MMSD

Mining, Minerals and Sustainable Development

December 2001

No. 202

Summary of the Interdisciplinary Workshop on Long-Run Availability of Minerals: Geology, Environment, Economics

Washington DC, 22-23 April 2001

Report prepared by Joel Darmstadter
Resources for the Future

The workshop was sponsored jointly by Resources for the Future (RFF) and the Mining, Minerals and Sustainable Development Project (MMSD)

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Mining, Minerals and Sustainable Development is a project of the International Institute for Environment and Development (IIED). The project was made possible by the support of the World Business Council for Sustainable Development (WBCSD). IIED is a company limited by guarantee and incorporated in England. Reg No. 2188452. VAT Reg. No. GB 440 4948 50. Registered Charity No. 800066

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RESOURCES FOR THE FUTURE

"THE LONG-RUN AVAILABILITY OF MINERALS: GEOLOGY, ENVIRONMENT, ECONOMICS"

Summary of an Interdisciplinary Workshop
by Joel Darmstadter
Resources for the Future

The workshop was sponsored jointly by Resources for the Future (RFF) and the Mining, Minerals and Sustainable Development Project (MMSD). It was held at RFF, Washington, DC, April 22-23, 2001.

The workshop keynote presentation by Prof. Brian J. Skinner (Yale University), appears in a companion release, on the RFF home page http://www.rff.org. Click on "Minerals" under the *Natural Resources* research area.

1616 P St. NW • Washington, DC 20036 •Telephone 202-328-5000 • Fax 202-939-3460 • http://www.rff.org

THE LONG-RUN AVAILABILITY OF MINERALS: GEOLOGY, ECONOMICS, ENVIRONMENT

Summary of an Interdisciplinary Workshop

Joel Darmstadter
Resources for the Future

Introduction

For most of the last century, economic growth has benefited from an adequate and affordable mineral supply. Whether factors emerging during the next century – the possibility of a discontinuity in resource abundance or constraints imposed by environmental imperatives – pose significant new challenges to private and public institutions was the subject of a workshop held in Washington DC on April 22-23, 2001. The workshop was sponsored jointly by Resources for the Future (RFF) and the Mining, Minerals and Sustainable Development Project (MMSD).[1] The workshop program and attendee list appear in Appendix A.

In dealing with the broad theme indicated above, the workshop deliberations proceeded along two paths. One path involved consideration of a draft manuscript prepared by John Tilton, tentatively entitled "Depletion and the Long-Run Availability of Mineral Commodities." (A provisional chapter outline of Tilton's manuscript is shown in Appendix B.) However, the Tilton draft and the comments it elicited served as well as a

[1] Numerous persons contributed to the success of the workshop through their role in its planning and execution—notably, Sarah Cline, Kay Murphy, and Michael Toman of RFF; and Caroline Digby of MMSD. John Tilton and the workshop speakers, whose contributions are reflected in this report, deserve major thanks for their important roles in the undertaking. It should be noted that the present write-up does not represent the views of either RFF or MMSD.

springboard for a wider-ranging discussion of issues of depletion, economic development, sustainability, and the environmental and other social costs arising from mineral extraction and use. The present account emphasizes primarily this second purpose of the workshop – i.e., the extended discussion that the Tilton draft stimulated.

Organization of the Workshop

As indicated in Appendix A, the workshop was organized along five lines:

- A keynote presentation by Brian Skinner. (His presentation, "Exploring the Resource Base," is posted on the RFF website at http://www.rff.org/conf_workshops/files/minsymp_skinner.pdf)
- Introductory remarks by John Tilton on the purpose and content of his manuscript.
- A session on "Conceptual and Empirical Perspectives: Economics, Geology, Technology."
- A session on "Mineral Production and Use: Social Costs and Implications for Sustainable Development."
- A closing session devoted to some "Reflections on the Day's Discussions."

The third and fourth of these five items involved, in each case, brief presentations by three discussants who, in addition to their oral presentations, prepared a written series of "talking points," shown (in somewhat abbreviated form) in Appendix C. In the write-up which follows, we put primary emphasis on Prof. Skinner's presentation and on the third and fourth parts of the workshop, since it was particularly in those two settings at which the Tilton draft provided the point of departure for extensive discussion among those in attendance.

Brian Skinner's Keynote Presentation

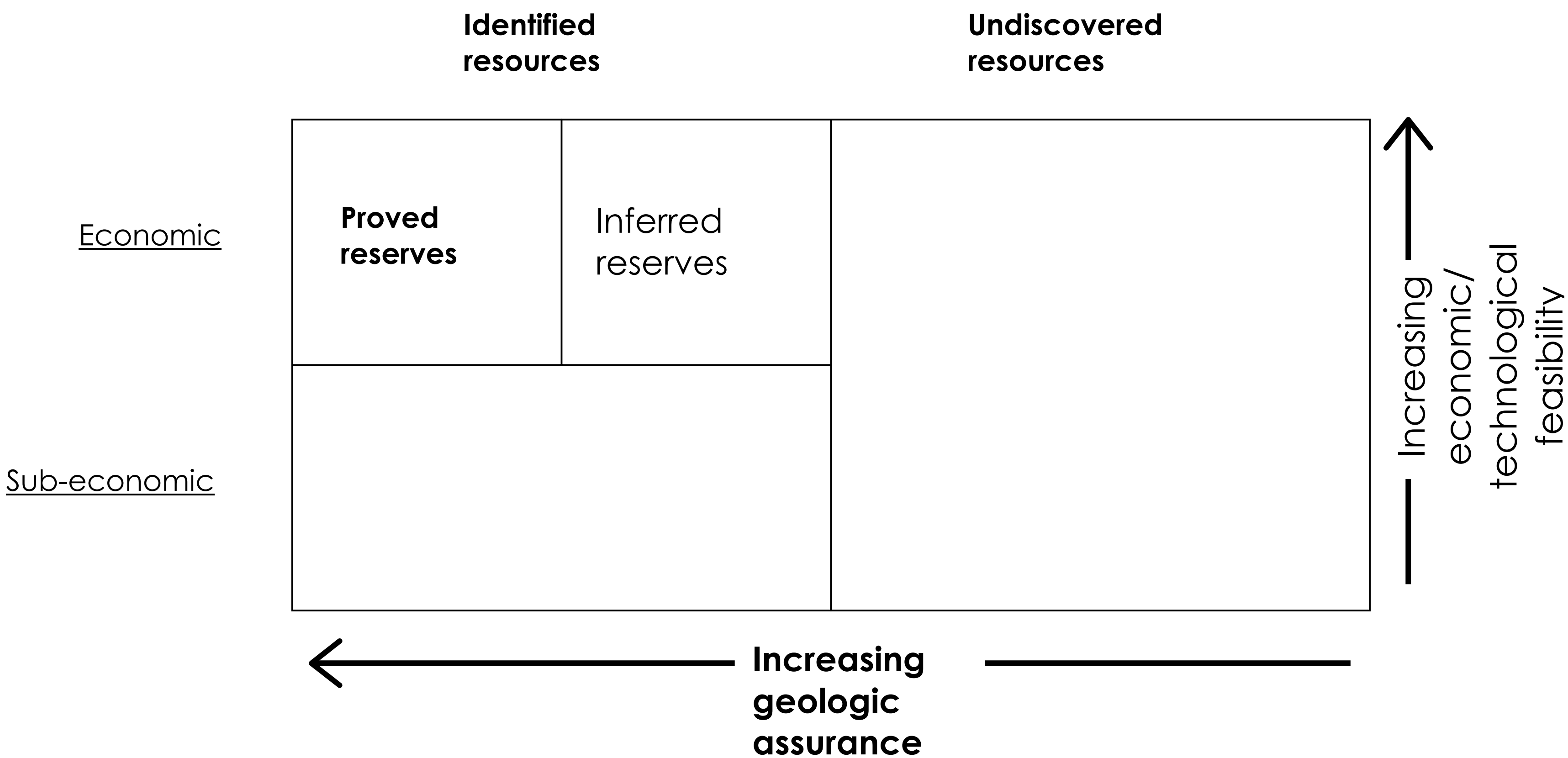
The workshop began with keynote remarks by **Brian Skinner**. At the outset of his talk, "Exploring the Resource Base," Skinner recalled his encounters, while working at the U.S. Geological Survey (USGS) in the 1950s and 1960s, with Vince McKelvey and M. King Hubbert, two notable geologists whose prominence and intellectual contributions few studies of mineral and energy resources fail to acknowledge. At the same time, while their emphasis tended to be on the analysis of rates of mineral discovery, Skinner recalls beginning to wonder "how their work could be tied back to the underlying science of how, where, and why mineral deposits form…." in a way that would make it possible to more completely integrate understanding of all aspects of resource supply.

However, efforts at such integration, Skinner cautioned, must guard against the trap of imposing uniform approaches to the understanding of fundamentally different resources. Thus, he argues that the chemical processes that form scarce minerals differ not only from those that form oil and gas but also from those that form abundant minerals (such as iron, bauxite, and magnesium), no matter how such highly differentiated resources may usefully be aggregated for certain economic purposes.

Skinner's reflections emphasized developments over the next 100 years or so – a perspective for which the legendary "McKelvey diagram," with its conceptual distinctions among reserves and resources—as these relate to economics, technology, and geology—proves especially instructive. As the accompanying simplified version of the diagram shows, technological progress in extraction and/or higher prices allows subeconomic resources to move (upward) to economically recoverable reserves; while enhanced geological probability allows hypothetical or highly speculative resources to shift (horizontally, from right to left) into a category which, while still conditional, represents diminishing uncertainty allowing the descriptor "identified resources."

Prof. Skinner dwelled particularly on the issue of deposits (in the undiscovered "resources" category), noting that they exist in parts of the world (largely outside Europe and North America) "that have not been intensively explored because they are politically unstable, topographically inaccessible, or for one reason or another withdrawn from access by social or political acts. But much more importantly, many undiscovered resources lie beneath a cover of younger barren rock and are sufficiently deep so that today's prospecting technology cannot detect them." To meet the challenge of successfully exploiting the potential of undiscovered resources requires both political will and technological acumen – e.g., the application of detailed three-dimensional mapping – but "scarcity need not be an issue unless we make it so for other reasons, such as environmental concerns…."

In turning to issues of resource assessment, Skinner cautioned against a "Lasky-type" construct which suggests that as grade declines arithmetically, tonnage goes up geometrically. There are geochemical reasons to consider a more pessimistic prospect, one that points to small rather than sizeable low-grade tonnages, and in addition, DeYoung (1981) shows that the relation postulated by Lasky (1950) cannot be extrapolated very much before it predicts physically impossible results. (The DeYoung



MINERAL RESOURCE CLASSIFICATION:
SIMPLIFIED VERSION OF McKELVEY DIAGRAM

and Lasky references are included with DeYoung's excerpted contribution in Appendix C.)

Somewhat relatedly, Skinner addressed the issue of a "mineralogical barrier." This refers to a sort of geologic/technological discontinuity, below which distinct mineral deposits might only be exploitable by "pulling a rock apart chemically" – a task which may entail enormous energy and other costs. There is, in short, no shortage of challenges for meeting, at an affordable cost, the developmental aspirations for mineral resources which a growing global population requires and deserves.

Conceptual and Empirical Perspectives: Economics, Geology, Technology

A background presentation by **John Tilton**, in which he outlined the purpose and organization of his manuscript, was followed by the first of two major sessions. It featured contributions by three discussants (synopses of whose remarks appear in Appendix C) and an ensuing discussion among the workshop participants. This write-up touches both on the points made by the discussants and the dialogue which their comments and the overall topic of economics, geology, and technology stimulated.

John DeYoung revisited some of the topics touched on by Brian Skinner – e.g., the enduring significance of the McKelvey diagram and the predictability of the tonnage-concentration relationship postulated by Lasky – but he also directed attention to the real-world challenge of meeting an expanding global demand for minerals over the next several decades. He pointed out, for example, that China's consumption for copper by the year 2020 will quite likely equal the level of *worldwide* consumption in the mid-nineties. This rapidly growing volume of consumption – in China as well as in other developing parts of the world – "will be accompanied by an increase in environmental residuals, many of which are unaccounted for and some of which will be 'exported' to the air and water." (The next session, taken up below, dealt with environmental dilemmas more specifically.)

Notwithstanding this increased demand for copper (and many other mineral commodities), the need for new discoveries, in DeYoung's view, may be less urgent for the nearer term than for the more distant future, since there are, for now, a lot of known deposits ready to be exploited. Restating a point in his keynote presentation, Brian Skinner – while not refuting DeYoung's judgment – observed that it's the "deeper stuff," longer time horizon and the genuine possibility of a stepwise increase in real extraction costs that should be matters of concern.

In contrast to the more strictly geological and technological orientation of her fellow discussants, **Lisa Morrison** – whose presentation reflected collaboration with **Robin Adams** – addressed the broadly economic (and related social) indicators of depletion and long-run availability of mineral commodities. In purely economic terms, she argued that scarcity is simply a non-issue, observing, for example, that "rising scarcity implies greater rents; [yet] recent history indicates that the reverse is true, as governments have been forced by competitive pressures to institute less aggressive royalty regimes."

Although much remains to be learned about the social costs of mining – e.g., is it clear that mining at deeper depths is going to cause more environmental damage? – Morrison acknowledges that to successfully deal with such externalities as can clearly be identified poses significant challenges, not least determination of the right price to be attached to a given externality. Among the issues she flagged that deserve particular attention:

- the migration of industry to countries with lax pollution control or enforcement;
- ensuring, in collaboration between host government and industry, that plant closure and abandonment contingencies are, *ex ante*, formalized in planning strategies and agreements;
- and, related to the last point, recognition of, and sensitivity to, the economic, social, and physical devastation that the termination of a mining project can inflict on a given community, no matter how attenuated such impact may appear when judged in the context of macroeconomic aggregates.

Toni Marechaux noted that, historical evidence to the contrary notwithstanding, there is some public skepticism over opportunities for technological advance to continue ensuring minerals adequacy and affordability. The opportunities, however, are genuine. In part, some of the potential progress depends on enhanced efficiency in the energy sector – a vital input into mining and mineral processing; in part, it depends on technological progress in the nonfuels minerals industry itself.

Marechaux reviewed some of these technological potentials as part of her presentation, noting, for example, that airborne and satellite imaging systems – though still in their infancy – have already contributed to the identification of *new* resources. Improved techniques for characterizing *existing* deposits show substantial promise as well. In mineral extraction, there are possibilities for advanced in-situ processes that reduce the amount of overburden and wastes for a given volume of ore. Certain advanced energy technologies – e.g., fuel cell-powered mining vehicles in lieu of diesel engines – can improve workers' productivity while benefiting their health and safety.

With respect to end-use products, Marechaux cited opportunities for substitution, redesign, and recycling which, along with the possibilities mentioned above, would go a long way toward sustainability of the earth's mineral resources. Markets will play – and are beginning to play – a major role in driving such trends. The public sector's supportive role includes data collection and dissemination and R&D funding. (Earlier in the workshop, Brian Skinner had pointed to the fact that, around the world, geological surveys – typically a category of public good viewed as the responsibility of government – were declining when they should be expanding.)

The general discussion that followed (or, in some cases, accompanied) the discussants' remarks reverted to several decisive issues, with the matter of scarcity, trends in end-use products and markets, and (in anticipation of the following session) environmental impacts drawing particular attention. By and large, the prospect of long-term depletion as a cause for anxiety did not seem to elicit much support, though the forces that would head off that spectre are more debatable. Thus, substitutability entered discussion at several junctures, with some participants taking a relaxed view of its potential and efficacy; others, a more skeptical view. With copper widely accepted to be the best conductor of electricity and heat, can aluminum be regarded as an economically adequate replacement should that become necessary? Indeed, aluminum investments – for now, at least – were described by one participant as being guided not by resource scarcity but by competition in end-use markets, a factor thought to explain some 90 percent of the long-term trend in aluminum prices. Clearly, then, understanding the extent to which mineral requirements are affected by changes taking place in industrial and other product markets (including the phenomenon of "de-materialization") remains a formidable analytical challenge.

Mineral Production and Use: Social Costs and Implications for Sustainable Development

If the preceding session surveyed issues – of geology, economics, and technology – that have been the enduring stuff of mining activity and research, the next session's focus on social costs and sustainability reflects a rapidly emergent area of interest and often spirited debate. In its broadest scope, the issue revolves around the question of whether quantitative measures of performance and growth adequately capture concomitant trends in peoples' quality of life. In no area is this dilemma more keenly manifested than in the matter of environmental integrity.

Raul O'Ryan, observing this emergent focus, urged attention to certain specific issues. (a) While not taking exception to the Brundtland Commission's conception of sustainability – meeting today's needs without jeopardizing the well-being of future generations – he suggested that the operational specifics of the minerals industry required a more clear-cut guide to its behavior. (b) Nowhere is that issue more pressing than in the relationship between a mining operation and the community in which mining takes place – a matter that, it will be recalled, had also been underscored in earlier remarks by Robin Adams/Lisa Morrison. (c) One can scarcely deny that the production and use of mineral commodities has frequently been polluting. And, most likely, environmental requirements will continue to put upward pressure on mineral production costs. Still, the *perception* of environmental harm seems to be vastly greater than its documentable occurrence, the "stigmatization" of minerals in Western Europe being a case in point. (d) Perhaps the application of "green accounting" rules could help to track the mining industry's performance with greater fidelity by allowing a comparison of conventional indicators with those embodying adjustments for demonstrable externalities associated with mineral activities.

David Humphreys reminded workshop participants of the extent to which the mining industry has for some decades successfully internalized numerous social and environmental costs in its operations and financial practices, much (though not all) of this in response to tightening regulatory controls. But he did not argue with the notion "that the full social and environmental costs of mining are not included in the price of mineral products and that more may yet need to be done to bring the private and social marginal costs of production closer into line."

Much of Humphreys' discussion centered on the efficacy of policies designed to achieve that integration of private and social costs. In particular, he singled out for critique the use of pollution taxes to regulate environmentally damaging mining activities, while also recognizing, however, that preferred approaches – notably, emission permit trading – have limited relevance for mining given the diversity of operations in this industry.

Summarized, Humphreys' critique may be collapsed into four elements: (a) There is a general difficulty of valuing the externality as a basis for setting the level of the tax, given the specificity of different mining sites, each having unique characteristics. (b) The imputation of externality values represents a "technocratic, top-down approach" by experts who do not themselves (like miners and neighboring communities) have to live with the consequences of their judgments. (c) The internalization of externalities can for the most part be satisfactorily achieved by a combination of good regulation and good governance. (d) A growing trend to voluntarism – in accountability, in "codes of conduct," and in openness regarding social and environmental performance – is a mitigating factor needing to be taken into account in devising regulatory constraints and/or green taxation. Ensuing discussion revealed hesitancy among some workshop attendees in accepting the efficacy of voluntarism, which, while recognized as one item in the arsenal of incentives, cannot be relied upon as a substitute for strict environmental laws and regulations.

David Chambers drew on his experience with environmental groups in addressing issues surrounding conflicts between environmental and economic interests in mineral development. He took note of various analytical techniques for setting a monetary price tag on such not-easily-quantifiable societal values as a clean environment, citing tools particularly favored by economists – e.g., contingent valuation, hedonic pricing, or inferences drawn from market transactions. In his discussion, however, he chose to dwell on still an additional approach – the “political process model” – which he believes best captures the framework within which resource development-vs.-environment debates and decision-making actually take place. Thus, in contrast to some NGOs with their macro, top-down perspective, Chambers describes his own organization (the Centre for Science in Public Participation) as one whose approach proceeds exclusively from a bottom-up, community-level orientation.

Nevertheless, even that more realistic setting is not necessarily a basis for optimism about the successful resolution of development-environment conflict, for Chambers believes that, even in a forum that allows the airing of divergent views, the combination of political, community, and mining interests are such that having an economically defensible project rejected for environmental or social reasons is often unlikely. No doubt a command-and-control regime could achieve results that this interplay or market considerations and political discourse cannot be depended on to produce, though Chambers’ reflections suggest that, in that case, the cure will be worse than the disease. In short, a somewhat gloomy assessment of things.

The discussion that followed highlighted the tension – not easily resolved – between, on the one hand, a firm’s incentive to explore and profit from its investments, and, on the other, the environmental contingencies it must inject into its risk assessment. For example, if mining property is appropriated for, say, a public wilderness area, equitable compensation can become a critical matter. Two related issues that remain to be satisfactorily resolved: the means of financing the remediation and treatment of abandoned and polluted mine sites; and the use and imposition on operating mines of taxes, bonding, or insurance requirements to cover social and environmental costs in the event of bankruptcy or mine closure. It seems evident that, while broad principles may, on a somewhat abstract level, have their global relevance, factors of scale – local, national, regional – will require targeted attention and analysis.

Some Concluding Reflections

Before its conclusion, **John Tilton** reviewed some of the principal themes of the workshop, singling out topics particularly germane to his manuscript. Not surprisingly, the task of identifying and putting a monetary value on externalities poses a formidable challenge as does the closely related dilemma of conducting an analysis that takes account of sustainability, however defined – no mean quandary in itself. Both of these topics spurred lively debate among the workshop participants, some of whom cautioned that we recognize the extent to which different levels of per capita income among countries and communities may lead to different values being placed on social and environmental externalities.

Externalities aside, it may be useful, in these closing paragraphs, to revert briefly to the other key theme of the workshop – the matter of depletion. On that question, Tilton had earlier discussed the recourse, in his manuscript, to the concept of a “cumulative supply curve” – a stylized, but pedagogically useful, representation of how the total stock of a mineral commodity varies over the indefinite future with its cost and price. He pointed out that the curve forces us to consider, and allows us to debate, the three key sets of forces that influence its shape and behavior – geology, society's commodity needs, and technological change.

The *geologic* phenomenon is one of the factors explaining the shape and upward sloping character of the curve; for, under given technological circumstances, only a rising price can elicit additional supply from new discoveries or less accessible deposits. *Society's needs* for mineral commodities – governed by population growth, rising living standards, and other factors – determines where on the curve we find ourselves at a particular point in time; while the rate at which these demographic and other demand factors change will, absent other changes, drive up mineral costs and prices. *Technological progress* would be reflected in a shift in the curve such that available supply would expand at a given price or, alternately, the price would drop for a given supply of the resource.

The discussion of the cumulative supply curve, notwithstanding participants' recognition of its conceptual virtues, raises a point touched on several times throughout the workshop: the question of whether there might be severe discontinuities in geologic occurrence as to cause a steep jump in costs and price somewhere along the curve and the immediately relevant challenge for technology to attenuate that turn of events. These matters are also guaranteed to be the stuff of serious mineral studies in the years to come.

Appendix A. Program and Attendee List

THE LONG-RUN AVAILABILITY OF MINERALS

A Workshop Sponsored by Resources for the Future and by
the Mining, Minerals and Sustainable Development Project,
Sunday, April 22-Monday, April 23, 2001

Sunday, April 22, Governor's House Hotel, 1615 Rhode Island Ave., NW, Washington DC

6:00 p.m.	Reception
7:00 p.m.	Dinner and Keynote Remarks by Prof. Brian Skinner (Yale University)

Monday, April 23, Resources for the Future, 1st floor, Conference Room C, 1616 P St., NW, Washington DC

8:00-8:30 a.m.: Coffee/rolls

8:30-8:45: Greetings by Paul Portney (President, Resources for the Future) and Caroline Digby (Research Manager, Mining, Minerals and Sustainability Project)

8:45-9:45: Introductory Session – "Purpose and Overview," John Tilton (Colorado School of Mines), followed by discussion

9:45-10:00: Break

10:00-12:15: Session One – "Conceptual and Empirical Perspectives: Economics, Geology, Technology"
Chair: Brian Skinner (Yale University)
Discussants:
John DeYoung (U.S. Geological Survey)
Lisa Morrison (Resource Strategies)
Toni Marechaux (National Academy of Sciences)

12:15-1:00: Working Lunch

1:00-3:15: Session Two – "Mineral Production and Use: Social Costs and Implications for Sustainable Development"
Chair: Glenn Miller (University of Nevada, Reno)
Discussants:
Raúl O'Ryan (Universidad de Chile)
David Humphreys (Rio Tinto Ltd.)
David Chambers (Centre for Science in Public Participation)

3:15-3:30: Break

3:30-5:00: Closing Session – "Reflections on the Day's Discussions"
Chair: Michael Toman (Resources for the Future)
Presentation: John Tilton (Colorado School of Mines)

5:00 Adjournment

Workshop Participants

Maria Laura Barreto
Centro de Technologia Mineral
Rua Quatro, Quadra D
Cidade Universitaria Ilha do Fundao
Rio de Janeiro 21941-590
Brazil
(T) + 55 21 260-9835
(F) + 55 21 260-9835
lbarreto@cetem.gov.br

Robert Cairns
Professor, Department of Economics
McGill University
855 Sherbrooke Street
Montreal H3A 2T7
Canada
(T) +514 398-3660
(F) +514 398-4938
rdcairns@hotmail.com

Brian Chambers
Chief, Resource Development Section
UNCTAD, Commodities Division
Palais de Nations
Geneva 10
Ch-1211 Switzerland
(T) +41 22 907-11234
(F) +41 22 907-0047
brian.chambers@unctad.org

David Chambers
Centre for Science in Public Participation
224 N. Church Avenue
Bozeman, MT 59715-3706
(T) +1 406 585-9854
(F) +1 406 585-2260
dchambers@csp2.org

Sarah Cline
Resources for the Future
1616 P Street, NW
Washington, DC 20036
(T) +1 202 328-5105
(F) +1 202 939-3460
cline@rff.org

Joel Darmstadter
Senior Fellow
Resources for the Future
1616 P Street, NW
Washington, DC 20036
(T) +1 202 328-5051
(F) +1 202 939-3460
darmstad@rff.org

John DeYoung
Chief Scientist
U.S. Geological Survey
988 National Center
Reston, VA 20192
(T) +1 703 648-6140
jdeyoung@usgs.gov

Caroline Digby
Research Manager
Mining, Minerals and Sustainability Project
International Institute for Environment
And Development
1a Doughty Street
London WC1N 2PH United Kingdom
(T) +44 (0) 20 7269-1634
(F) +44 (0) 20 7831-6189
caroline.digby@iied.org

Roderick Eggert
Professor and Director, Division of
Economics and Business
Colorado School of Mines
Golden, CO 80401
(T) +1 303-273-3981
(F) +1 303 273-3416
reggert@mines.edu

Magnus Ericsson
Raw Materials Group
P.O. Box 44062
Grondalsvagen 118
Stockholm S-10073
Sweden
(T) +46 8 744-0065
(F) +46 8 744-0066
magnus.ericsson@rmg.se

Thomas E. Graedel
Professor of Industrial Ecology
School of Forestry and
Environmental Studies
Yale University
205 Prospect Street
New Haven, CT 06511
(T) +1 203 432-9733
(F) +1 203 432-5556
thomas.graedel@yale.edu

David Humphreys
Chief Economist
Rio Tinto
6 St. Jame's Square
London SW1Y 4LD
United Kingdom
(T) +44 20 7930-2399
(F) +44 20 7930-3249
david.humphreys@riotinto.co.uk

Richard Kerr
Writer
Science Magazine
American Association for the
Advancement of Science
1200 New York Avenue, NW
Washington, DC 20005
(T) +1 202 326-6587
(F) +1 202 371-9227
rkerr@aaas.org

Hans H. Landsberg
Senior Fellow Emeritus
Resources for the Future
(T) +1 301 656-8666
(F) +1 202 939-3460

Toni Marechaux
Director, National Materials Advisory
Board and Board on Manufacturing and
Engineering Design
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418
(T) +1 202 334-2000
tmarecha@nas.edu

Luís Martins
Head, EuroGeo Surveys Policy Sector
Instituto Geológico e Mineiro
Estrada da Portela – Bairro do Zambujal
Apartado 7586
2721 – 866 Alfragide
Portugal
(T) +1 351 21 471-8922
(F) +1 351 21 471-8940
luis.martins@igm.pt

Glenn Miller
Director, Environmental Sciences and Health
Mackay School of Mines
University of Nevada
Reno, NV 89557-0139
(T) +1 775 784-4108
(F) +1 775 784-1142
gcmiller@scs.unr.edu

Richard Minnitt
Associate Professor of Mineral Economics
Department of Mining Engineering
University of the Witwatersrand
Johannesburg
Private Bag 3
2050 WITS South Africa
(T) +27 (+11) 717-7416
(F) +27 (+11) 339-8295
minnitt@egoli.min.wits.ac.za

Lisa Morrison
Resource Strategies
495 Thomas Jones Way, #206
Exton, PA 19341
(T) +1 610 363-6700
lisa.morrison@rsic.com

Carmine Nappi
Director, Industry Analysis
Alcan Aluminium Limited
1188 Sherbrooke Street West
Montreal, Quebec H3A 3G2
Canada
(T) +1 514 848-8134
carmine.nappi@alcan.com

Raúl O'Ryan
Department of Industrial Engineering
Universidad de Chile
Domeyko 2361
Santiago
Chile
(T) +562 678-4061/4066
(F) +562 689 54-55
roryan@dii.uchile.cl

Paul R. Portney
President and Senior Fellow
Resources for the Future
1616 P Street, NW
Washington, DC 20036
(T) +1 202 328-5103
(F) +1 202 939-3460
portney@rff.org

Juanita Gana Quiroz
Roberto del Rio 1540, Depto 305
Santiago
Chile
jganaq@yahoo.com

Felix Remy
The World Bank
2121 Pennsylvania Avenue, NW
Washington, DC 20433
(T) +1 202 473-4236
(F) +1 202 522-0396
fremy@worldbank.org

Brian Skinner
Professor Geology Department
Yale University
P.O. Box 208109
New Haven, CT 06520-8109
(T) +1 203 432-3175
brian.skinner@yale.edu

Larry Smith
Manager, Project Evaluations
Billiton Base Metals
120 Adelaide Street West, Suite 2600
Toronto, Ontario M5H 1W5
Canada
(T) +1 416 365-6568
lsmith@rioalgom.com

John E. Tilton
Coulter Professor of Mineral Economics
Colorado School of Mines
Golden, CO 80401
(T) +1 303 273-3485
(F) +1 303 273-3416
jtilton@mines.edu

Michael A. Toman
Director, Energy and Natural Resources Division
and Senior Fellow
Resources for the Future
1616 P Street, NW
Washington, DC 20036
(T) +1 202 328-5091
(F) +1 202-939-3460
toman@rff.org

Mike Waller
Chief Economist
BHP
600 Bourke Street
Melbourne
Victoria 3000
Australia
(T) +61 3 9609-3132
(F) +61 3 9609-3111
waller.mike.ma@bhp.com.au

April 18, 2001

Appendix B. Tentative Chapter Outline of John Tilton's Manuscript "Depletion and the Long-Run Availability of Mineral Commodities"

Chapter 1

The issue: Availability of non-renewable mineral resources is a long standing concern. Many feel it is just a matter of time before our minerals are depleted, other believe they are for all practical purposes inexhaustible.

Purpose, scope, and organization: Much written on this topic over the past 30 years. Purpose is to provide an overview of this work and place it in a conceptual framework for the non-specialist. What have we learned? Where is there widespread agreement among experts? Why does the debate continue? What are the important implications of what has been learned?

Chapter 2

Concern over the availability of mineral resources can be traced back to the Classical economists, and continues today in the sustainable development movement. This chapter will review this literature, contrasting concerns over renewable and non-renewable resources.

Chapter 3

Many different measures have been used to assess long-run trends in resource availability. This chapter will identify these measures, and assess their usefulness. Physical measures (e.g., reserves, the resource base) will be considered, along with pure economic measures (e.g., real prices, real costs). This chapter will explain in terms a non-specialist can understand the concepts of user costs, economic depletion, physical depletion, Ricardian rents, Hotelling rents. It will note that resource costs can actually decline over time if the cost-reducing effects of new technology more than offset the cost-increasing effects of resource depletion.

Chapter 4

This chapter will explore trends in resource scarcity over the past century. It will review the seminal work of Barnett and Morse on trends in production costs, and the more recent work of Slade and others on mineral commodity price trends. Most of the studies in this area indicate that scarcity has declined substantially over the past century, but a number also suggest that this favorable trend has over the past several decades come to an end.

Chapter 5

The past, of course, is not a perfect guide to the future. This chapter will look at the availability of mineral resources over the near future (the next 50 years) and the distant future. Are there good reasons to believe that the favorable trends over the past century will not continue? Here the work of Skinner on the geological nature of deposit formation will be considered. The cumulative supply curve for mineral commodities will also be introduced as a useful conceptual technique for categorizing the various factors that will determine future trends in mineral resource availability.

Chapter 6

So far the analysis has not considered the environmental and other social costs associated with mineral exploitation that are not paid for by producing firms and ultimately the consumers of mineral commodities. This chapter, described above under item 2, will address these costs, and consider how they are likely to affect mineral resource availability.

Chapter 7

This final chapter will highlight the important findings, and explore their implications for sustainable development, green accounting, population growth and poverty, the protection of social goods (e.g., indigenous cultures, biodiversity) that may be incompatible with mineral extraction, and public policies to promote recycling and the use of renewable resources. For example, this chapter will address the question: Is sustainable development (here probably defined narrowly as a future where opportunities of coming generations are as good or better than the opportunities of the present generation) possible with growing scarcity of mineral resources? Or alternatively, if mineral resources are becoming less scarce does this ensure sustainable development? Other questions might include: Can society prohibit mineral exploitation to protect indigenous cultures or biodiversity without creating mineral resource scarcity? Does the availability of mineral resources necessarily impost a ceiling on the world's population?

Appendix C. Excerpted Comments by Discussants

Conceptual and Empirical Perspectives: Economics, Geology, Technology

John DeYoung (U.S. Geological Survey):

The draft of John Tilton's proposed study (outlined in Appendix B) presents a remarkably large number of views and approaches that describe and analyze the puzzle of mineral-resource availability and sustainable development. I have grouped a few thoughts under four headings.

(1) <u>Terminology</u>. A major obstacle to reaching agreement on the long-run availability of mineral resources is our inability to reach a common understanding on definitions of terms and to practice their use consistently. This is one of the reasons that the debate continues over 200 years after Malthus and that intelligent and informed people engage in debate despite all the work that has been done on this issue. The dichotomy of physical versus economic views of scarcity, while appealing to some, may obscure the fact that because both physical and economic factors are needed to define resources, they both must be considered in analyzing the role of resources in sustainable development.

Although resources are defined physically and economically, the availability of resources is a function of social realities. Environmental concerns in general (air, land, and water pollution), issues of social justice, withdrawals of land either explicitly or implicitly, questions of traffic or noise or dust, impacts on biodiversity, all act as limits on potential production. One strong motivation for **recycling** is the desire to limit these perceived adverse impacts—not just to limit potential scarcity. The perceived **externalities** of nonfuel mineral production are strongly linked to supply.

(2) <u>Essential minerals and substitution</u>. Nitrogen, phosphorus, and potassium can be thought of as the only essential nonfuel mineral elements. They are essential because they have no substitutes and because their production is required to support the agricultural base of human society. These three elements exist in almost inexhaustible resources. Nitrogen can be extracted from the atmosphere, potassium from vast deposits, and phosphorus exists in igneous apatite, outside the still vast marine phosphorite deposits that are the source of the majority of current production. All other nonfuel minerals have known substitutes—including organic substitutes—for some, if not all, of the properties they impart to final products. Even so, many of the most economically important minerals are in vast supply, including construction minerals, limestone, aluminiferous ores, iron ores, and magnesium, and could, in the long-term, substitute for some functions of less common minerals such as copper.

(3) <u>Physical factors that may restrict availability; studies of grades and tonnages and reserves and resources</u>. A schematic representation of the physical factors that affect

metal supply (and that were alluded to by Singer (1977)) was presented in the 75th Anniversary Volume of Economic Geology (DeYoung and Singer, 1981, p. 940). The flow chart was used as a framework for a discussion of the effects that grade, tonnage, depth, geographic location, grain size, and mineralogy have on the discovery and production stages of a mineral resource. Some researchers have made global calculations of crustal content (Erickson, 1972) or sought extrapolatable meaning in the relation between crustal abundance and reserves (McKelvey, 1960). Other researchers have examined the role that these variables (especially grade and tonnage) have at the mine or district level.

For example, about 50 years ago USGS geologist Samuel Lasky wrote a paper concerning the relation between tonnages of "ore" (material produced or in place) and the associated average grades (Lasky, 1950). The assertion that Lasky and later writers assume that tonnage of mineralized material increases exponentially as grade declines arithmetically has been misinterpreted to predict exponential increases in metal (DeYoung, 1981). It is the mineralized material ("ore"), not metal, that increases. In fact, using Lasky's equation, an increase in "ore" may be consistent with a decrease in metal! Statements by Lasky in his 1950 paper indicate that he understood the limitations of this type of analysis, but these limitations have not been apparent to many subsequent researchers.

(4) Recent consumption trends and implications for developing economies. Tilton examines variables that determine primary commodity demand—population, real per capita income, intensity of use, and secondary production and the relation between resource availability and world population. Recently, Dave Menzie and I (DeYoung and Menzie, 1999) examined major trends in the per capita industrial consumption of aluminum, cement, copper, and salt in the United States, Japan, and the Republic of Korea at 5-year intervals between 1965 and 1995. The three countries were chosen to cover a mature industrial economy, a country that recently reached industrial maturity, and a country that has been undergoing rapid industrialization.

We made several observations about per capita consumption in the three countries. Firstly, we noted that temporal patterns of commodity use per person vary by commodity for each country. No single pattern of behavior is evident in all cases. For the United States, commodity use per capita has been stable for cement, copper, and salt. The pattern of use of these commodities would be consistent with the phenomenon of dematerialization or decreased intensity of use of a commodity with an increasing GDP in mature economies (Wernick and others, 1996). In contrast, consumption per capita of aluminum has grown slowly and steadily from 17 kilograms per person in 1965 to 30 kilograms per person in 1995. This may be due to substitution of aluminum for steel in manufactured goods such as automobiles. For Korea, per capita commodity use has grown exponentially for aluminum, cement, and copper. Growth of per capita consumption of salt has been significantly slower. Growth of these first three commodities mirrors the industrialization of Korea. Japan shows patterns of commodity use that are intermediate between those in the United States and Korea. This reflects the fact that Japan industrialized after the United States and before Korea. Japan shares

Korea's pattern of salt use. Both countries lack primary supplies of petroleum that form the basis for petrochemicals.

Our studies showed that as Korea changed from a developing to a developed economy between 1965 and 1995, it increased its per capita consumption of aluminum, cement, and copper and decreased its annual population growth from 5 percent to 1 percent. Based upon this study of mineral consumption in Japan, Korea, and the United States, we hypothesized that while per capita consumption of some commodities, such as cement and copper, has stabilized in developed countries, per capita consumption of other commodities, such as aluminum, continues to grow.

A subsequent paper (Menzie, DeYoung, and Steblez, 2000) examined changes in consumption of the same four mineral products (aluminum, hydraulic cement, refined copper, and salt) for 17 (China, India, the United States, Indonesia, Brazil, Russia, Pakistan, Japan, Mexico, Germany, Philippines, Iran, Egypt, Turkey, Thailand, the United Kingdom, and France) of the 20 most populous countries in the world as of 1996 for the period 1970 to 1995.

This study, which includes additional developed countries (Germany, UK, and France), supports the earlier finding that the per capita consumption of some commodities, including cement and copper, does not change greatly over relatively long periods and per capita consumption of other commodities, such as aluminum, continues to increase in most developed countries. In addition, we identified additional countries that are significantly increasing consumption of aluminum, cement, and copper. China, Thailand, and Turkey show significant increases in the per capita consumption of all three commodities. Several other countries show significant increases in one of the commodities – aluminum (Mexico), cement (Egypt), and copper (Iran). Other of the 20 most populous countries, such as India and Indonesia, show increases in per capita consumption of several commodities, but their growth is not as advanced as that of the previously mentioned countries.

These results suggest that there could be major increases in mineral consumption mainly within developing countries within the next 25 years. For example, in 1970, Korea's per capita consumption of copper was negligible; by 1995, Korea's per capita consumption of copper was 14 kilograms per person. In 1970, China's per capita consumption of copper was about one-quarter of a kilogram per person; by 1995, China's per capita consumption of copper was more than 1 kilogram per person, or about 1.3 million tons per year. This represents a growth rate of about 6 percent per year. If China's growth in consumption continues at about the same rate for the next 25 years, its per capita consumption of copper would be about 4.8 kilograms per person. If this rate of increase in per capita consumption is maintained for the next 25 years and China's population continues to grow at its current rate, China's consumption of copper in 2020 could exceed 8 million tons. Total world consumption of copper in 1995 was only 10.5 million tons. If China's rate of growth of per capita consumption of copper were to increase to a per capita consumption of 10 kilograms per person, its consumption of copper in 2020 could be nearly 17 million tons. Thus, if China's per capita consumption of copper continues to increase, its consumption of copper in 2020 could exceed that of the entire world in 1995.

Acknowledgments

I am grateful to David Menzie and Eric Rodenburg, colleagues at the U.S. Geological Survey, for their invaluable suggestions, additions, and technical review.

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Robin Adams/Lisa Morrison (Resource Strategies):[2]

Background

Numerous of the topics explored at this workshop arise from a growing concern about the need for "sustainable development". The core issue is therefore whether the inherently non-renewable nature of mineral resources poses a limit to sustainable development.

Physical Availability

In dealing with the (largely) "non-issue" of physical scarcity, it is worth noting the basic point that many mineral resources are not destroyed as they are "consumed" but merely transformed into some other form. Gold is an extreme example. Still, it may be instructive to ponder whether there are any commodities that are actually destroyed for which there are no long-term substitutes.

Notwithstanding its bugaboo character, the running-out theme doesn't look for adherents or audience. Thus, *The Limits to Growth* was extraordinarily influential and completely wrong in its prognosis. Moreover it has been indirectly responsible for a very great deal of financial, political and environmental mischief – government seizure of mineral assets in the 70s, huge financial losses in state run mining companies, inappropriate development with environmental risks, political corruption and so forth. A contemporary example – the Bush administration's desire to open up the Arctic National Preserve to oil drilling – demonstrates the practical consequences of this kind of mentality.

Economic Scarcity

The academic studies are inconclusive and depend on technical issues such as the measurement of inflation and on debates over the stability or otherwise of coefficients in various econometric hypotheses. Most applied economists, industry participants and financial institutions believe that both costs and prices have been falling, generally between 0% per annum and 3.5% per annum. They do differ regarding the rate at which future declines can occur, largely depending on differing assessments of the timing and significance of technology changes in the pipeline. However, there is very little support for the proposition that natural resource commodity prices will rise in real terms any time soon.

The subject of trends in royalties may warrant a closer look. With rising scarcity, the incidence of Ricardian rents should be on the increase. Anecdotally we believe the reverse is true. In particular governments are becoming less aggressive in respect of royalty regimes than in the 1980s.

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[2] Comments were delivered by Lisa Morrison.

In liquid commodity markets, the opinions of all relevant players are captured in the structure of cash and forward prices. At present, there is very little liquidity in distant positions (i.e. 10+ years out). Specifically consumers have not been prepared to pay a premium for long-term secure supply (in contrast to large premiums for immediate delivery in certain cases).

In general, therefore, markets are telling us not only that these commodities have not historically exhibited economic scarcity, but that they are not expected to do so in the future.

Environmental and Social Impacts

The new version of limits has the world collapsing not because we run out of resources but because we poison ourselves trying to extract and use these resources. Is this a modern version of revisionist communism ? Capitalism was supposed to collapse in the face of the proletarian revolution, then as a result of successful competition from communism, then because of the pollution is causes etc., etc.

An initial issue that is not adequately covered is whether the exploitation of lower grade and more difficult ores necessarily imposes increased environmental cost. As a Devil's advocate, let me suggest the opposite is true. Underground mines have less environmental impact than open pit mines. As the study says, artisanal mining is resource exploitation at its worst. Artisans are not going to be able to mine undersea manganese nodules! The thesis that putting more economic resources into resource extraction means creating a bigger environmental impact is just that – a thesis. It has not been subjected to rigorous analysis. Intuitively we argue the opposite is likely to be the case. Modern mining operations conducted by large and technically sophisticated companies appear to have a lesser environmental impact that older operations, particularly now that financial markets are sensitized to the potential liabilities – witness the impossibility of funding nuclear power in the private markets.

Government action to internalize externalities represents the standard economist's answer. Unfortunately there are both practical and theoretical problems. At the practical level, unilateral efforts will probably simply encourage production elsewhere. Multilateral efforts are seen as a code word for protectionism by the industrial countries. The theoretical problem is more difficult. Take global warming. What is the right "price" for a permit to emit carbon dioxide ? We do not really know what will be the impact of global warming, so how can be price this damage in order to internalize it ?

The case of the auto industry in Switzerland presents a useful dose of reality. Gas prices are 4 times those of North America, parking is highly restricted and expensive in all urban areas (and it is enforced !) and there is arguably the world's best modally integrated public transit system. Yet Swiss buses and trains are half empty, the highways are clogged despite massive environmentally damaging highway construction in the Alps. Might it not be the case that no politically viable level of gas taxes will modify behavior

– suggesting mandatory technical standards as a substitute. In short, while we agree with the theoretical case, the practical issues limit what can be achieved.

A more significant issue, in my opinion, is the impact in specific communities. While we are not going to run out of mineral resources (physically or economically) in general, we are going to run out at specific mines and in specific communities. Thus at the microeconomic level mining is, de facto, unsustainable. The assumption that the factors of production used in mining can find a substitute use in alternative activities when mining ceases is overly optimistic in many instances. Moreover this problem is going to get worse as we move to more remote regions to find new mineral deposits.

There are several reasons why this is inevitable:

(1) historic underexploitation or resources in developing countries relative to industrial countries
(2) NIMBY opposition to mineral development in richer countries

There are a number of serious problems and deficiencies arising from mine closure planning. These involve not only physical closure, environmental rehabilitation and long-term safety, but also the social closure plan. Not only are such costs not adequately considered when the feasibility studies are done, but they are not accounted for realistically in corporate financial statements.

Conclusion

The broad conclusion that the non-renewable nature of mineral resources has only a tenuous link with sustainable development at the macro level seems unassailable. We are obviously not running out of resources from a physical perspective, the economic evidence suggests that both producer and consumer technology gains are more than offsetting any depletion despite a record acceleration in use and the notion of an environmental limit (at a macro level) is largely conjectural.

However, it is also the case that the impact of this industry at a local and community level, where these resources *do* run out, can pose a serious dilemma. Not only does mining have a huge social and environmental impact in a limited area but it also has eventual consequences that do not tend to be properly understood as part of the initial decision making process. Moreover there is little or no international political or industry consensus on how to deal with these real problems. In our view it would be useful for this issue to be forcefully confronted. The big picture is reassuring. It is the little picture that is more problematic.

Toni Marechaux (National Academy of Sciences):[3]

Comments on Technology and Minerals Sustainability

History clearly demonstrates the role of technology in keeping the minerals supply adequate for our constantly escalating needs. We no longer mine native copper, nor pan for gold nuggets, nor find oil bubbling from the ground, yet we mine and use these minerals daily. However convincing the evidence, the American public professes little apparent faith this trend can continue. The technologist, conversely, easily recognizes that new opportunities to extend the reserve and resource base are far from finite. Discussed here are several technology options in the various stages of mineral extraction, processing, and use.

Mining traditionally provides raw materials and energy to fuel our economy. In doing so, mining and mineral processing consumes more than 3% of industrial energy used in the United States. By making mining (and all industrial processes) more efficient, our reserves of coal, oil, natural gas, and uranium can be substantially extended. For this reason, energy efficiency and process improvements are highlighted throughout this discussion.

Exploration

Identifying new and better resources is the most obvious place to apply new technologies to minerals sustainability. Airborne and satellite imaging systems have already been proven to discover deposits invisible from the ground, and this technology is still in its infancy. Advanced simulation and modeling of geologic formations only gets more effective as computer processing speeds increase and more physical information can be considered. Finding richer and more accessible deposits is a straightforward way to apply new technologies and extend the reserve base.

Resource Characterization

Better characterization of existing deposits is a very effective way to extend life and increase yield of current reserves. Underground imaging, either with borehole systems or directly from the surface, has many benefits. It allows the mining of higher quality minerals, and can enable mining while moving less overburden and less 'interburden' (low quality material interspersed among higher quality regions).

Better characterization technologies can also enable the exploitation of deposits currently considered impossible to develop. Mining smaller deposits, thinner seams, or deeper ore bodies can become realistic by accurately demonstrating ore location, quality, and projected value. In addition, better characterization of surrounding strata can enable the use of other technologies such as advanced blasting strategies or in-situ mining.

[3] Formerly with U.S. Department of Energy until April 2001.

Mining

The excavation and removal of ore is an integral part of a larger process to produce industrial and consumer products. In doing so, it may also produce a large amount of industrial waste.

Mining can be a crude and brutal process, involving drilling, blasting, and excavating tons of overburden to reach the ore, and then proceeding to do the same to remove the ore deposit itself. Technologies such as in-situ mining, bio-processing, or solution mining can result in far less material removed by leaving the deposit in place and removing the dissolved product via pumping. Advanced tunneling technologies could mean the elimination of blasting altogether, which would provide a large boost to productivity and safety by removing a potential threat and reducing noise, dust, and seismic consequences.

The social costs of mining certainly include the safety and health of workers. More than a thousand people still die from black lung disease each year due to coal dust exposure, and exposure of all underground miners to the effects of diesel particulates is only beginning to be understood. Diesel engines are possible culprits in hearing loss for many miners as well. Many technologies that will improve productivity will also affect worker health and safety. A primary example is fuel cell mining vehicles to replace diesel propulsion. Another cutting edge technology is underground positioning and communication devices that work through-the-earth using handheld antennae. This communication technology provides a tremendous safety advantage, but combined with positioning and sensors, can improve process control to new levels. Innovative ventilation strategies in underground applications can save substantial energy, increase worker health, and improve climate control.

If more non-invasive mining technologies and teleoperation schemes can be commercialized, deposits in currently inaccessible locations can become viable. This clearly includes the known smaller deposits and thinner seams, but also may extend our reserve base to include deposits under cities, or in remote locations like the Arctic Circle, or even in outer space.

Mineral Processing

Prior to the smelting and refining stages of processing, the most energy-intensive process in mineral production is comminution, or crushing and grinding of rock into powder prior to separation of ore and waste. By some estimates, this process consumes more than 90% of all processing energy. By mining more efficiently, less material needs to be processed this way, and a tremendous energy savings can be realized.

New mineral processing technologies can make currently underutilized reserves more productive. For example, aluminum metal is today made from bauxite, or alumina. Deposits of alumino-silicates are far more widespread and more easily accessible. If a viable process existed, the aluminum reserve base would be greatly increased.

Developing processing methods that use less toxic chemicals, less water, or no water at all would result in fewer tailings and vastly reduced industrial waste production.

Product Engineering

Redesigning end-use products to maximize efficiency during manufacture and use, as well as for recyclability is key to extending the reserve base. Some examples include:

- Consumer products. Reducing packaging and applying innovative concepts like edible food wraps.
- Durable goods. Engineering vehicles and appliances to be lighter and stronger, to have more recycled content, and to be more efficient.
- Constructed environment. Using industrial waste products like mine tailings in cement, foundry sand in concrete, demolished buildings for road fill, and many others.

Recycling

This is the other obvious place (in addition to exploration) to apply new technologies to increasing the reserve base. However, the main barriers to recycling are not technologies, but are distance, regulations, and knowledge. Too often, it is not economical to transport the collected glass or paper to an appropriate processing plant. Many times, it is illegal to take an industrial waste containing a valuable mineral across state lines or on a major highway. And finally, many manufacturers are unaware of other industrial processes that might use their waste products effectively.

Some technology problems do exist, and must be solved. The amount of trace metals in foundry sand, for example, currently precludes its use in concrete. Another timely example is trace radioactivity found in a small fraction of steel scrap that is currently threatening the entire steel recycling industry.

Substitution

In my opinion, every engineered material has multiple possible materials and manufacturing paths. (In fact, there are only three elements with no possible substitute.) For example, a potential shortage of chromium in the 1970's triggered a successful research program to develop a new class of superalloys. A rise in the cost of sulfur can mean more use of chlorine. A new manufacturing process for transparent alumina can reduce the demand for polycarbonate.

Today, product choices are based on a combination of factors, including availability, price, and marketing strategies. By educating producers, manufacturers, consumers, and recyclers, choices in the future might be made based on environmental impact or the extent of the reserve base. Technology can ensure buyers have these choices and can exercise their collective judgment.

Summary Remarks

What is the role of government in all of this? In the case of the U.S., the federal, state, and local governments provide many services that can contribute to the materials cycle. These include data collection and dissemination, materials and processing regulations, and research and technology funding. In this author's opinion, the government should apply these tools to bring us closer to a closed loop, where the waste product from any process is the feed stock for another. Too often, however, this is not the end goal of government data, technology, or regulatory actions.

It is important to consider that economics have already driven large portions of the materials cycle into this loop. Automobiles are recycled to their full extent, and a larger and larger portion of each shredded vehicle is put back into the cycle. Steel produced from scrap using electric arc furnaces has taken over more than half the US market, and is targeting the rest. The government must tread carefully to ensure these functions are continued.

Materials producers and manufacturers today realize that any pollution they emit is a product they are not selling. Many are actively seeking markets for their waste products, but many of these markets are obstructed by regulations, distance, or lack of knowledge of potential uses. Others have legitimate technology barriers to the application of waste products in new processes and industries, and these beg to be addressed.

In this author's opinion, many companies and consumers, given adequate information, will make sensible choices to preserve natural resources. Recommended actions include:

- Better and more thorough collection and dissemination of data on materials and energy flows
- Reduced materials and energy intensity of products through technology deployment
- More effective recovery of mineral resources

If these actions are taken today, and continued successfully in the future, there is no reason to believe that the Earth's mineral resources cannot be sustained indefinitely.

Mineral Production and Use: Social Costs and Implications for Sustainable Development

Raúl O'Ryan (Universidad de Chile):

Although economic availability is at least as significant as—if not more than—physical availability, the matter of social costs and sustainable development adds a dimension with potentially significant implications for both the quantitative assessment of resource availability and the cost of extraction. There are four issues related to this topic that deserve particular attention.

(1) <u>Defining Sustainability</u>. The frequently cited "Brundtland" definition—satisfying the needs of today's society without compromising the needs of future generations—though widely accepted as a legitimate position on ethical and economic imperatives, may be too broad for the operational specifics of the mineral industry.

Two key points here are:

> (i) What makes mining different from other productive sectors, and why is it especially relevant to sustainable development? Are the rents key, or is it the long-term impacts, or the large investments?
> (ii) The concept of "sustainability" is actually in the eye of the beholder. Producer countries care about the impacts of production on the environment, but also on their development needs. They must weigh carefully these tradeoffs; how they exploit their resources will define their sustainability (economic, social and environmental), while improving the welfare of today's poor. User countries care about global impacts and the impact of metals on their environment and on "future generations". Who should define sustainability? Caring for whom, today's poor or the unborn?

Sustainable development means different things to different countries (and regions):

-Thus, 30 years is very long run for developing countries, meaning that it is difficult to enact policies (e.g., greenhouse gas mitigation) that have an effect after such periods (example global warming).

-Sustainability includes inter- and intra-generational concerns. Developing countries worry strongly today about intragenerational issues (inequity). The focus for developed countries is more on the intragenerational.

-Different countries have different concerns: some care a lot about the environment, others feel they need to grow fast, and others care about inequities and poverty.

I prefer a country-level definition because these resources belong to the country. In its policy application, a definition of sustainable development answers the question: How can a country's mineral resources be optimally employed so as to achieve the maximum economic growth rate consistent with the country's social and environmental objectives?

Here, the degree to which this dual objective is realized becomes the indicator of sustainability.

(2) The Problem of Mining and Local Sustainability. If producer countries are to continue exploiting resources they must begin to consider seriously how the local community feels about them. Mining projects increasingly have to be legitimate for the surrounding community that will live with the projects, and (hopefully) long after! Otherwise the community will hamper their development.

Projects must ensure that: environmental problems are few and manageable; pose no long-run risks (for example ensure adequate closure and abandonment procedures); firms are credible in case of accidents; there are benefits in the present and future for the local community; there is excellent risk communication by the firm, i.e., involvement of community leaders. Without such considerations and safeguards, mining sustainability will be jeopardized by community opposition.

(3) Stigmatization of Mineral Production and Products. This is a serious problem for producer nations. Minerals are increasingly being viewed with suspicion by the general public. This frequently implies greater production, transport and user costs.

- The fact that mineral production has frequently been highly polluting has spawned a negative image of the industry. This state of affairs needs to be changed; otherwise availability will fall as mining projects are opposed. The trend to internalizing social and environmental costs is thus a necessary condition for taking us to a more desired social optimum. The questions here are: is this enough? what else is needed to change perceptions?

- A new trend is the opposition to mineral use based on environmental considerations. With concern that copper may cause health problems, pipes and roofs are being targeted, even though health effects are weakly documented and the sources of these effects are not at all clear. Opposition would be acceptable if the health concerns were warranted. However uncertainties are high and the precautionary principle plus unequal distribution of the costs and benefits of restrictive measures resulting in reduction of copper use, can mean a shift to the use of resources whose health impacts may be no clearer. Opposition by consumers to the use of mineral products is therefore a dangerous threat to sustainability of the sector and producer countries. The political, economic and legitimate health interests behind this threat must be confronted by the sector in the future years.

- To be sure, internalizing the social and environmental costs of production may alter the economic status of the resource but that is to be expected. It is a correct trend under which market forces will take us to a new, more socially desirable equilibrium. However environmental (health) concerns *can* affect the use of minerals with implications for sustainable development in mineral-producer countries. At the same time, increasing mineral costs imply increasing possibilities to substitute away from minerals towards other materials. Producer countries must react now as they ponder these resource issues in the context of their future development.

(4) A “Checklist” of Policy Implications for Mineral Mining

- It is necessary to discuss and define what is unique to mineral mining.
- Sustainability must be defined at the country level.
- Research on health effects of mineral (and substitute products) must be undertaken.
- Local sustainability must be discussed and promoted. Firms should not be left on their own here.
- “Green accounting” techniques—whereby resource and environmental trends can be viewed in their relationship to conventional GDP accounts—can be useful.
- Use of mineral stabilization funds can be considered.
- Small and artisanal mining require support to become cleaner and not “tarnish” the image of the whole industry.
- With particular reference to my own country, objectives for the copper sector must be defined (jobs, foreign currency?).

David Humphreys (Rio Tinto Ltd.):

Over the past 30 years, productivity improvements in the mining industry have permitted mining companies dramatically to reduce their costs of production and at the same time substantially to raise their game in social and environmental matters. However, it remains possible that the full social and environmental costs of mining are not included in the price of mineral products and that more may yet need to be done to bring the private and social marginal costs of production closer into line. In other words, there may still be externalities to be internalised. There are, on the other hand, many ways to skin a cat.

Alternative Approaches

The traditional way to approach this matter is through a variety of regulatory measures. For example, they come through permitting processes designed to ensure that the social costs of establishing a mine are not unacceptably high and that if mining does go ahead that it is required to operate to certain clearly specified standards, which will almost certainly have cost impacts. The conditions specified may well include provisions for eventual closure. These additional expenses, plus the increasingly high costs involved in permitting a mine and preparing the necessary documentation (which these days could well include a million dollar-plus Environmental Impact Assessment), are effectively forms of cost internalisation. And they are not trivial. One of the few sources available on this subject (*Environmental Protection Expenditures in the Business Sector*, Statistics Canada, August 2000), shows that capital expenditures for environmental purposes in the Canadian mining industry in 1997 were C$80 million while operating expenditures for such purposes were C$272 million.

It is no doubt the case that a number of successes of recent years in tackling the pollution association with mining and smelting—increased lead recycling, reduction of emissions from aluminum smelters, and the reduction of sulphur from copper smelters—are all products of legal restrictions, i.e. command and control. The same applies to the advances that have been made in mine site clean-up and rehabilitation, a subject about which Rio Tinto knows a bit in that its clean-up of the Bingham Canyon site in Utah so far cost the company some $300 million.

However, there is an alternative school of thought, associated with the name of Pigou, which believes that taxation—or other forms of 'economic instruments'—potentially have a role to play in forcing private and social costs into alignment. The OECD has, over the years, been a vocal proponent of such environmental taxation which it refers to as 'full cost pricing'. The virtue of this approach, it is argued, is that rather than imposing command and control restrictions on companies engaged in polluting activities, it makes better sense to try and harness the power of the market to incentivise them to behave in a less polluting fashion. I have written arguing against the application of this thinking in mining on a couple of occasions.

So as to avoid misunderstanding, let me emphasise that my comments on this subject have not been intended as a root and branch critique of all forms of environmental taxation, far less of the internalisation of environmental externalities. There are some circumstances where environmental taxation does have something to commend it. However, the circumstances under which environmental taxation can work effectively to address pollution problems are highly restrictive. These circumstances were laid out by a working group of the Confederation of British Industry which I participated in a few years ago. (*Coming Clean: Using Market Instruments to Improve the Environment*, CBI, March 1998.) This group considered that tackling air pollution through taxation was one of the more promising areas, though the strong preference of the group was some form of trading of emission permits. However, there were areas where, for a variety of reasons, the approach seemed much less suitable and mining was numbered among these areas.

The Critique

The first part of the critique against the use of taxation to address pollution problems in mining - though in many respects the least important - rests on practical matters of measurement, scope and enforcement. I am profoundly skeptical of the notion that experts can impute precise values to the environmental impacts of mining through surveys, however well designed and skillfully conducted. This applies particularly to attempts to impute ‘existence values’ to places that interviewees have never visited, have conceivably not previously heard about, and where they will not actually be required to act on their assessment of value by putting their hands in their pocket.

In the draft manuscript prepared for consideration at this workshop, John Tilton offers the plausible suggestion that iron ore miners operating in rainforest areas could be taxed on their acreage mined to incentivise then to find more efficient ways to operate and to reduce deforestation. There is, however, the thorny issue of what criteria should be used in setting the tax. It presumably has to be set at a level high enough to change behaviour. However, if it is set too high then it compromises the company’s ability to invest in new, cleaner, more efficient capital equipment. Bear in mind also that very few other major producers of iron ore are mining in rainforest areas so such a tax could seriously hamper the ability of Brazilian iron ore producers to compete in world markets.

Moreover, in setting the level of the tax, is the frame of reference for valuing the rainforest disturbed, the region, the country as a whole, or the world at large? And how does one take into account reforestation by mining companies? Many strip miners (e.g. in mineral sands and bauxite) typically rehabilitate each year as much as they mine.

Last, but not least, is the issue of enforcement. Who collects the tax and how, and what use is to be made of the tax revenues? Will they be fed back into the affected region and be used for environmental purposes or just treated as general taxation? Extracting taxes from large public companies may pose few problems but if much of the environmental damage is being done by small-scale and illegal miners then this does not contribute much towards environmental objectives.

Call these practical issues of implementation but they seem to me to be petty fundamental problems, the resolution of which is likely to be extremely difficult and highly controversial. The industry, and many outside also, are always going to feel uncomfortable about the results of these exercises and to dispute the outcomes.

My second, and more substantive concern about economic instruments arises from the specificity of mining. Every site is different and each needs to be treated according to its particular characteristics. The absurdity of assuming otherwise is well illustrated by the UK government's proposed introduction in 2002 of a flat-rate (mineral) aggregates tax across the industry when the research it commissioned into the subject revealed huge differences (from £0-£22 per tonne) in social and environmental externalities at different sites. The aggregates tax, set at a flat £1.60 per tonne across the industry, provides no incentive for producers to locate in areas creating less environmental damage, is unlikely to influence consumer behaviour (since demand is highly inelastic), and is to all intents and purposes just a form of generalised taxation.

While in principle, of course, it would be possible to impose a different tax at each site, this runs into massive practical problems of evaluation and administration. More fundamentally, unless the basis for the taxation can be cast in clear, objective, transparent and universal terms, such differential taxation risks contravening a basic principle of equity under the law. (See F A Hayek's *The Constitution of Liberty,* Chapters 10 and 14.)

A third objection that I have is that imputing externality values is an expert-based process and that the experts involved will not typically be themselves either impacted by the mining activities under investigation nor ultimately responsible for living with the consequences of their advice. It is, in essence, a technocratic, top-down approach where the analyst deals with the issue then goes away, leaving the implementation of recommendations to others. This may been an odd objection, coming from an economist. However, it is fundamental since it raises both issues of legitimacy and of effectiveness of implementation.

The issue of legitimacy arises from the fact that the impacts of mining are largely local ones and therefore community ones. As such it is the community itself which should have the predominant voice in assessing the social and environmental impact of mining and in helping to design appropriate solutions where problems exist. It is not easy to see what useful role third party experts have to play in the process, or that it is much helped by such experts attaching numbers to these values. Indeed there are several reasons to consider that they might get in the way of the two key parties, namely those responsible for the impacts and those subject to them. It may be relevant that many of the economic techniques designed to address the shadow pricing of environmental externalities were developed before community perspectives emerged as a key issue for mining in the 1980s and 1990s.

Far better, surely, to leave these two parties to establish a common understanding of the problem. From this understanding, will naturally follow the implementation. With agreement on what is wrong and what needs to be done, it is only a short step to implementation. Environmental and community issues get to be addressed simultaneously. The additional benefit of dealing with things in such a pragmatic and decentralised fashion is that the establishment of dialogue and engagement between miners and the communities in which they work furnishes the basis of a long term partnership that both have every interest in developing to address past problems but also - and more importantly - to help to avoid new ones arising as a result of a lack of communication. The analytical approach to these problems is the old economics. Dialogue, engagement, and voluntary action is the new and more sustainable economics.

Which leads to the <u>fourth</u> issue, which *is* that of voluntarism. This is an issue of rapidly growing importance and critical to the objective of dealing effectively with the externalities of mining. One hears increasingly today about 'corporate social responsibility' which is shorthand for this emerging voluntarism. Faced with the plethora of regimes that multinational companies are now subject to and the wide diversity of circumstances under which they operate, they are finding it increasingly necessary to codify the values to which they subscribe and the standards by which they operate and to expose themselves to scrutiny in this regard by making much more information available to the public about their performance.

Many mining companies now have 'codes of conduct' and annual reports detailing their social and environmental performance. Many have invested heavily in the communities in which they operate and have developed, or are developing, extensive partnership agreements with local and regional communities in relation to social and environment objectives as well as with global communities, such as environmental NGOs and educational establishments, which are relevant to their core business activities. It is important to note that almost none of this activity is mandated by government or by financial regulatory authorities. For the moment, the companies' voluntary activities are putting them ahead of the regulatory game, and they are doing it because it is in the interest of their business that they do so.

The relevance of this activity to the theme of this meeting is that this voluntary activity represents a *de facto* internalisation of the costs of a mining company's social and environmental impacts. These costs are not insignificant. It is not possible specifically to isolate environmental expenditure, but in 2000, Rio Tinto, for example, spent $50 million on its social programmes. Such spending can be viewed, in a sense, as a form of voluntary, hypothecated taxation, which is to say, taxation the company imposes on itself by choice to meet specific, designated objectives. The enormous advantage it has over environmental taxation which might be imposed by government is that the spending can be targeted directly and efficiently towards matters which the communities themselves consider to be important without the involvement and cost of third parties and intermediate levels of government. The other advantage is that by integrating these matters into the way in which mining companies go about their business, the standards and approach that get applied are similar wherever in the world the company is operating. As a result of this, it is not just the rich and better-organised countries which benefit.

The fifth issue that I want to address is that of institutional structures and the role of government. Tilton's manuscript portrays the approach I have advocated for dealing with the matters as one of public goods and public choice. I don't have a problem with this. Moreover, I accept that such an approach puts a huge burden on the process of public policy formation.

It is probably fair to say that, after the presence of ore bodies, there is nothing more important to the establishment of a successful mining industry than the presence of good institutions of government, meaning open and responsive political systems, clear and stable laws, effective enforcement, and honest officials. Equipped with these, there is very little that governments cannot do to ensure a close correspondence between private and social costs of mining. However, the fact that mining continues to be focused on relatively few countries shows how hard it is to find these conditions. Through the use of open and clear permitting regimes, which honestly and realistically reflect each country's distinctive national and regional priorities for economic development and environmental conservation, much is achievable in ensuring that the company can operate in a profitable fashion and that society can benefit from mining without having to pay unacceptable costs.

The reality is that countries which have good rules and apply them well don't need to impose green taxation on mining, while those that don't have good rules are unlikely to produce an effective system of green taxation anyway. Government's energies would generally be better devoted in this area, as in others, to devising regulatory arrangements which incentivise companies to do things better rather than to single them out for punishment through customised taxation arrangements. And perhaps the companies can help here in some countries by assisting capacity building in countries which do not yet have appropriate and effective representative institutions. At the end of the day, these are not technical matters but social ones requiring institutional solutions. And as Tilton observes, they are commonly tougher issues than the technical ones.

David Chambers (Centre for Science in the Public Interest):

There are several different models for establishing the value of environmental resources—that is, for internalizing environmental costs into the natural resource development decision-making process and establishing a value for non-quantifiable societal goods.

Among these models are:

(1) Creation of a market for environmental goods,
(2) Hedonic Pricing
(3) Contingent Valuation, and
(4) Through the Political Process.

Here, I will briefly address the "Political Process" model, because I have seen it applied to many mineral development situations, and because I believe it is the process that is being most widely used today in the public arena to establish the value of non-quantifiable societal goods.

I believe the fundamental question to be asked is, "Can the political process be used to adequately address resource development issues?

Here are some of the Problems in using the political process to address non-quantifiable (and probably other) values:
(1) The wealthy are likely to have more influence on the political process (through financial resources, personal contacts, etc.) than the poor.
(2) Public officials are not neutral at the beginning of the 'evaluation' process; they usually have some opinion, and the goal of the political lobbying is to reinforce or change that opinion, not to provide basic data upon which the decision will be made; and,
(3) More specifically to the mineral development case, the free market economic system creates a situation that encourages mineral developers to resist any political decision on a mineral development.

To appreciate the third problem, consider a model for "Political Decision Making About Where (or Where Not) to Mine:"

Present Situation - there is much political (and economic) resistance to having an economically viable project rejected for environmental or social reasons.

The developer in another industry could just move elsewhere (and there might in fact be competition between localities for this development, as in the computer and automobile industries).

A "political" determination of the costs and benefits to society would be more viable if

(1) The developer of the deposit that is being "lost" were the developer of a new deposit that has now become economically viable; and,
(2) The "lost" deposit and the "next" deposit are of equal value.

Although it would be possible to address both these problems in a 'command and control' economy, it will be difficult to solve either of them in a free market economic system.