taxes, and royalties, where applicable, calculated at a 0% DCFROR.

[5]Equal to the sum of net operating costs, taxation, and capital recovery determined at a 0% DCFROR.

[6]Includes property, State, Federal, and severance taxes, and royalties, where applicable, calculated at a 15% DCFROR.

[7]The revenue increase per pound necessary to obtain a 15% DCFROR.

[8]Equal to the sum of net operating costs, taxation generated at a 15% DCFROR, capital recovery, plus the return on investment.

ENVIRONMENTAL COSTS

Additional environmental regulatory costs to domestic primary lead mines, mills, smelters, and refineries were discussed in Bureau OFR 55-88 (*18*). This report states that regulatory compliance costs have significantly added to the capital and operating costs for the domestic lead industry. From 1970 to 1985 the primary lead industry spent about $221 million (1987 dollars) on pollution control measures. The regulatory compliance operating cost (1987 compliance level) for the primary industry was $0.025/lb lead, while the secondary industry averaged $0.03/lb lead in 1987. At the time of the study, both primary and secondary smelters were not in full compliance with existing regulations. If the proposed stricter regulations had been imposed, the primary smelters would have been forced to close. The secondary industry could have complied after investing about $87 million and experiencing an operating cost increase of $0.038/lb lead.

NOMINAL VERSUS REAL COSTS

Cost comparisons for lead and zinc over time between countries are complicated due to each country's relative competitiveness and costs (in U.S. dollar terms) and are significantly influenced by differing rates of inflation and fluctuating foreign exchange rates. The major countries producing lead and zinc have experienced widely different rates of inflation during the past decade. To compare the international competitive advantages of certain countries, both the nominal costs (without inflation) and real costs (with inflation) were analyzed and compared. Reductions in nominal cash operating costs include the combined effect of inflation differentials and devaluation of local currencies relative to the U.S. dollar (the currency in which lead and zinc prices are denominated). Real cash operating costs expressed in January 1990 dollars were determined by converting estimated average nominal cash costs for operations as of 1981 and 1990 and adjusting for inflation based on the consumer exchange rates up to January 1990. The United States, Canada, and Australia had cumulative inflation from January 1981 to January 1990 of 50.39%, 69.8%, and 102.03% (*19*), respectively. Over the same period, foreign currencies were devalued against the U.S. dollar at extremely different rates. The Australian dollar was devalued against the U.S. dollar at 44%, while the Canadian dollar appreciated 1.3% over the same period. No adjustments were made for byproduct credits.

Nominal cost changes for lead production in the United States and zinc production for the United States, Canada, and Australia in January 1981 and January 1990 dollars are shown in table 10. For primary lead mines, the United States experienced a slight decrease in nominal costs.

Nominal average zinc production costs for two of the countries shown in the table, the United States and Australia, declined between 1981 and 1990. Canada experienced increases in these same operating costs.

Nominal cash operating cost reductions reflect the inflation and exchange rate situation relative to the U.S. dollar (the denomination of lead and zinc valuation) at the time of analysis. Real cash operating costs expressed in January 1990 dollars were calculated to remove the inflation and exchange rate effect. An estimation of real cash costs in January 1990 dollars was accomplished by converting estimated average nominal cash costs for operations as of 1981 and adjusting for inflation (based on the consumer price index) and exchange rates up through January 1990. Byproduct credits were not deducted in the real cost analysis. Real average cash operating costs for the three selected countries as of January 1981 and 1990, expressed in January 1990 dollars, appear in table 10.

Table 10.—Nominal and real cash operating costs in 1981 and 1990 for producing primary lead and primary zinc mines in selected MEC's

	Primary lead	Primary zinc		
	United States	United States	Australia	Canada
Recoverable metal, 10^3 mt:				
1981	446	312	508	1,097
1990	402	566	1,116	1,144
Nominal cash cost,[1] U.S. $/lb:				
1981	0.34	0.65	0.61	0.61
1990	0.33	0.53	0.60	0.81
Real cash cost,[2] (1990 U.S. $/lb):				
1981	0.51	0.98	0.86	1.026
1990	0.33	0.53	0.60	0.81

[1]Cash operating costs are the sum of mining, milling, smelting, refining, and transportation costs in U.S. $/lb lead or zinc. They do not include depreciation, interest, profit, or taxes. Byproduct credits have not been deducted.

[2]Real cash costs expressed in 1990 U.S. dollars = nominal cash costs for operations as of 1981 and 1990 and adjusted for inflation and exchanges to January 1990; byproduct credits have not been deducted.

In January 1990 dollar terms, United States primary lead operations experienced significant decreases in real average operating costs between 1981 and 1990.

U.S., Australian, and Canadian primary zinc mines also experienced reductions in real operating costs, in that order. The large real cost reductions in the United States and Australia and the more moderate decreases in Canada demonstrate the degree that cost-reducing measures may have been masked by offsetting exchange rate and inflationary movements.

In real terms, lead and zinc producers in the United States had a large amount of success in lowering weighted average cash costs, with a decrease of 35.46% and 46.1%, respectively, (see figure 10). Canadian and Australian zinc

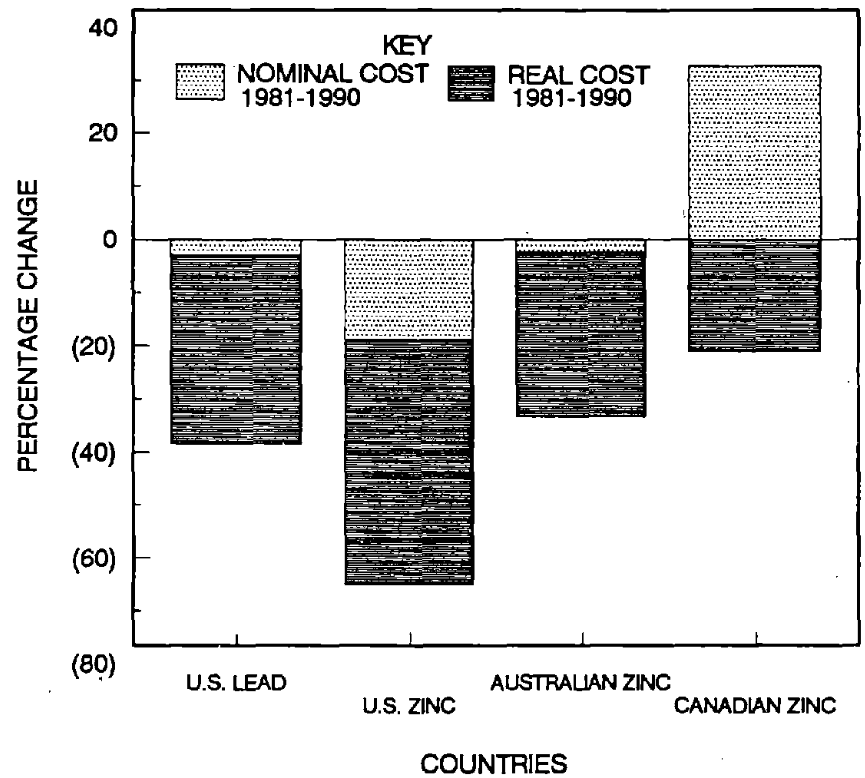

Figure 10.—Percentage change for nominal and real costs, 1981-1990.

producers lowered their average cash operating costs 30.2% and 21.1%, respectively. This reduction was probably because of cost-cutting procedures in labor, more efficient equipment, and less recovery of capital due to already emplaced capital.

AVAILABILITY

TOTAL RECOVERABLE LEAD AND ZINC

The tonnage of recoverable lead potentially available from the selected producing mines and nonproducing deposits analyzed in MEC's for primary and byproduct lead is shown in figure 11. For operating mines, the lower level reflects breakeven costs (where all costs are covered) at a 0% DCFROR, and the upper level includes a 15% DCFROR. A total of 12.7 Mmt of recoverable lead is potentially available from the demonstrated resources of the 16 producing MEC deposits evaluated as primary lead properties. At a cost of $0.40/lb lead (January 1990 U.S. price), for both 0% and 15% DCFROR levels, 9.2 Mmt of recoverable lead would be available.

Approximately 34.7 Mmt of byproduct lead is potentially recoverable from 147 of the 188 selected mines and deposits (both producers and nonproducers) evaluated as primary zinc deposits at prices up to $5.22/lb zinc. At 0% and 15% DCFROR, 23.2 and 21.7 Mmt of recoverable lead, respectively, are available from primary zinc producers at the U.S. high-grade zinc producer price of $0.80/lb (fig. 11).

The tonnage of potentially recoverable zinc from evaluated producing primary zinc mines is shown in figure 12. For producing mines the lower level reflects breakeven costs at 0% DCFROR and the upper level includes 15% DCFROR. A total of 127.3 Mmt of zinc is potentially recoverable from the demonstrated resources of the primary zinc properties. Of the total, 64% is from mines that were producing in 1989.

At 0% and 15% DCFROR levels, respectively, a total of 68.4 and 65 Mmt of recoverable zinc is available under $0.80/lb (the January 1990 U.S. high-grade metal price), and 16.4 Mmt is available at 15% DCFROR for nonproducers. From 14 of the 15 properties evaluated as primary lead deposits, approximately 3.2 Mmt of recoverable zinc was potentially available.

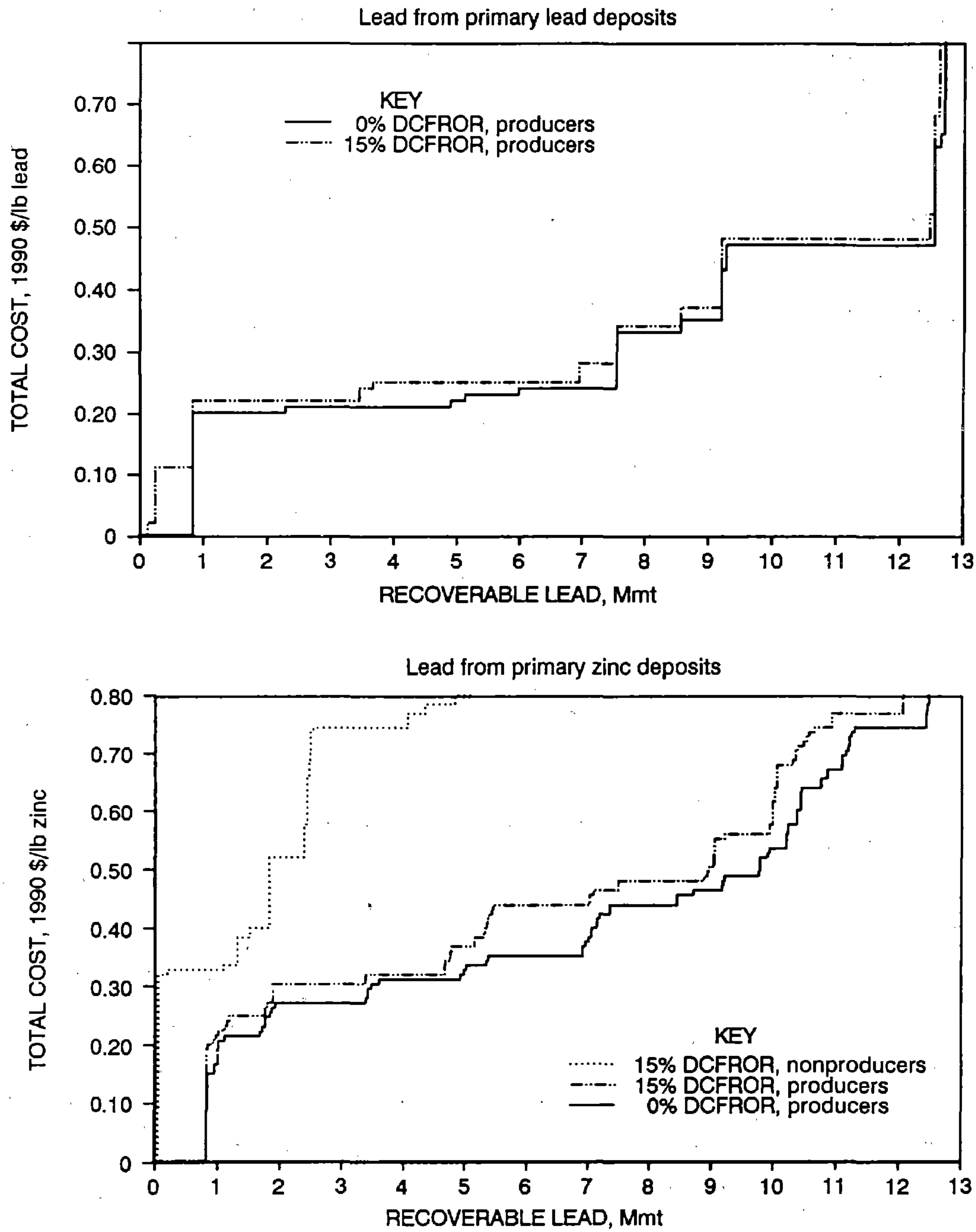

Figure 11.—Potential total lead available from primary lead and zinc operations in MEC's.

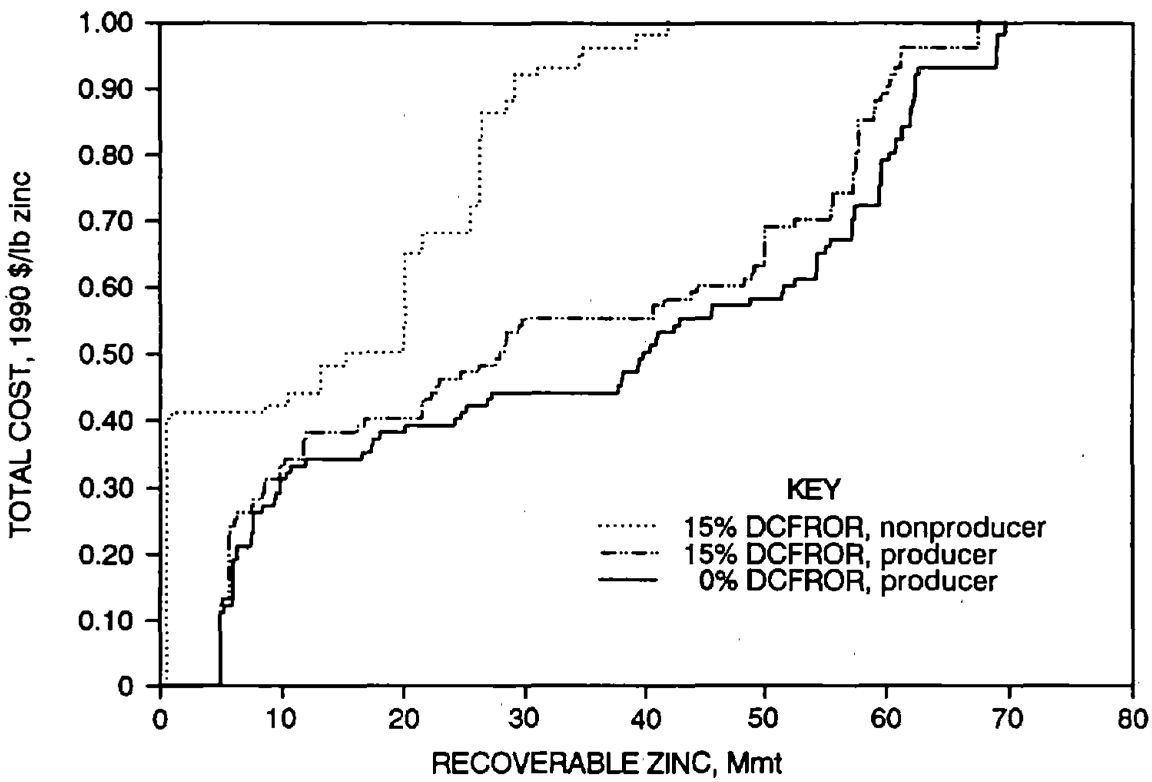

Figure 12.—Potential total zinc available from primary zinc operations in MEC's.

1989 AVAILABILITY

Figure 13 shows potential 1989 lead production at full capacity from producing MEC and U.S. mines for mines designated as primary lead or primary zinc operations in this study. In 1989, about 2.2 Mmt of lead were potentially available from the mines evaluated in MEC's. Primary lead mines accounted for 624 kmt and primary zinc mines produced 1.6 Mmt. This availability compares closely with an estimated 1989 actual lead production of 2.2 Mmt from MEC's. Unlike other MEC's, U.S. lead production is dominated by primary lead producers.

The producing U.S. mines evaluated have the capacity to produce an estimated 389 kmt of lead from primary lead properties and 103 kmt of lead from primary zinc operations (a total of 492 kmt), compared with a 1989 actual estimated production of 419 kmt. Differences in capacities and estimated 1989 actual production figures are most likely due to additional tonnages available from lead produced as a byproduct or coproduct of copper and silver properties as well as other smaller mines not included in this study.

An estimated 340 kmt was available from primary U.S. lead mines, if considering only those producers with an average total cost at 0% DCFROR equal to the January 1990 price for lead in the United States of approximately $0.40/lb. At a cost equal to the January 1990 U.S. high-grade zinc price of $0.80/lb, an additional 90 kmt is potentially available from mines evaluated as primary U.S. zinc mines.

Similarly, potential 1989 zinc production, at full capacity, from selected producing primary MEC mines and from the United States, Canada, and Australia is shown in figure 14. A total of 4.8 Mmt of zinc were potentially available from producing MEC primary zinc mines. The U.S. mines studied had the capacity to produce an estimated 490 kmt compared with an estimated 1989 production of 288 kmt; Canada had 905 kmt of capacity compared with estimated production of 1.22 Mmt; Australia had an estimated capacity of 1.1 Mmt compared with estimated production of 811 kmt; Mexico had 235 kmt of capacity compared with 228 kmt of production; and Peru had 580 kmt of capacity compared with estimated production of 598 kmt (*12*). Overproduction differences between capacity and production were mainly due to byproduct and coproduct production from lead, silver, and copper properties, while underproduction differences were mainly due to production from smaller mines that were not included in this study.

Each graph shows a lower operating cost level and an upper cost level that includes a 0% DCFROR. At an average total cost (including a 0% DCFROR) roughly equal to the January 1990 price for zinc in the United States of approximately $0.80/lb, 4.1 Mmt were potentially available from all MEC mines, while 1989 production was estimated to be 4.7 Mmt. In the United States at $0.80/lb zinc, approximately 475 kmt were potentially available, while 1989 production was estimated to be 288 kmt. Canada's capacity was at 492 kmt at the $0.80/lb zinc cutoff compared with 1.2 Mmt of actual production. Australia's capacity at the same cutoff was 1.1 Mmt compared with 811 kmt of actual production.

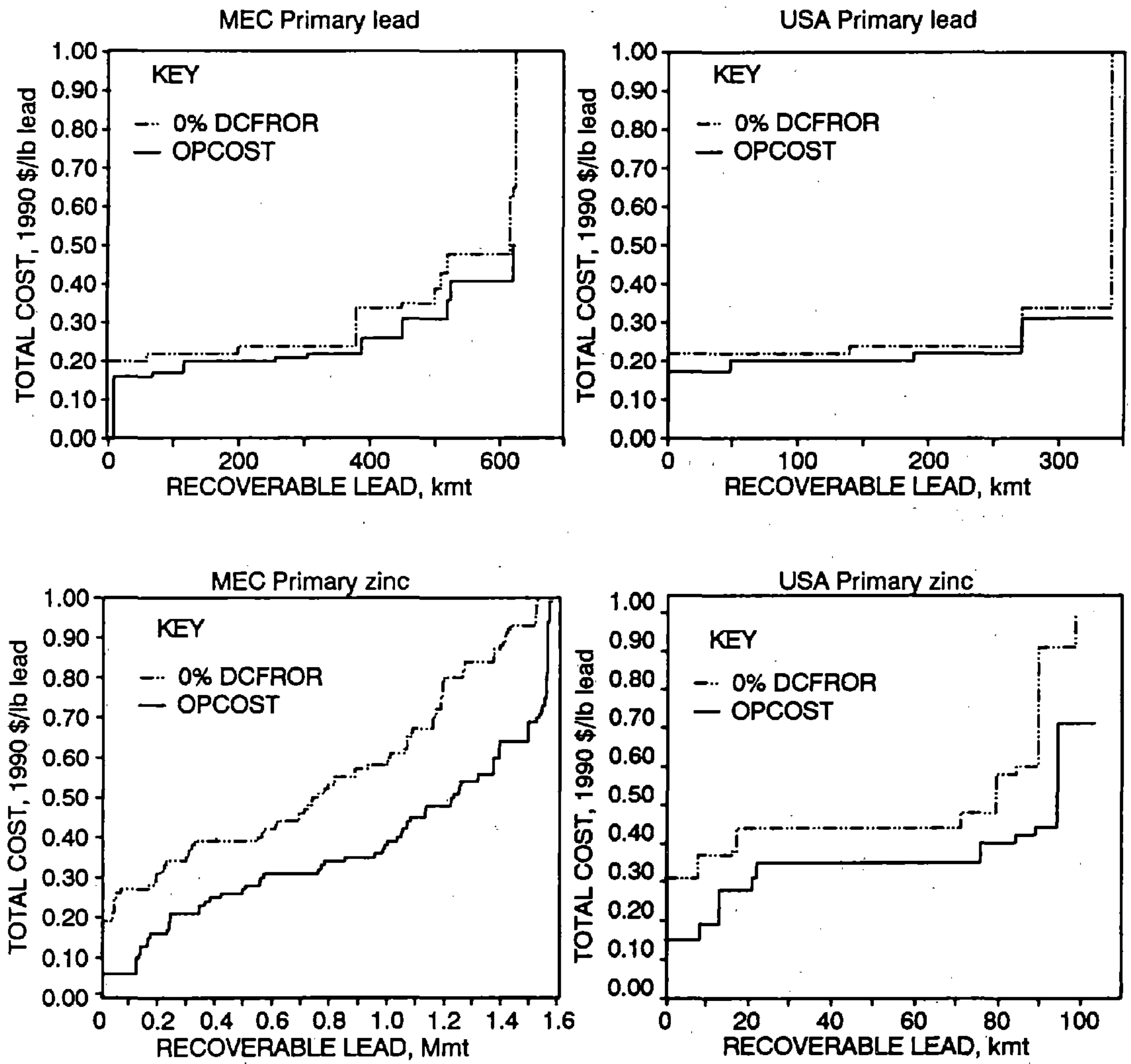

Figure 13.—Lead capacities from producing lead and zinc operations, 1989.

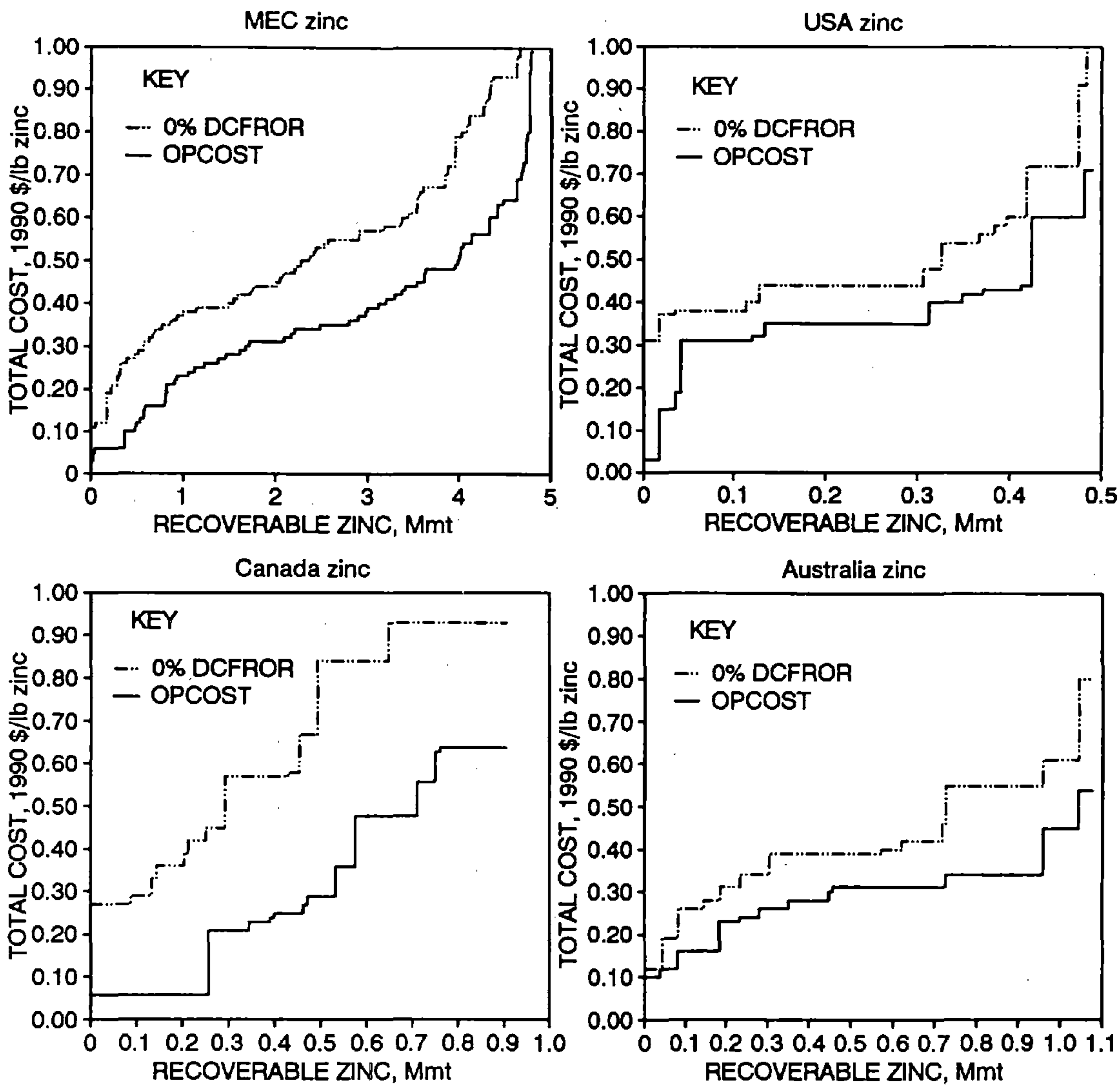

Figure 14.—Zinc capacities from producing mines, 1989.

POTENTIAL ANNUAL AVAILABILITY

Potential production of lead from 1989 to 1994 from the demonstrated resources of producing primary lead and zinc mines in all MEC's and in the United States is shown in figure 15. The curves reflect the production capacity of existing mines utilizing an average ore grade over the life of the mine, including planned expansions. It is assumed that all operations produce at full capacity over the life of the resource. If actual production were less than capacity, the curves would not actually decline as rapidly as shown. It is doubtful that the demonstrated resources of these producing mines will decline at the rates indicated by some of the curves. As stated before, the reserves in a deposit or group of deposits are proven progressively over a period of years. Many of the lead and zinc operators report their demonstrated resources for only a few years ahead of their current mining position, and increase demonstrated resources each year as a result of ongoing exploration programs. This gradual exploration is due in the most part to the highly complicated geology (see the appendix) and the tax advantages delaying may offer, where only defined reserves are taxed. Therefore, there is a high probability that additional resources exist that will allow most of the currently producing mines to continue beyond the time frame of reported resources.

The MEC curve for primary lead properties shows a prominent increase from 1989 to 1990, which is due to planned expansions coming on-stream. A gradual decline begins in 1991 due to the potential depletion of several foreign mines. The curve for lead from MEC primary zinc mines shows some minor variation until the year 1998 when a much more rapid decrease occurs as demonstrated resources at many mines are depleted. As shown, domestic primary lead mines have sufficient resources to maintain production close to capacity levels from 1989 through 1994.

Potential annual production of zinc from the demonstrated reserves of producing mines in MEC's from 1989 to 1994 is shown in figure 16. The MEC curve for primary zinc properties shows a prominent increase from 1989 to 1990, due to expansions and attainment of full production levels at some new mines (especially the Red Dog Mine in Alaska). A gradual decline begins in 1992 due to the potential depletion of several foreign mines. As shown, domestic primary zinc mines have sufficient resources to maintain production at capacity levels close to the 1990 level at least through 1994. The curve for zinc from Canadian primary zinc mines shows some minor variation until the year 1993, when a leveling effect appears. The curve for Australia shows a gradual increase through 1994 due to the coming on of new properties and expansions of already existing mines.

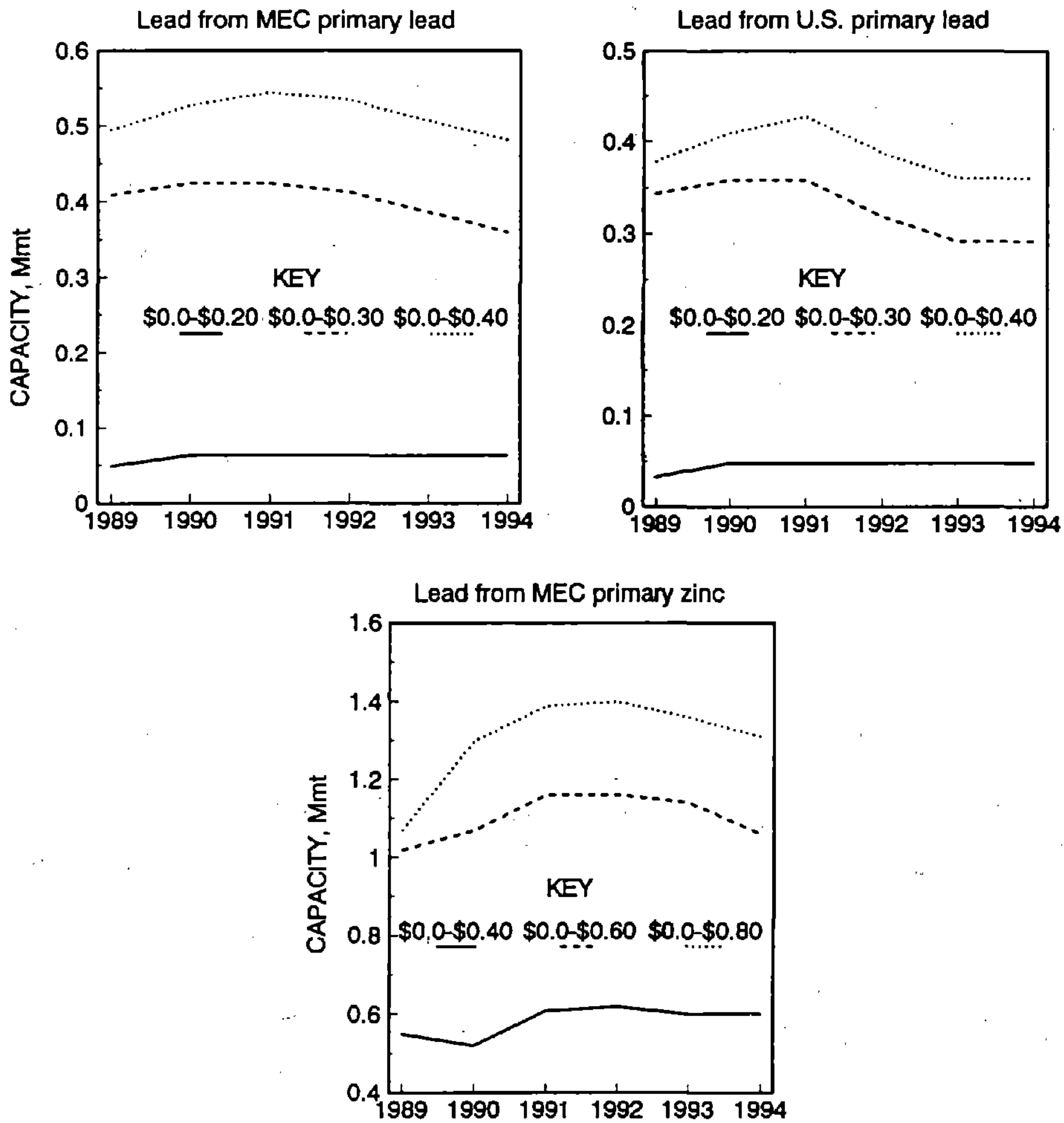

Figure 15.—Potential annual lead production from producing primary lead and zinc mines in the MEC's and the United States.

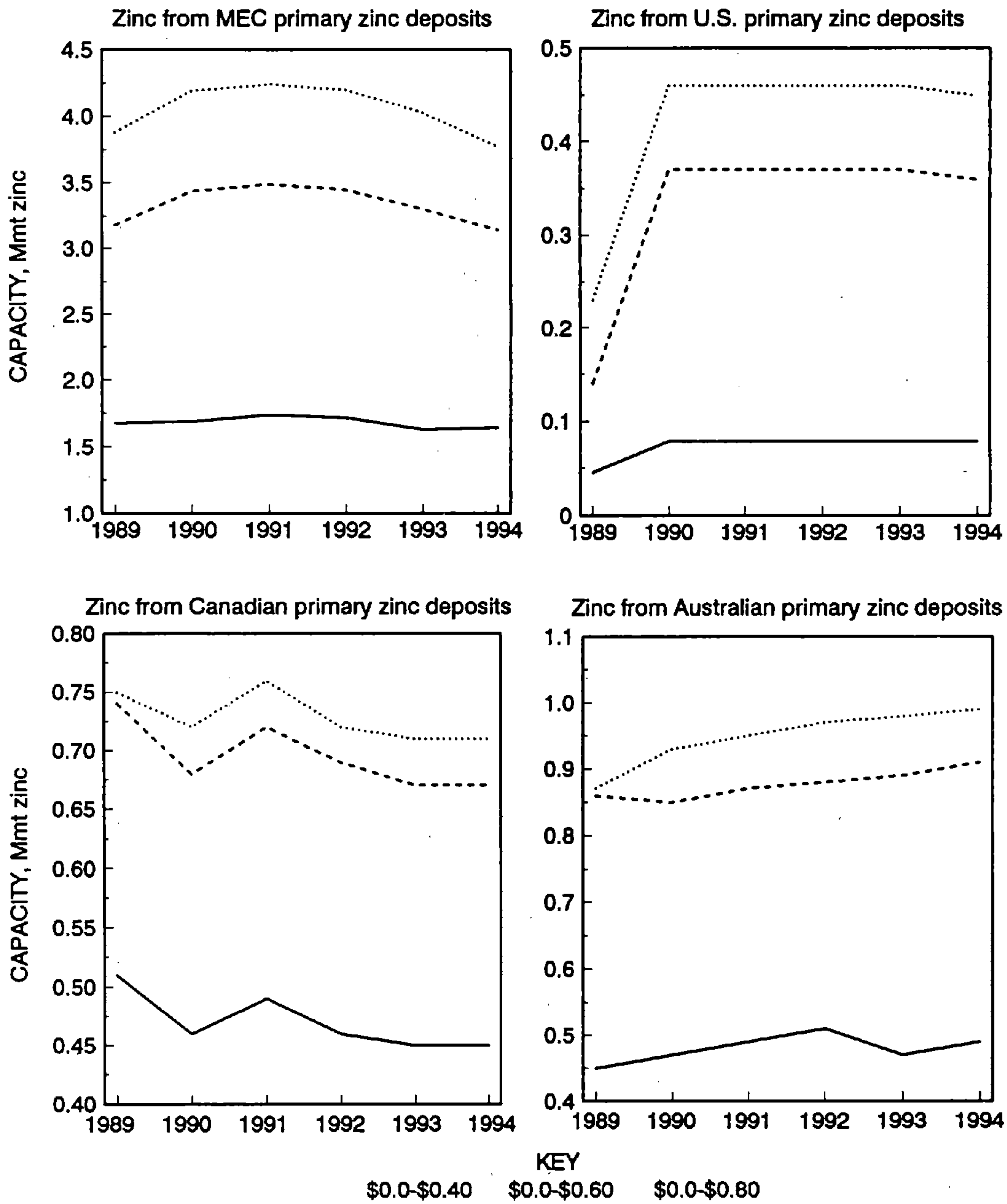

Figure 16.—Potential annual zinc production from producing primary zinc deposits in selected countries.

CONCLUSIONS

Lead and zinc continue to be useful to the industrial world. They will be especially critical for transportation batteries (lead) and galvanizing (zinc). Market conditions are cyclical and demand should continue to be strong. The lead battery is still the most economically efficient source of electrical power for the transportation industry; and zinc is also in strong demand as new cars continue to be protected by traditional as well as newly perfected galvanizing methods.

Sustained growth in lead battery sales and increased usage of zinc in galvanizing have allowed the lead and zinc industry to survive the low prices of the mid 1980's, in a smaller, less intact form than 20 years ago. Although environmental concerns have made the mining, milling, smelting, and refining of lead and zinc increasingly difficult, cost-reducing measures have allowed it to survive the hard times.

A total of 205 deposits that contain lead and/or zinc were evaluated in this report. Approximately 48 Mmt of lead is estimated to be recoverable from the 163 primary lead and zinc mines and deposits evaluated for lead in this study. The mines evaluated as primary lead mines have a weighted-average total production cost (including a 15% DCFROR) of $0.34/lb. Total potential lead production from these mines amounts to 12.7 Mmt, having 9.2 Mmt available at or below a long run total cost of $0.40/lb. The U.S. producing lead mines have a weighted-average total estimated cost of $0.27/lb, while foreign mines averaged $0.41/lb.

A total of 130.5 Mmt of zinc is potentially recoverable from the properties evaluated in this study. The producing mines evaluated as primary zinc mines have a weighted-average total production cost (including a 15% DCFROR) of $0.63/lb. Total potential zinc production from these mines amounts to 81.5 Mmt, with 68.4 Mmt potentially available below the January 1990 high-grade metal price of $0.80/lb. The weighted-average estimated total production cost (including a 15% DCFROR) for U.S. producing mines is estimated to be $0.61 for the 41.7 Mmt of recoverable zinc. Nearly 46 Mmt is potentially recoverable from nonproducing zinc deposits that have a weighted-average total cost of $1.11/lb (including a 15% DCFROR).

Since 1981, real cash costs per pound of metal show decreases in operating costs for the United States, Canada, and Australia. This decrease is evidence of the rationalization (the mergers and restructuring) of the lead industry in the United States and Australia and of the lead and zinc smelting-refining industry in Europe (not discussed in this report), which has served to consolidate the industry into larger and economically stronger groups. This restructuring should make the major players in the industry less vulnerable during the next downturn of the business cycle or economic recession.

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APPENDIX A.—SPECIAL TOPICS

Special topics were selected for analysis to determine the relative importance of location and ore content to the availability of lead and zinc. These topics include the following: (1) Arctic Circle mines, especially the Red Dog Mine and its impact on the rest of the lead and zinc industry, were examined for any unusual effects on costs due to severe weather or unduly long transportation requirements; (2) Tennessee mines without byproducts were compared to mines with major byproducts to illustrate the effects of byproducts on production costs; and (3) a generic mine scenario was developed and superimposed on several different country locations to indicate the effects of differing political and economic conditions or policies.

ARCTIC CIRCLE MINES

This section of the paper will present the different factors that allow the Red Dog Mine to operate at a relatively profitable cost, in comparison with other mines, even though severe weather, large storage facilities, large haulage distances, limited shipping season, and break-in-bulk port maintenance add to its cost.

Analyzed zinc mines located within 10 degrees of the Arctic Circle include the Red Dog and Green's Creek, both in Alaska, the Polaris, Nanisivik, and Faro mines in Canada, the Vihanti in Finland, and the Zincgruvan mine in Sweden. The net operating cost for zinc for these mines (minus the Red Dog) averaged $0.42/lb zinc. This cost was only 3 to 4 cents higher than that of all MEC surface and underground mines. These mines do not show any negative cost effects from being located in a severe weather locale.

About 70% of the production in the Arctic area comes from the Red Dog Mine (*19*).[1] Allowing for extensive infrastructure, including storage facilities for about 9 months of production and harbor facilities (ore can be shipped only about 100 days per year), equipment, and severe climatic conditions (most personnel work 2 weeks on and 2 weeks off), the Red Dog Mine still had mine and mill operating costs lower than the Arctic Circle mines and the MEC average for surface mines and underground mines (see figure A-1). Smelter-refinery costs followed much the same pattern as the mine and mill operating costs, most likely due to much of the concentrate being vertically integrated (mine, mill, and smelter-refinery owned by the same corporation). Transportation costs, however, were well above the three other areas due to the long haulage to port and port maintenance costs. Byproduct credits for the Red Dog Mine are close to that of the other Arctic Circle mines but below those of the MEC surface and underground mines. The combination of all of these factors produced a net cost several cents lower than the other areas analyzed. It is also important to note that the high grade of the ore appreciably adds to the lower costs realized by the Red Dog operation. When other producing surface mines are taken into account, the Red Dog had a lower total cost at 15% DCFROR. The cost components that added to this were the Red Dog's appreciably lower mine and mill operating costs due to economies of scale. Underground producing zinc mines had even higher mine costs than the surface mines, but a lower mill operating cost. Transportation costs at the Red Dog Mine were several times the amount for producing surface and underground mines due to the long distances that must be traversed. Byproduct credits were several times lower for the Red Dog Mine due to the relatively low amount of byproducts available in the ore. These factors still allow Red Dog to come out several cents lower than the net cost for either the producing zinc underground or surface mines. The recovery of capital is lower due to the newness of the mine and aid and subsidies received by Red Dog from Federal, State, local and the Northern Alaska Native Association (NANA) regional government. The large economies of scale that are present in such a huge surface operation are reflected in the lower costs presented here.

TENNESSEE ZINC PRODUCERS VERSUS BYPRODUCT PRODUCERS

As mentioned in previous sections, most lead and/or zinc mineral properties are associated with polymetallic sulfide ore bodies. This relationship means that revenues from other byproducts or coproducts (lead or zinc and any combination of silver, copper, or gold) covered some or all of the production costs associated with the particular metal being analyzed. Of the properties studied, only some zinc mines produce without any appreciable byproducts or coproducts. Such mines include the Gordonsville-Elmwood, Zinc Mine Works, and the Young, Immel, Coy, and New Market mine group in Tennessee. For the region, zinc grades averaged about 3.5% zinc. The costs for producing a pound of zinc averaged about $0.68/lb, including a 0% DCFROR, in mines recovering only zinc. MEC surface and underground zinc producers had a weighted-average production cost of $0.60/lb and $0.58/lb zinc, respectively.

The question is, what factors contribute to the still relatively low total production costs, considering the absence of byproduct or coproduct credits (fig. A-2). Mine operating costs were higher for the zinc-only mines due to combination mining methods and the mixture of haulage

[1]Italic numbers in parentheses refer to references preceding the appendixes at the end of this report.

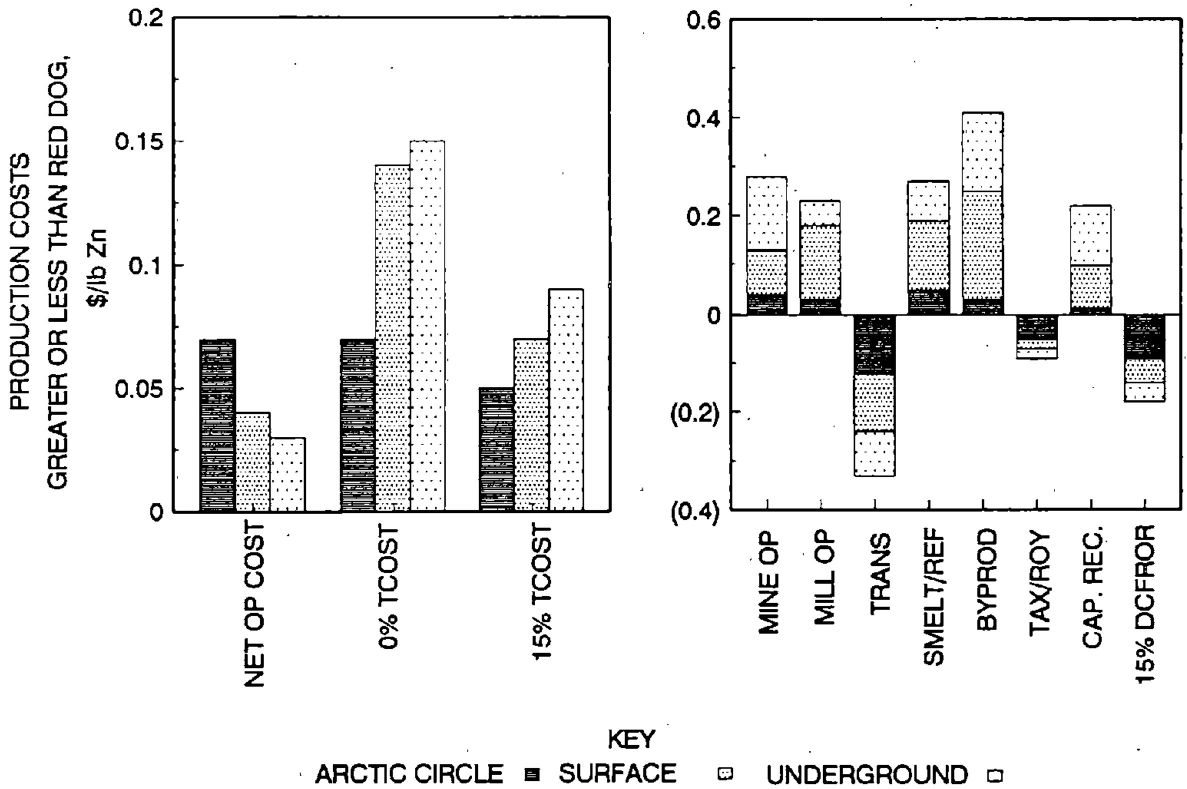

Figure A-1.—Cost differentials for Red Dog.

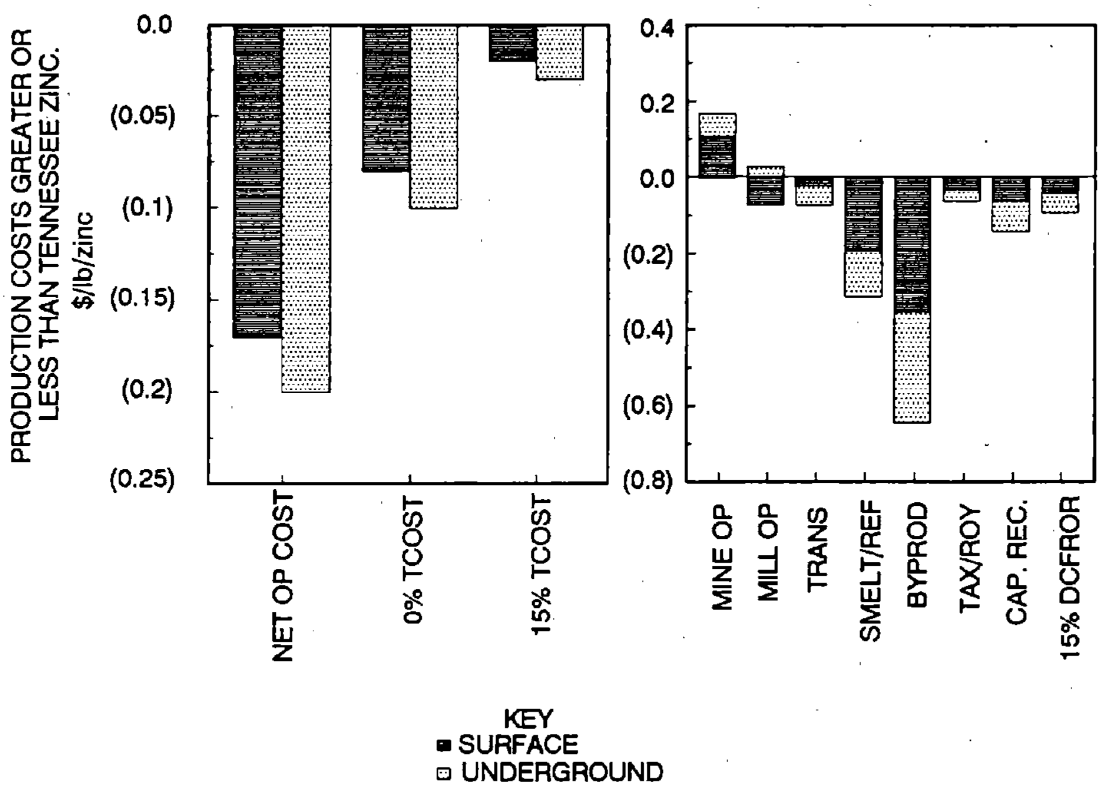

Figure A-2.—Cost differentials for the Tennessee zinc properties.

methods being used. Mill operating costs were higher for MEC surface mines but lower for MEC underground mines. Smelting and refining costs are lower for Tennessee zinc-only mines due to the relative simplicity of the ore. Transportation costs were also much lower for Tennessee zinc-only mines due to well-established transportation routes and close proximity of smelter-refineries. At this point, the net cost disadvantage for zinc-only mines was about $0.21/lb zinc. Recovery of capital and taxes was greater for MEC surface and underground byproduct producers, having an advantage of $0.12/lb zinc ($0.58 versus $0.70/lb) for the byproduct producers.

GENERIC MINE FINANCIAL MODEL

A generic lead-zinc mine was constructed to determine the possible effects of country location on production costs. The model was tested at the locations of producing mines in eight different MEC countries. All cost elements are constant (throughput, feed grades, recoveries, concentrate grades, mine operating costs, mill operating costs, smelter-refinery costs) except transportation, depreciation, severance, royalties, taxes, and update factors. Results at 15% DCFROR show that total costs averaged $0.67 (all costs are weight averaged in January 1990 $/lb zinc) and ranged from a low of $0.37 in India to a high of $1.17 in Peru. Mine operating costs averaged $0.16, while mill operating costs averaged $0.10. The Peruvian high for these costs and other costs is due to a very high inflation rate over the past several years. Transportation costs averaged $0.10, while recovery of capital and taxes averaged $0.14 and $0.02, respectively, (see figure A-3).

Major factors that impact the difference between the total costs in these various countries are as follows: higher mine-operating, mill-operating, and smelter-refinery operating charges for Peru and Spain; higher recovery of capital costs for Mexico, Spain, and Peru (due to variations in country update factors); and a large inflation factor.

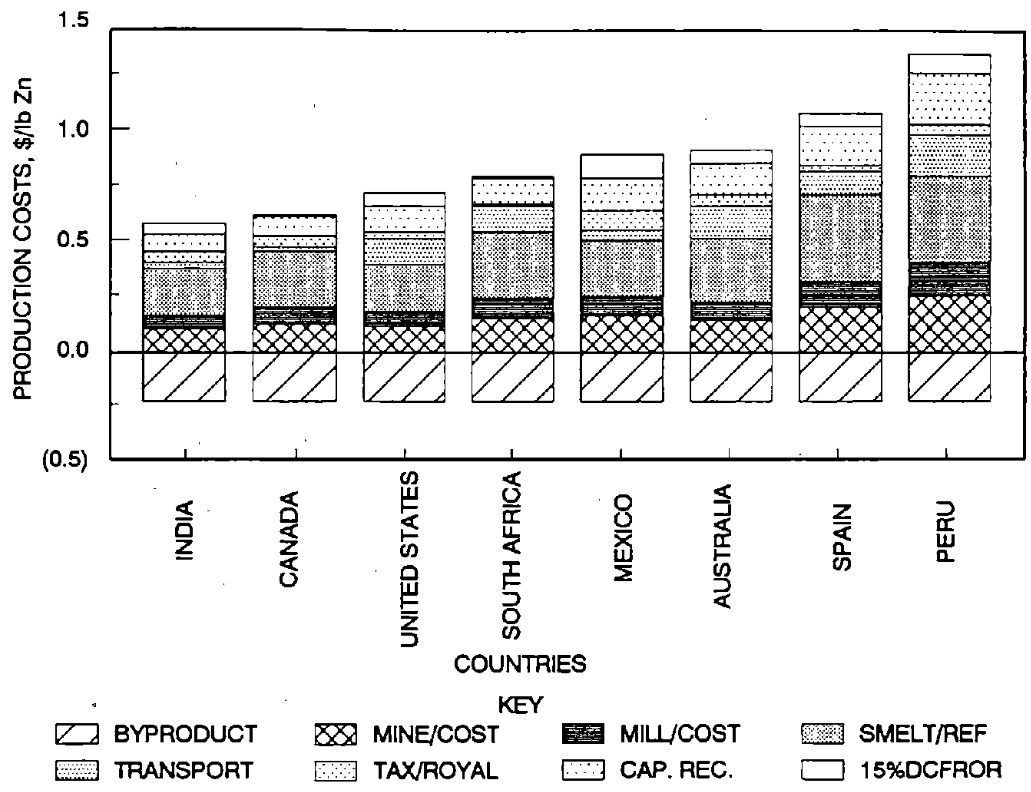

Figure A-3.—Generic lead-zinc model cost comparison.

APPENDIX B.—GEOLOGY

The minerals in lead and zinc ores are relatively simple, including the sulfides galena (PbS) and sphalerite (ZnS) occurring as major minerals . Most lead deposits contain galena associated with sphalerite, pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and other base metal sulfides or sulfosalts, some of which are recovered to yield byproducts or coproducts. Although galena, which usually contains variable amounts of silver, is resistant to chemical alteration, it is sometimes altered and minable as ore bodies of cerussite ($PbCO_3$), anglesite ($PbSO_2$), or other oxidized lead minerals. Lead is a major constituent in several important deposit types, including volcanogenic stratabound, replacement, vein, and contact metamorphic deposits.

Most sphalerite has associated cadmium in quantities from traces to 2% and small quantities of germanium, gallium, indium, and thallium, as well as lead and copper. A few important zinc deposits contain oxide, carbonate, or silicate zinc minerals derived from the altered sulfide minerals, such as zincite (ZnO), smithsonite ($ZnCO_3$), willemite (Zn_2SiO_4), or hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$). Most zinc ores mined occur in three types of deposits: massive sulfides, breccia-filled replacement, and volcanogenic stratabound.

Massive sulfide deposits occur in two major groups of host rock: (1) limestone or dolomites and (2) other sedimentary (e.g., sandstone) rocks and volcanic rocks. Included in the first type of deposit are the Mississippi Valley type (MVT) ore deposits, which represent the majority of U.S. lead-zinc deposits. These deposits generally range more extensively in the lateral than in the vertical direction, and ore commonly occurs as open-space fracture fillings.

Sedimentary-structural features such as reefs, host-rock facies changes, zones of minor jointing and/or collapsed breccias associated with ancient karst drainage serve as loci for ore bodies within the favorable formations. Examples of such stratabound deposits are in the Southeast Missouri lead district; the Missouri-Oklahoma-Kansas district; the Upper Mississippi Valley district; the Pine Point deposit, Northwest Territory, Canada; the Laisvall deposit, Sweden; and the Central and Eastern Tennessee zinc deposits.

Volcanogenic-stratabound massive sulfide (VMS) type deposits contain sulfide bodies commonly interlayered with volcanic or sedimentary rocks. Most VMS deposits are found in folded and disturbed orogenic belts that have been metamorphosed. Deposit sizes can range from small lenses to enormous masses. Ore is commonly a fine-grained mixture of pyrite or pyrrhotite, sphalerite, galena, and/or chalcopyrite, with minor amounts of industrial and carbonate minerals. Examples of VMS deposits are those near Bathurst, Kidd Creek, and Sullivan in Canada; Broken Hill and Mount Isa in Australia; Kuroko in Japan; and the Red Dog in Alaska in the United States.

Replacement deposits of lead and zinc are commonly irregularly shaped hydrothermal type deposits in carbonate rocks, but some also occur in ortho-quartzites or other metamorphic rocks. The form and extent of the ore bodies are controlled by the structural and stratigraphic elements that localized the replacement activity of the ore-bearing solutions. Orebody shapes include tabular or cylindrical flat-lying bodies called mantos, pipelike structures that cross bedding planes, and irregularly branching bedded deposits associated with veins. Some of the well-known replacement deposits include Cerro de Pasco, Peru; the silver-lead district of Central Mexico; Tsumeb, Namibia; and Tintic, Utah and the Leadville and Gilman districts in Colorado in the United States.

Veins are the best known type of ore deposits and consequently were the first deposits to be exploited by early miners. Lead and zinc vein deposits are commonly situated in faults or joints or at formation contacts. Many minable veins range from 1 to 10 miles wide and extend downward hundreds of meters. Some of the better known lead-zinc-silver-copper vein systems occur in the Coeur d'Alene district in Idaho and the Silverton area in Colorado in the United States; the Santa Barbara, Fresnillo, and Taxco mines in Mexico; and the Harz Mountains, Clausthal, and Freiberg deposits in Germany.

Contact metamorphic deposits are associated with igneous intrusions, which have either injected mineralized solutions creating a deposit or altered and recrystallized (or replaced) a mineral deposit present prior to the intrusion, or both. Deposits range in size from small-vein systems to massive pods hundreds of meters long. The Kamioka, Obori, Chichibu, and Nakatatsu deposits in Japan are examples of this type of deposit. Although many deposits of this type are mined for other metals in the United States, only a few have produced significant amounts of lead, usually as a byproduct (*3*).[1]

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[1]Italic numbers in parentheses refer to references preceding the appendixes at the end of this report.

APPENDIX C.—MINING AND PROCESSING TECHNOLOGY

Nearly 90% of the producing lead and zinc mines in MEC's are underground operations (*3*).[1] Underground methods used in lead and zinc mining include open stoping, timbered stopes, filled stopes, and caving, as well as a combination of these methods. Actual methods depend on the depth and attitude of the ore body as well as characteristics of the mineralized zone and surrounding rock. Open-pit mining is employed in Alaska and Montana in the United States, Australia, Brazil, Canada, Mexico, Peru, Spain, and Thailand.

Over 90% of all producing properties utilized conventional crushing, grinding, and flotation techniques. Flotation generally involves the following: (1) flotation of lead-copper minerals and the depression of zinc and iron minerals; (2) flotation separation of the lead-copper (if copper occurs in recoverable amounts) concentrate into lead and copper concentrates; (3) activation and flotation of sphalerite (zinc) from iron and other gangue minerals; and (4) flotation of pyrite, if recovery is desired. As many as four concentrates (lead, zinc, copper, and pyrite) are produced by flotation. Major byproducts (silver, gold, etc.) are usually contained in the lead and copper concentrate, as well as gold in the pyrite concentrate if it is produced.

SMELTING AND REFINING

Conventional blast furnaces are used to smelt about 90% of the lead concentrates (*3*). Blast furnace smelting normally involves the following: (1) sintering, which fuses an agglomerated mixture of concentrates, fluxes, and various recycled materials to meltable size and also removes sulfur, which is recovered by an acid plant; (2) smelting, which produces impure bullion and slag; (3) drossing, which removes copper from the bullion as dross by the addition of elemental sulfur; and (4) pyrometallurgical refining, in which any remaining copper and silver is removed by adding sulfur and zinc dust, respectively. Additionally, bismuth, arsenic, antimony, calcium, and magnesium are removed to produce a 99.95% to 99.99% pure lead. The imperial smelting furnace process is utilized in some applications to treat both complex and simple lead and/or zinc ores, typically producing both lead bullion and zinc, plus some cadmium. Electrothermic refining is used in about one-fifth of present-day lead refineries.

The conversion of zinc concentrates to metal is accomplished by distillation (retorting in a furnace) or by electrodepositing the zinc from a zinc sulfate solution (electrolytic refining accounts for approximately 80% of total zinc refining). Four process stages are generally used for electrowinning: (1) calcining to eliminate sulfur and form leachable zinc oxide; (2) leaching with H_2SO_4 to form a $ZnSO_4$ solution; (3) purification of the solution to remove deleterious elements, e.g., copper and cadmium; and (4) electroplating the $ZnSO_4$ solution to produce a zinc cathode product as high as 99.995% pure.

[1]Italic numbers in parentheses refer to references preceding the appendixes at the end of this report.

APPENDIX D.—OWNERSHIP AND VERTICAL INTEGRATION

Although lead and zinc are now mined in 47 countries throughout the world, the lead and zinc industries have become much more concentrated and vertically integrated in the major producing countries. The increasing concentration of ownership has been most apparent in the United States and Australia. The largest primary lead producer in the United States is the Doe Run Company, which was formed in 1986 as a joint venture by Fluor Corp. and Homestake Lead Co. of Missouri. Fluor acquired full ownership of Doe Run in May 1980. It accounts for about 60% of the primary lead production in the United States. Doe Run operates six underground mines and four concentrators along the Viburnum Trend in southeastern Missouri. Lead concentrates from these concentrators are sent to the Herculaneum smelter 40 miles southeast of St. Louis. The Herculaneum smelter produced slightly under 217 kmt of refined lead in 1989. The Doe Run Company also owns the Buick smelter in Boss, MO, which was shut down in 1986 (due to conflicts with environmental regulations) and has remained on standby status ever since, although it operated briefly in 1988 and 1989 as a backup to Herculaneum and has processed secondary material in recent years. Herculaneum processed secondary materials in 1989.

The operations currently operated by Doe Run were previously operated as separate entities under St. Joe Minerals and Amax/Homestake. Homestake purchased Amax's half interest in the Buick mine, mill, and smelter complex near Bixby, MO, in 1986. St. Joe Minerals operated the Viburnum mines and mill, the Fletcher mine and mill, the Brushy Creek mine and mill, and the Herculaneum smelter. Fluor Corp., the parent company of St. Joe minerals, restructured the company in 1986 by spinning off its gold operations into a new company called St. Joe Gold Corp. That set the stage for the formation of Doe Run whereby Fluor contributed its five mines, three mills, and smelter to the venture with Homestake in return for a 57.5% interest in Doe Run. Homestake contributed the Buick operation in return for 42.5% of Doe Run. In May 1990, Fluor announced the purchase of Homestake's 42.5% share for $125 million, thus making Doe Run a 100% subsidiary of Fluor.

The formation of Doe Run, which provided for a fully integrated operation utilizing the full capacity of the Herculaneum smelter, created the flexibility to enable the conversion of the Brushy Creek mill as a designated copper concentrator to treat copper ores from Casteel, Fletcher, and Brushy Creek and to utilize the capacity at the Buick mill to treat lead, zinc, and copper ore from Brushy Creek (*20*).[1] The redundant Buick smelter provided an excellent setting for Doe Run to enter the secondary lead market through the planned development of a $34 million recycling facility adjacent to the existing smelter for all forms of lead scrap. The company completed an engineering plan proposing the use of the idled refinery capacity at Buick for secondary production. The plant became operational in September 1991. Mill destinations and ore grades mined at Doe Run are shown in table D-1.

[1]Italic numbers in parentheses refer to references preceding the appendixes at the end of this report.

Table D-1.—Mill destinations and ore grades mined at Doe Run

Division	Mine	Output (mt/d)	Ore grades (%)	Ore sent to:
Viburnum	28 Mine	1,250	Pb/Zn/Cu 5.0/0.4/0.25	Viburnum.
	29 Mine	3,125	Pb/Zn/Cu 4.0/0.5/0.25	Do.
	Brushy Creek	270	Cu	Buick.
		1,000	N/A Zn/Pb	Do.
	35 Mine (Casteel)	2,100	Pb/Zn/Cu 4.0/0.25/1.0	Viburnum.
		1,250	Cu/Pb	Brushy Creek.
Fletcher	Fletcher	4,000	Pb/Zn/Cu N/A	Fletcher.
Buick	Buick	5,000	Pb/Zn/Cu N/A	Buick.

N/A Not available.

ASARCO, Inc., integrated backwards by developing the West Fork mine in Missouri, which started up on a limited production basis in September 1985. West Fork reached full capacity in August 1988 following completion of a ventilation shaft. ASARCO purchased the Milliken mine from the Ozark Lead cosubsidiary of Kennecott Corporation in December 1986. The company renamed it the Sweetwater Unit after the name of the principal ore body. The Sweetwater Mine, which had been shut down since 1983, was reopened in December 1987.

With the development of West Fork and the acquisition of Sweetwater, ASARCO now has the potential capacity to eventually supply all of the lead concentrates required to feed its smelter-refinery in Glover, MO. Previously, the Glover smelter had operated solely as a custom smelter. ASARCO also operates a lead smelter in East Helena, MT, and a refinery in Omaha, NE. The East Helena smelter treats lead concentrates from ASARCO's lead-zinc mine in Leadville, CO, plus lead concentrates obtained from other companies.

Cominco Ltd. owns 50% of the Magmont mine in Missouri through a joint venture with Dresser Industries and Cominco American Inc. (a wholly owned subsidiary of Cominco). The Magmont mill treated 962.2 kmt of ore in 1989 to produce 81 kmt of 77.9% lead concentrates, 13.4 kmt of 57.6% zinc concentrates, and 1.34 kmt of copper concentrates. Lead concentrates from Magmont are shipped to ASARCO's Glover smelter.

Cominco's main emphasis in the lead-zinc sector over the past several years has involved the development of the Red Dog Mine in northwest Alaska. The property is owned by the NANA Regional Corporation, Inc., and leased to Cominco Alaska Inc., which owns and operates the facilities. Development at Red Dog began in late 1986, and production began in November 1989. When Red Dog reaches full production, the mining rate will be 5.44 kmt per day for an annual production of 508 kmt of zinc concentrate, 109 kmt of lead concentrate, and 45 kmt of bulk concentrate. About 50% of concentrate shipments from Red Dog are expected to fulfill 50% of the feed requirements of Cominco's smelting and refining complex at Trail, B.C. The other 50% of concentrates produced will go to Europe and Asia. Concentrate production from Red Dog will replace production from the Pine Point and Sullivan mines in Canada, which have been closed.

Slab zinc is produced at four primary plants and six secondary plants in the United States. The four primary plants include the Clarksville, TN, plant of Jersey Miniere; the Monaca, PA, and Bartlesville, OK, plants owned by the Zinc Corporation of America; and the Sauget (East St. Louis), IL, plant owned by the Big River Zinc Corporation. While the primary zinc refining industry in the United States is much less vertically integrated than the lead smelting-refining industry, the ownership structure has changed dramatically over the past decade.

Fluor sold its domestic zinc operations in 1987 (including its mines and mill in Balmat, NY, its smelter in Monaca, PA, and its refinery in Bartlesville, OK) to Horsehead Industries, which earlier had acquired several New Jersey Zinc properties. The zinc operations acquired by Horsehead Industries were integrated into a new company, Zinc Corporation of America. AMAX sold its Sauget zinc refinery to Big River Minerals Corporation in August 1988. The Sauget refinery operates as a custom refiner with concentrates supplied from mines in Illinois, Missouri, Canada, and Peru.

ASARCO closed its Corpus Christi zinc plant in June 1985 and now sends its Tennessee zinc concentrates to the Clarksville, TN, electrolytic refinery owned by Jersey Miniere Zinc Company. Jersey Miniere Zinc was formed in 1975 as a partnership between the New Jersey Zinc Company (a wholly owned subsidiary of Gulf + Western Industries Inc.) and Union Zinc, Inc., an affiliate of Union Miniere, S.A., of Belgium. Jersey Miniere became a division of Union Zinc in 1984 when it acquired Gulf + Western's interest. As of January 1, 1990, the mines and refinery of Union Zinc, Inc., are grouped within the Vieille-Montagne division of Acec-Union Miniere.

In Australia, CRA Limited and North Broken Hill Peko Limited announced on June 22, 1988, that they had agreed to merge their lead and zinc mining and smelting production facilities and all marketing activities other than Australian zinc sales associated with these operations. The new joint venture company formed is Pasminco Limited with ownership split 40% each for CRA and North Broken Hill Peko, and the remaining 20% owned by the general public. Pasminco now combines the ownership of the mines at Broken Hill that were formerly run by CRA (ZC Mine) and North Broken Hill Peko (North Mine) as well as other North Broken Hill Peko mines such as Elura in New South Wales, Beltana in South Australia, and Rosebery mines in Tasmania. On the smelting side, North Broken Hill Peko contributed the Risdon zinc smelter in Tasmania. The CRA group contributed the Cockle Creek zinc-lead-cadmium smelter at Newcastle in New South Wales, the Commonwealth zinc and lead complex at Avonmouth, United Kingdom, and CRA's 50% stake in the Budelco zinc smelter in the Netherlands, as well as manufacturing plants in the United States that were formerly managed by Impalloy and Pasco Zinc Corp. The Broken Hill Associated Smelters Pty. lead smelter and refinery at Port Pirie, South Australia, which was jointly owned by CRA (70%) and North Broken Hill Peko (30%), is also part of Pasminco.

The formation of Pasminco rationalizes the distribution of concentrates for more efficient ore blending and transportation to the smelters. For example, zinc concentrates from Elura can now be processed at Cockle Creek rather than be transhipped from Newcastle to Tasmania for processing at Risdon (*21*). The merger also provides operational efficiencies at Broken Hill and overhead savings in terms of a combined management infrastructure and shared research and development expenses. Pasminco is now the world's largest producer of zinc ore, and the combined output of all of its smelters places Pasminco as one of the top three zinc metal producers in the world after Acec-Union Miniere and Metaleurop Group.

MIM Holdings Ltd. is a fully integrated producer of lead and copper and exports zinc concentrates from its operations at Mount Isa and Hilton in central Queensland, Australia. Lead-silver bullion from the lead smelter at Mount Isa is refined at the plant of MIM subsidiary Britannia Refined Metals Limited in the United Kingdom. Britannia Metals also toll refines lead from the Pasminco lead-zinc smelter in Avonmouth. MIM also holds a 50% interest in Ruhr-Zink GmbH which operates a zinc refinery in Datteln, Germany, and a 33% interest in Rheinzink GmbH, which is a producer of zinc products.

The company also has a 3% stake in Metallgesellschaft AG. MIM has a presence in the United States through its 24.5% holding in ASARCO. ASARCO currently holds 18.5% of MIM. MIM is involved in Canada through a 10% interest in Cominco Ltd., 32% of Granges, Inc., and 4.6% of Teck Corporation.

In Europe, aside from the restructuring of Acec-Union Miniere, the largest change in the lead-zinc industry was the formation in 1988 of Metaleurop Group as a merger of Preussag and Penarroya's nonferrous metallurgical operations. Metaleurop Group operates lead smelting and refining complexes at Noyelles-Godault, France, Nordenham, Germany, and Cartagena, Spain. Metaleurop Group is the world's largest producer of commercial lead, having a 1989 production of 430 kmt from its primary and secondary smelters.

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15. Supplementary Notes

16. Abstract (Limit: 200 words) The Bureau of Mines estimated the potential availability of lead and zinc from 205 mines and deposits in Market Economy Countries (MECs), by performing detailed geologic, engineering, and cost evaluations. These evaluated properties had demonstrated resources totaling 57 Mmt of contained lead, and accounted for approximately two thirds of the Bureau of Mines reserve base for lead in MECs (almost 96 Mmt). These properties had (in situ contained metal) zinc resources totaling 160 Mmt, and also accounted for almost two-thirds of the Bureau's reserve base for zinc in MECs (259 Mmt). Total recoverable (contained metal, milled, smelted and refined) MEC lead resources from evaluated mines and deposits were 48 Mmt; 27% was from primary lead mines and deposits, and the remaining 73% from primary zinc mines and deposits. Of the primary lead mines, the United States had the lowest estimated weighted average total cost for producers at $0.25/lb recoverable lead at 0% discounted cash flow rate of return (DCFROR).

Total recoverable MEC zinc resources evaluated were 131 Mt, 95% of which were from primary zinc mines and deposits. The remainder was from primary lead mines and deposits. The estimated weighted average total cost of production from producing mines in the United States amounted to $0.49/lb zinc in January 1991 at a 0% DCFROR.

17. Document Analysis a. Descriptors

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