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Energy and Sustainable Development in the Mining and Minerals Industries

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Energy and Sustainable Development in the Mining and Minerals Industries

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Abstract

The nature and structure of the global energy industry is likely to change significantly in the 21st Century. This is driven by a number of factors, including activities related to sustainable development. Change in the global energy industry will include the price, as well as the balance of resources it depends upon. This will have significant implications for a closely related industrial sector, namely the mining and minerals industries.

The present report discusses how the mining and minerals industries can adapt to the challenges and opportunities posed by trends and drivers in global energy use. As a result of the demands of their production processes and their products, these industries have an important role in managing energy use at the local, regional and global levels. This is part of their contribution to sustainable development. The report identifies some examples of where and how the mining and minerals industries can respond to the trends and drivers affecting energy use.

1. The Energy Industry

1.1 Introduction

For the past half-century, the world energy industry has been undergoing major changes that are reshaping traditional roles, creating opportunities for new participants, and redefining the scope and character of government regulation.

These changes are arising out of the interaction of several driving forces:

- Increasing market liberalisation that is replacing traditional forms of government regulation and shifting the role of national governments in economic affairs from owners of productive assets and natural resources to regulators of privately held companies;
- Dramatic transformation of scale in energy conversion technologies as small-scale, distributed energy technologies become more valuable than traditional centralized sources;
- Increasing de-carbonisation of energy fuels that is accelerating the emergence of less carbon-intensive or even carbon-free energy resources;
- The rise in the role of an Internet-empowered civil society which is creating powerful, new demands for lower-cost and more benign forms of industrial development;
- The declining ability of central governments to stabilize and protect domestic industries from global market volatility, and the increasing need for business strategies that increase flexibility and adaptability;
- A shift in economic focus that is rewarding companies for providing a continuous flow of energy services to their customers rather than sporadically selling them commodity goods.

The energy industry is responding to these forces by experimenting with a host of business strategies: flexible pricing for large customers; unbundling of upstream and downstream assets and of various price and risk attributes; diversification into integrated energy services businesses; aggressive efforts to contain costs; and corporate restructuring. Emerging from these experiments is a less tightly integrated, more diversified and, above all, a much more competitive energy industry. It is an industry that, during the next decade, will continue to shift from the traditional commodity sales focus into a much more heterogeneous structure made up of companies fulfilling various traditional roles, independent power producers, energy service providers (integrated with or separate from vendors of end-use efficiency and onsite supply), energy brokers and marketers, transmission operators, and "pipes & wires" local distribution companies.

But the path from the traditional energy business to the more competitive and distributed industry of the future is strewn with issues and obstacles, some of which may resist resolution and movement more stubbornly that is commonly assumed today. These include: disagreements over the rules and procedures that should govern access to pipeline, transmission, and distribution facilities; the division of regulatory authority between local and national government agencies; new demands for more stringent environmental protection; and a number of questions related to cost and risk allocation, cost recovery, and energy security. How these issues are resolved will control the pace and scope of change in the energy industry and, in turn, answer a question of increasing interest: How will the changes in the energy industry affect the mining and minerals industries?

Approach – This chapter provides a global strategic-level review of how the transition to a more sustainable society may affect energy supply and use, including climate, water, other large-scale environmental issues, that might constrain energy use related to minerals activities; other factors that could cause energy scarcities or restrictions; likely or plausible surprises and discontinuities in energy use and supply; and links between energy alternatives and other societal goals and values. It focuses on solutions, such as climate-neutral energy supply options and examples of their profitable use (and the use of advanced end-use and conversion efficiency) by other energy-intensive industries. Sidebars address key indirect energy/minerals-industry links, *e.g.* through water, use of more copper to save energy, and impact of Hypercars on demand for various metals. The chapter addresses how the minerals industries can foster or inhibit energy transitions toward sustainability, and how these industries' energy transitions make them more economically competitive. It emphasizes the implications of natural capitalism—especially solutions-economy business models and biomimicry—in transforming the minerals industries in ways that confer both economic and environmental advantage. It also includes an overview of salient facts, trends, and drivers in world energy supply and usage patterns, to the extent that data are available. The chapter draws on publicly available data from a wide variety of governmental and industry sources primarily covering the past ten years. It is important to note that comprehensive and detailed information about energy use in the mining and minerals sectors is scarce and insufficient to support fine-grained analysis.

Structure and Scope – The chapter is organized in five sections:

- Energy Industry – An introduction to the major changes reshaping the energy industry, including trends and drivers, global energy balances, changing trends in energy productivity, and surprises and discontinuities.
- Energy and the Mining and Minerals Industries – A discussion of several issues relating to the intersection of the energy and mining and minerals industries, including data insufficiency, energy use in the mining and minerals industries, the role of price in commodity businesses, cost drivers and market prices, and mining and minerals industries as drivers of energy investments.
- Sustainability Trends and Their Impacts on Mining and Minerals Activities – A review of various issues relating to sustainability, including the definition of sustainability and drivers of sustainability (such as water, energy efficiency, energy prices, planning, climate modification), and their implications.
- Sustainability and Competitiveness for the Mining and Minerals Industry – A more detailed investigation of key sustainability issues impacting competitiveness, including natural capitalism, resource efficiency, new processes, materials inputs reductions, improving production quality, recycling and reuse, and the solutions economy.
- Going Forward – A closing section on research and development, innovation, and recommendations for further study and action.

It is important to note that the paucity of detailed data on energy use in the mining and minerals industries was a significant barrier to deep analysis of the issues. Where available, data was primarily drawn from industry activities in OECD countries. In addition, discussions about sustainability issues in the mining and minerals industries are most commonly based on experience in developed countries. Still, the authors have attempted to generalize the import of the findings to a global context, even while recognizing that local and regional issues often play a dominant role in impacting mining and minerals businesses. Finally, it should be noted that the chapter does not specifically address the use of energy minerals.

1.2 Trends and Drivers

The 21st Century is witnessing the convergence of a number of major historic trends with the emergence of new driving forces that are changing the energy industry. The combined forces have potentially significant implications for the mining and minerals industries. In each case, this collision of trend and driving force creates the very real potential for a new prescription of the energy future in which the mining and minerals industries will operate, potentially leading to an entirely new vision of a family of minerals services industries.

The potential of a fundamental transformation of the mining and minerals industries of today into a mineral services industry model is profound, and perhaps the most significant change to face the sectors since their establishment. This shift toward "servicizing" the benefits that the mining and minerals industries ultimately deliver today, while not necessarily adversely impacting the viability of the sectors, could likely lead to broad industry restructuring and realignment. The groundwork for such a fundamental shift is being laid not only in the energy sector, so vital to the mining and minerals industries and discussed immediately below, but also in the broader application of sustainability principles to industry and in the changed nature of the relationships between industry and the social, regulatory, and economic context.

The discussion that follows sets out six key trend and drivers pairs that are at work around the globe today. While the pace and complexion of local and regional impacts varies, these overall directions and forces are at work everywhere.

1.2.A. Increasing Liberalisation /Market Forces

Trend: It is the greatest sale in the history of the world. Governments are getting out of the business of owning and controlling productive resources by transferring what amounts to trillions of dollars of assets to the private sector. It is happening not only in the former Soviet Union, Eastern Europe, and China but also in Western Europe, Asia, Latin America, and Africa—and in the United States, where federal, state, and city governments are turning many of their traditional activities over to the marketplace.

The rapid growth of privatisation reflects a major revision of the role of the public sector as owner of resources and productive assets in the economy. Moreover, the perceived demand for ever larger capital investments to support expansion of essential services infrastructure has challenged the funding capabilities of national or regional governments and led to a search for capital from more broadly based private markets.

Driver: Markets, in lieu of policy, are increasingly the dominant source of influence on the behavior of companies in today's increasingly global economy. In a growing number of situations, oversight by market forces armed with ubiquitous, instantaneous information provides more rapid and effective discipline than governmental oversight. Both investors and consumers increasingly demand efficiency, returns on investment, and reduction of risk. More rapid in evolution than traditional forms of regulation, markets are forcing response strategies in the energy sector, with premia going to cost-containment, service delivery, and effective delivery of customer-perceived value. Collisions between private and public interests, as in California electricity in 2000–01, will inevitably focus more attention on ensuring full and fair competition and on mechanisms for limiting certain forms of market gaming and withholding of supply.

1.2.B. Emergence of Right-Sized Energy Resources

Trend: New technologies, new market structures and actors, competitive pricing regimes, automated information systems, "smart" grid architectures, sophisticated analytic methods, and advanced control techniques are all transforming the energy industry toward small unit-scale, dispersed siting, and high efficiency. Decentralized ways to convert, save, and store energy are offering distinctive economic benefits unavailable to traditional, centralized sources. The magnitude of the transformation of scale currently underway is hard to overstate. In competitive markets, large central thermal power stations stopped getting more efficient in the '60s, stopped getting cheaper in the '70s, stopped getting bigger in the '80s, and stopped getting bought in the '90s. Such changes will save customers billions of dollars in annual energy expenses, reduce air and water pollution associated with producing and using energy by several fold, and usher in tremendous business opportunities for early adopters.

Driver: An emerging pattern of diminishing, rather than increasing, returns associated with energy infrastructure investments has created a powerful new driver in the energy sector. This new force encourages careful matching of energy production and management with end-use demands for energy services. It is changing the value proposition between energy suppliers and end-use energy customers, and driving the establishment of new business models based on the values of delivered energy services rather than the sale of commodity gigajoules. More than one hundred economic, financial, and engineering benefits have been identified that are fundamentally changing the patterns of returns to scale and the basic nature of energy investments that prevailed for much of the 20th Century.

1.2.C Increasing De-Carbonisation of Energy Fuels

Trend: Modern economic development has been characterized by the successful exploitation of fuels with high-carbon content. Readily oxidized in a variety of combustion technologies, these abundant fuels were used with relatively little regard for overall system efficiency. Increasingly, however, energy fuels have been shifting toward lower concentrations of carbon, and therefore of mass. Most notably, natural gas use is rapidly growing and is expected to be the fastest growing source of primary energy (other than renewables and end-use efficiency) over the next two decades. Coal use has declined since the mid-1990s. By now, two of every three fossil-fuel atoms burned worldwide are hydrogen, not carbon, and the H/C ratio is rising inexorably. Over time, such de-carbonized fuels as hydrogen from natural gas or coal, or hydrogen produced by renewable or biological processes, or direct renewables, have the potential to supplant large parts of the coal, gas, and petroleum combustion industries. The trend in de-carbonisation of energy fuels has been greatly aided by increased concern over the climate impacts of unregulated carbon emissions. The uncertainty associated with potential regulation of or limitations on carbon emissions has led many leading businesses to begin inventorying and controlling carbon emissions within their operations; some conduct internal or external carbon trading.

Driver: Increasing pressure to reduce or eliminate the carbon emissions associated with energy use will be strengthened by the increasing availability of cost-effective, efficient and contextually valuable technologies that provide energy services without carbon emissions. Matched more precisely to demand for energy services, such technologies as fuel cells, cogeneration, trigeneration, and distributed renewables will become increasingly attractive to business with mature cost-accounting capabilities, increasing aversion to financial risk and idle capacity, and disciplined financial planning skills. Moreover, as the business sector continues to integrate environmental performance and sustainability values into overall business activities, the pressure to explore and exploit less carbon-intensive and/or carbon-emissions-free energy technologies only increases.

1.2.D. Rise in the Role of Civil Society

Trend: Regardless of controlling political ideology, almost every nation has seen an increase in the role of civil society in day-to-day and strategic affairs. Increasing amounts and ubiquity of information resources, growing multi-national networking among non-governmental organisations (NGOs), and experience and expertise in citizen activism have all increased the effectiveness of civil organisations and individual activists, and have accelerated the trend toward increased accountability by both government and industry to civil society's concerns. For the energy sector, the increasing influence of civil society has imposed new burdens on siting processes, planning, and risk management. These burdens often extend the time required for governmental approvals and add costs to project development where perceived impacts are controversial rather than benign or restorative.

Driver: Formerly bi-polar decision making processes involving direct relationships between government and the private sector have been increasingly supplanted by a tri-polar model of society-wide decision making – as government, the private sector, and civil society act in concert to guide and shape public policy and initiatives. The net impact for the energy sector is increasing pressure to adopt strategies that deliver the benefits of industrial development without as much compromise of the public interest or subjugation of civil concerns. Societal values articulated by an increasingly vocal, innovative, and effective civil society will become essential planning criteria in energy and mining infrastructure development plans. As a result, the demands of civil society increasingly shape the energy and mining development options pursued, often toward more socially equitable, less environmentally controversial, and less expensive options. Often this is achieved through design processes that deeply engage diverse stakeholders.

1.2.E. Declining Governmental Structural Protection

Trend: The traditional role of many national governments with regard to the energy sector has been a combination of cost distribution through regulatory processes and protection against revenue-eroding competition or substitution. But increasing economic globalisation and pressure for free trade are challenging prevailing trade laws and related regulatory regimes established to protect domestic industries from foreign competition. The trend toward liberalisation has simultaneously increased industry exposure to economic cycles and the discontinuities associated with global commodity markets. Increasing pressure on limited public funds has combined with these forces to accelerate a shift in the focus of traditional government spheres of influence from system-wide regimes to more local concerns.

Driver: Without the benefit of overarching governmental regulatory and protective regimes, the energy industry has seen increasing pressure to adopt industrial growth and development models that are flexible, adaptable, more resistant to the effects of cyclical and random commodity price swings, and more robust over a broader range of potential changes in consumer demand. In some cases this has led to the development of such sophisticated secondary market tools as hedges and derivatives, and the increased application of financial portfolio theory to investment strategies. The pressure for improved management skills in response to market fluctuations and to the reality that larger multi-national companies face a wider variety of local, regional and national market conditions will increase as the effects of this driver become more widespread—moving beyond direct energy industry activities to those in energy-intensive industries such as mining.

1.2.F. Emergence of Business Model Based on Service Value

Trend: – Increasingly competitive markets are characterized by a shift of focus from supply of undifferentiated commodities to customized end-use services and values. The focus on end-use, least-cost solutions has led to new profitable business models that also accelerate market developments in so-called “disruptive technologies”—technologies that are vernacular and right-sized, and that represent a basic discontinuity in development rather than mere incremental improvements.

Driver: – The ultimate driver of business success will increasingly be, and in some energy sectors is already, customer perception of service value. The impacts of increased focus on service value have already been revealed in dramatic improvements in energy intensity (energy consumed per unit of GDP) and an effective decoupling of the conventionally assumed immutable linkage between economic development and increased energy consumption. The implications of these forces extend far beyond the energy sector as the industrial sector identifies new opportunities to support growth in national economies without strictly parallel increases in resource consumption.

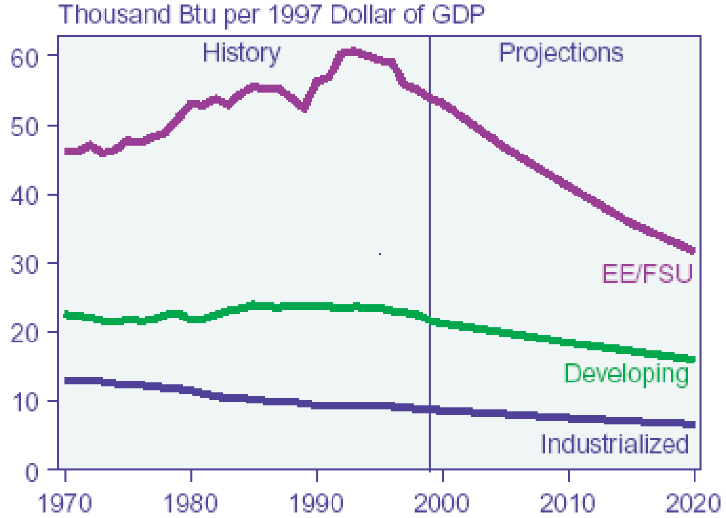
1.3 Global Energy Balances

Globally comprehensive data about energy production and consumption are about averages. Valuable and important detail is often lost in the process. Even at this level of abstraction, however, important trends and relationships become clear.

1.3.A Energy and Economic Indicators

In the decade of the 1990s, the world's total output of primary energy grew at a rate of 0.9%/year, far slower than world economic growth of 2.5%/y and population growth of 1.5%/y over the same period. This continues a longer historical trend of decreasing global energy intensity measured in primary energy consumed per unit of gross domestic product. The energy data research arm of the United States Department of Energy, the Energy Information Administration, forecasts this trend to continue, with the strongest improvements coming from Eastern Europe/Former Soviet Union nations.

Figure 12. World Energy Intensity by Region, 1970-2020



Sources: **History:** Energy Information Administration (EIA), Office of Energy Markets and End Use, International Statistics Database and *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, January 2001). **Projections:** EIA, World Energy Projection System (2001).

1.3.B. World Energy Consumption

World energy consumption is projected by the US Department of Energy to increase by 59% from 1999 to 2020, or an average of 2.8% per year. Much of the growth in worldwide energy use is expected in the developing world. These predictions seem high compared to historical trends, and are unlikely to materialize in the face of the technological trends and drivers described above and others summarized in section I.4 below. In general, the aggregate energy efficiency of North America is somewhat worse than that of Japan and Europe, but that of developing and formerly socialist economies is about three times lower than that of OECD. These less efficient economies have the strongest incentive to improve their energy productivity in order to de-bottleneck their development process and avoid costly supply-side investments.

1.3.C. Primary Energy

Natural Gas: Natural gas demand is projected by USDOE to double between 2000 and 2020, providing a relatively clean fuel for very efficient new gas combined-cycle power plants.

Coal: Although coal use is expected to be displaced by natural gas in some parts of the world, only a slight drop in its share of total energy consumption is projected by 2020. In DOE's conventional forecast, coal continues to dominate many national fuel markets in developing Asia, although in fact China after 1996 shifted dramatically to gas, efficiency, and renewables.

Petroleum: Oil is expected to remain the primary fuel source for transportation throughout the world, and transportation fuels are conventionally projected to account for almost 57 percent of total world oil consumption by 2020.

Nuclear: Nuclear power is projected by USDOE to represent a growing share of the developing world's electricity consumption from 1999 through 2020. New plant construction and license extensions for existing plants are expected to produce a net increase in world nuclear capacity.

Renewables: The renewable energy share of total world energy consumption is expected to decline slightly, from 9 percent in 1999 to 8 percent in 2020, despite a projected 53-percent increase in consumption of hydroelectricity and other renewable resources. This projection is particularly odd because windpower and photovoltaics have lately been growing at 20–40 times that rate; the USDOE projection appears to reflect modelling problems in fitting distributed resources into a structure meant for centralized ones.

We offer these econometrically based USDOE projections because they reflect widespread traditional views, not because we believe them. We consider them a seriously defective basis for business planning. It is indeed the goal of many energy enterprises to make such projections as wrong as possible, and many experts would take serious issue with EIA's assumptions in many areas ranging from end-use efficiency and renewables to nuclear power. As a cautionary illustration, compare the USDOE view just summarized with the latest biennial Royal Dutch/Shell Group Planning scenarios released in autumn 2000.[1] These scenarios are not forecasts, but rather vehicles for telling internally consistent stories that help change executives' mental maps. However, neither scenario is unrealistic. One envisages a third of the world's energy supplies, and all its new energy, coming from renewable sources by 2050. The second scenario explores a more radical and technologically discontinuous shift to a hydrogen economy, so that world oil demand is stagnant until 2020 and then declines steeply. Shell, BP, and other major energy firms are investing strongly in elements of both these futures. The moral of this story is that the energy future is not fate but choice, and can be advantageously chosen with very great flexibility. Energy customers, like the mining and minerals industries, are participants in that choice, and will be able to exercise an increasing part of it as investors in their own supply, not just as passive purchasers of supplies built by others.

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[1] www.shell.com/files/media-en/scenarios.pdf

1.4 Changing Trends in Energy Productivity

Evidence is accumulating that the traditional interpretation of energy demand as governed by price and price elasticity is not wholly satisfactory and is likely to become less so. Firms that forecast energy use based on price are therefore advised to proceed with caution, bearing in mind the following points that are well-known to most energy-efficiency practitioners but often surprising to economists:

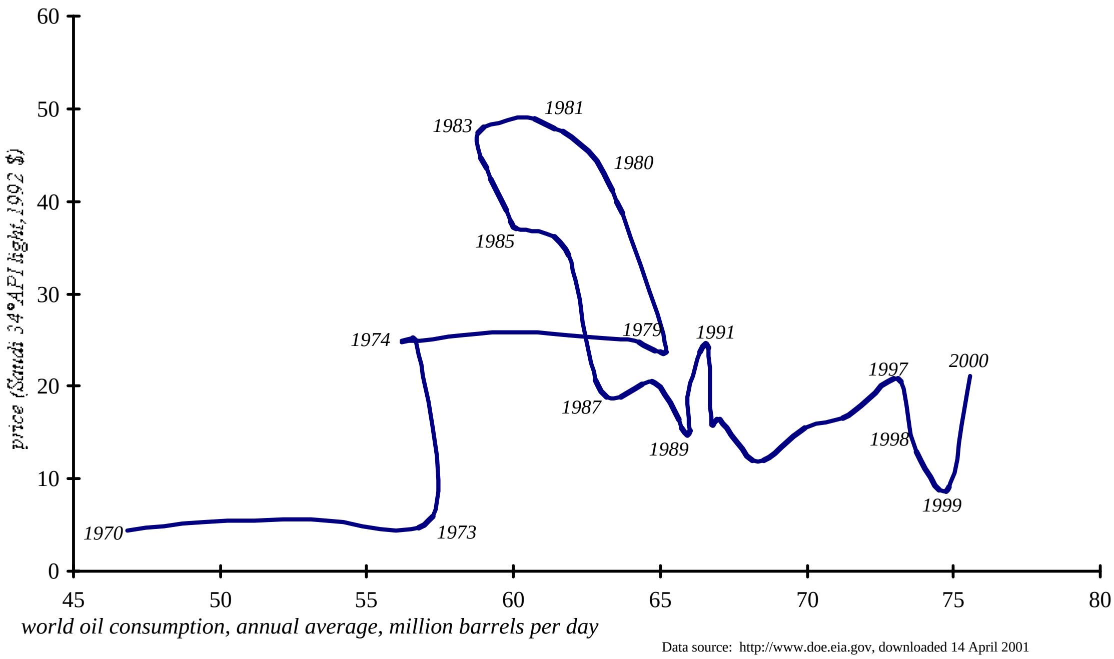
- Reduced energy intensity is not a trivial activity. In the United States, for example, it is the biggest and fastest-growing energy "source", currently providing 40% of all energy services (1.7× oil consumption, 3× oil imports) compared with 1975 intensity, and growing ~3%/y.
- Its adoption is influenced but not primary driven by price. For example, US energy intensity fell at a near-record pace (3.2%/y) during 1996–99, due to both structural shifts in economic output and technical improvements in end-use energy productivity despite record-low and falling energy prices. Whatever was getting users' attention, it wasn't price. Ability to respond to price has turned out to be even more important. Not surprisingly, the energy efficiency resource is poorly understood by most economists. More surprisingly, it is also poorly understood even by many technologists whose expertise is on the supply side.
- Efficient use of energy, well executed, is empirically cheaper in virtually every case than the energy it saves. Retrofit returns on investment upwards of 100%/y aftertax are not uncommon even in such sophisticated industrial facilities as modern refineries and microchip fabrication plants. However, users' motives for raising their energy efficiency may be more related to valuable side-benefits than to the energy savings themselves. For example, since a typical office in a developed country spends about 100 times as much for people as for energy, the 6–16% higher labour productivity commonly observed in well-designed efficient buildings (due to their greater visual, thermal, and acoustic comfort) is worth about 6–16 times as much as eliminating the energy bill. Similar knock-on benefits are often observed in many industries, and can be marketed and bought accordingly, achieving profits with little or no regard to traditional energy-saving engineering-economic calculations.
- The reserves of efficiency are expanding and its costs are falling, because technology, design, and deployment are improving faster than the opportunities are being depleted. In general, this improvement outpaces even the stunning gains in (say) oil exploration and production techniques. Both efficiency's unbought proven potential and the further potential emerging from R&D are truly enormous. Recent empirical results in many uses and sectors indeed show how to achieve expanding rather than diminishing returns to investments in saving energy—that is, how to make very large savings cost less than small or no savings. Thus the logic so familiar in the mining and minerals industries—that technology generally outpaces resource depletion, causing real commodity prices to fall over the long run—is even more true for productive use of energy.
- Available gains in energy productivity nonetheless remain largely unbought, even in the most efficient societies, because of 60–80 well-understood market failures. These obstacles are listed in RMI's report Climate: Making Sense and Making Money and

summarized in a box below.[2] (In section III.2.B we offer a few examples relevant to the mining and minerals industries.)

- Gains in energy productivity can be greatly accelerated by at least ten classes of policy instruments. Price is one; regulation is another; and the other eight are not yet widely considered.[3] A diversified portfolio of policy tools should work better, faster, and more reliably.

1.5 Surprises and Discontinuities

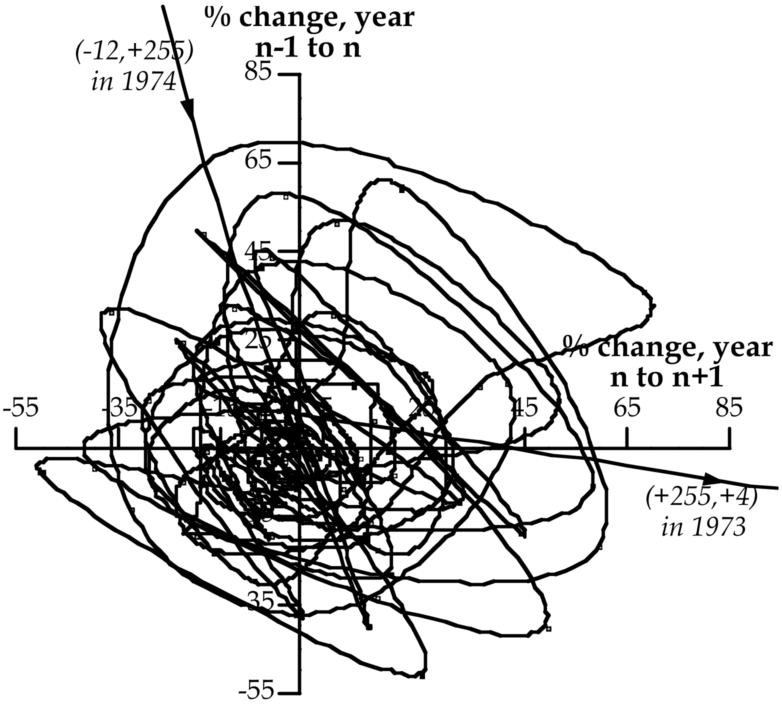
The energy sector, more than most, is rich in surprises. For example, consider the relationship between the world's real crude-oil price (using the standard Saudi marker crude) and demand for oil over the past 30 years:



[2] Lovins, A. B. & Lovins, L. H. 1997: *Climate: Making Sense* and *Making Money,* Rocky Mountain Institute, at 11-20, www.rmi.org/images/other/C-ClimateMSMM.pdf. The right-hand column in the original text lists how to turn each obstacle into a business opportunity.

[3] www.rmi.org/images/other/S-ECEEE8FoldWay.pdf

or the history of movements in the world's real oil price from 1881 through 1993:



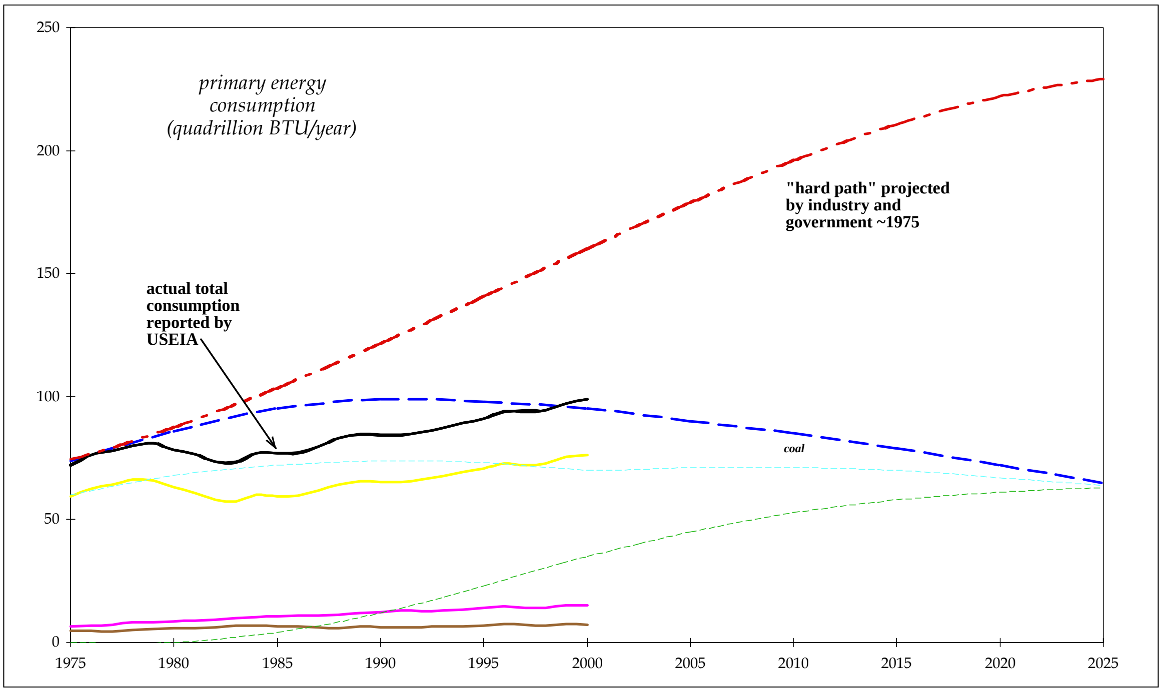
No prudent oil-industry planner, in light of this history, can talk sensibly about "business as usual" even in the past, let alone in the future. Those still paid to forecast oil prices would do better to put the previous diagram on the wall and throw darts at it, for the price behaviour revealed in the market is perfectly random. All that changed after the first oil shock in 1973 was that the price volatility trebled.

The mining and minerals industries are used to the normal shocks of industrial life: political upheaval, corporate failures, financial instability, unforeseen market shifts, unusual weather, and the like. Energy, however, even more than mining and minerals processing, is unusually exposed to technological discontinuities. Some of these, such as superefficient ultralight vehicles and the transition they permit to a climate-safe hydrogen economy, are mentioned below. Here are a few more for flavour:

- Upheaval in Saudi Arabia could, for an unknown time, take ~8 Mbbl/d off the world oil market. A serious attack on Ras Tanura or other critical and hard-to-repair oil facilities could remove ~6 Mbbl/d overnight even if the government remained eager to sell oil.
- Accident or terrorism could black out virtually any sizeable region of the world for hours to months.
- A major accident or attack on a nuclear facility could kill millions and cause most other nuclear facilities to be shut down.
- Sudden climatic change, such as the failure of the North Atlantic Conveyor that drives the Gulf Stream, has happened before, and if it recurred, could cause a worldwide stampede away from fossil fuels, especially coal as well as political reactions against industrialism.

- Any of several promising R&D routes could at any time yield very cheap and easily mass-producible solar cells, making obsolete perhaps a trillion dollars' worth of power plants and most of the coal industry.
- Energy demand could go down instead of up, even during periods of substantial economic growth. (It's happened before. For example, during 1979–85, US GDP grew 16% while oil use fell 15% and Persian Gulf imports fell 87%.)
- Governments could get serious about "barrier-busting" that allows people to use energy in a way that saves money.
- Wholly new sources of energy could be discovered. (There are enough puzzles and "loose ends" in modern physics that this possibility cannot be excluded.)

That the possibility of big surprises on the demand side, in particular, is not just theoretical is illustrated by the following graph. Its top line shows the consensus industry/government 50-year forecasts of US primary energy demand around 1975. The next line down shows an alternative trajectory described by one of us (ABL) in *Foreign Affairs* 25 years ago. It was considered heretical and was heavily criticized. The heavy black line shows what has actually happened so far. Many suppliers that bet on the official forecast are no longer in business.



Yet startling though that 40% reduction in US energy intensity was at the time, recent progress in technologies, their application and delivery, their marketing, and the evolution of energy service markets themselves now make the originally envisaged potential for substantially declining long-term US energy use look today very conservative. This is worth bearing in mind not just because the mining and minerals industries depend on energy and could share in such savings, but also because similar surprises are conceivable in demand for materials too, partly on the lines noted later in this chapter.

One conclusion that we consider essentially predetermined, not a surprise, is that there is no economic future for nuclear power. New nuclear plants of any imaginable kind are grossly uncompetitive with at least three widely available and extremely abundant options: electric end-use efficiency and load management, onsite industrial or commercial co- or trigeneration from natural gas, and windpower in good sites. (Cheap fuel cells and solar cells will probably be the next two fatal competitors.) As relatively centralized units, nuclear plants also suffer from grid costs, high financial risks, and vulnerabilities. These are some of the reasons why the technology clings to life only in a handful of centrally planned energy systems, but is unfinanceable in competitive markets and will become more so as its competitors improve faster.

Similar considerations apply, albeit more weakly, to conventional central coal-fired power stations, but this might change with integrated-gasified-combined-cycle options or, even better, with climate-safe coal-to-hydrogen options now being explored. In general, hydrogen is worth more without than with associated carbon: hydrogen used very efficiently in a fuel cell, plus the value of being paid to sequester carbon, are often worth more than hydrocarbon fuel. To put it another way, hydrocarbons are often worth more as reformer feedstocks than as refinery feedstocks. This is conventionally accepted for natural gas (CH_4) and sometimes for oil or equivalent synthetic feedstocks (CH_2). But it may also be true for coal (roughly CH). Although it is less hydrogen-rich and harder to handle than natural gas, coal may be cheap enough to make up the difference. BP-funded research at Princeton University suggests a plausible case that long-run hydrogen production may be cheaper from coal than from natural gas, with carbon sequestration in both cases. It is therefore possible that a carbon-constrained world may nonetheless hold an important and attractive role for coal—a conclusion we would not have considered plausible even two years ago.

This illustrates yet another kind of surprise: people can have better ideas or correct old errors. A decade ago, we would not have considered a hydrogen economy to be potentially profitable or cost-effective. At least one of us (ABL) made the basic error of considering hydrogen too costly on a $/GJ basis—without counting its severalfold greater conversion efficiency in a fuel cell. That advantage can more than make up for its apparently high cost in energy terms. What matters is of course the cost of services provided, such as traction in a car, torque in a mill, or comfort and power in a building, so efficient conversion from fuel to service can offset costly fuel. The history of energy policy is replete with such surprises as people stop repeating inherited thoughts and start thinking anew.

In summary, energy is subject to so many competing, converging, combining, and rapidly emerging technologies, from so many disciplines (including unfamiliar ones like biomimicry, discussed below), that almost anything permitted by the laws of physics can happen—and even our understanding of some of those laws may be up for review. Whatever the energy future is like, it will almost certainly not be predictable or predicted. Our decades of experience in this field therefore make us approach it with humility. We urge those less familiar with its strange twistings and turnings to do likewise. Mining and minerals strategists will be wise to design for surprises, robustness, and indifference to a very large range of energy conditions, because that's just what they're likely to need as the energy system enters the most radical and disruptive transformations—technological, institutional, conceptual, cultural—in at least the past few centuries.

2. Energy and the Mining and Minerals Industries

2.1 Data Insufficiency

The mining and minerals industries worldwide use impressive amounts of energy, perhaps as much as 4–7% of global energy use. It is important to note, however, that detailed and authoritative estimates of this energy use are not available and that the right number defies easy and precise quantification. The ability to characterize aggregate energy usage is limited by a number of obvious obstacles, such as data availability and consistency in reporting conventions, as well as by a larger number of subtle and more intractable issues, such as system boundaries in specific operations, secondary and tertiary energy demands, parasitic demands, byproduct and coproduct relationships requiring the allocation of energy use among joint products, and a number of questions relating to energy conversion, energy transport, and mine reclamation and environmental remediation. In many cases, even transparent definitions of the mining sector itself are difficult to find and interpret, and often do not include sufficient detail with regard to what is included and not included in data sets, i.e., quarrying, well operation, beneficiation (crushing, screening, washing, and flotation), extraction, conveying, hauling and other mineral preparations. As a result, it is also difficult to report benchmarking data about comparative energy use among regions or operations mining or processing similar minerals. Further, the paucity of data makes it extremely difficult to pinpoint trends in more detailed aspects of energy intensity, such as carbon intensity, over the past decades. Generalized data concerning improvements in energy intensity suggest that energy intensity in the mining and minerals industries has been improving consistently over the past decades, however. For example, the International Aluminium Institute reports a steady decline in electric power used in the primary aluminium industry since 1899. (http://www.world-aluminium.org/environment/challenges/energy.html).[4] Knowing that the aluminium and steel industries are particularly large users of energy does not by itself inform the more specific question of whether these are the best industries for targeting greenhouse gas emission reduction strategies. What must be known first are the opportunities for emissions reductions, the relative cost-effectiveness of such measures, and whether excavation, processing, distribution, or end-use strategies offer the greatest return on emissions-reducing investments. Likewise, knowing that the aluminium industry (or any other segment of the mining and minerals industries) has made significant progress in reducing energy per pound of product does not inform the question of whether improvements in carbon intensity per unit of product have also been improved by the industry. That is, the trend (discussed above) toward decarbonisation of fuels may or may not have included mining and minerals industries. In addition, the relative fraction of greenhouse gas emissions from one industry may grow if that industry fails to keep pace with global improvements in carbon intensity.

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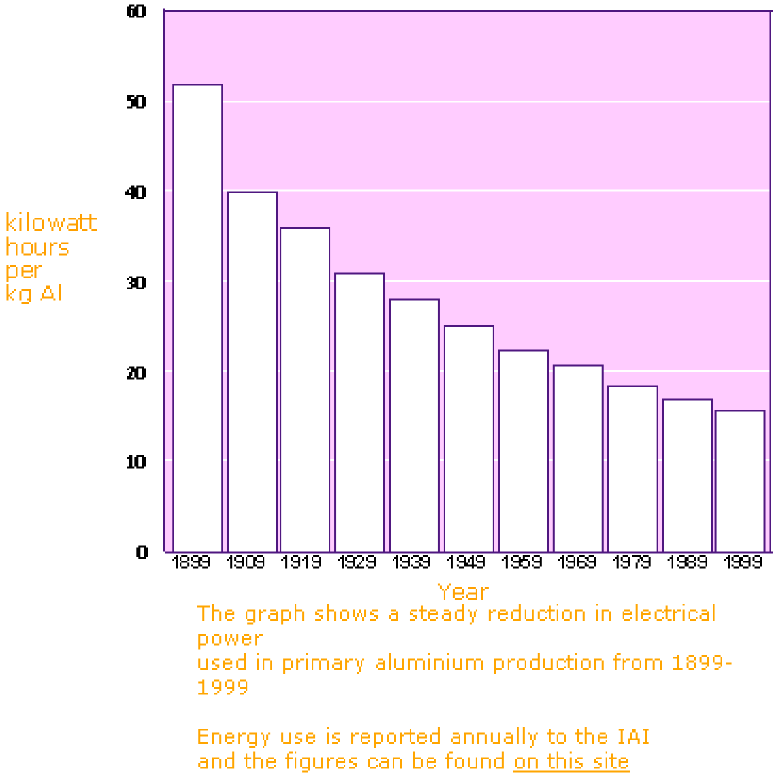
[4] Other industry efforts to estimate energy use include: Energy and Environmental Profile of the US Mining Industry http://www.bcs-hq.com/mining/ReviewPage/; Energy use in the steel industry, authors, C.J. Cairns ..[et al.] 1998 http://www.worldsteel.org/pub_item/tech_energy_millenium_summary.pdf; South Africa – mining 25% of total electricity consumption, in Parsons and Hume, UNEP Industry and Environment Oct-Dec 1997; Boustead Consulting (1998) Ecoprofile of Primary Zinc Production, report for IZA; also some IEA data for OECD and non-OECD countries.



Reduction in the electrical power used in primary aluminium production during the 20th Century. Source: International Aluminium Institute

In the end, the most important metric for progress toward sustainability is likely *environmental damage and risk of damage per unit of minerals services*. In essence, what needs to be know is how much damage and risk to the environment—in the form of land, water, and air pollution, climate modification, etc. is imposed on society for each unit of societal benefit delivered by the services that the mining and minerals industries ultimately provide to end users. Due to the strong overlap between greenhouse gas emissions and other indicators of environmental damage and risk of damage, a more simplified metric of *greenhouse gas emissions per unit of minerals services* may serve as a more easily quantifiable indicator. It is in the inability to even roughly approximate such values for the mining and minerals industry that the paucity of good data shows most strongly. The good news, discussed below, is that with such breadth in examining the sustainability issue, the opportunities for improvement (and enhanced profitability) multiply exponentially.

Broader coverage, greater consistency, and industry-wide discipline in collecting and disseminating energy use data in the mining and minerals industry should be a higher priority for government, industry associations, and trade groups. When the head of a US government program dealing with energy use in the mining and minerals industries was asked for data sources, he replied "You will never find the answer…we haven't."[5] Enhanced understanding and resolution will be critical to project aggregate energy usage in national

[5] Personal communication to Karl R. Rábago by Michael Canty, head of US DOE's Mining Industry of the Future program.

and regional energy planning, and will be valuable for industry managers concerned with energy costs, availability, and reliability.

The importance of better product and mineral specific data is underscored by the numbers in following table. Sectoral energy intensities show a much larger variation in the mining sector than in agriculture or construction, or in the overall economy of each country. These wide variations are the result of the kind and type of mining activity specific to each country as well as the product specific volumes.

1994 Sectoral Energy Intensity

Country	Energy Intensity MJ/1990 US$ Value Added			
	Total	Agriculture	Mining	Construction
Australia	7.6	5.5	17.3	2.4
Denmark	6.0	11.5	5.0	1.6
Finland	4.3	6.9	16.7	0.7
Italy	1.7	4.2	1.3	0.2
Japan	2.6	9.3	7.0	1.0
Sweden	4.5	8.4	26.3	1.6
UK	1.4	4.0	0.6	0.9
USA	7.6	7.3	19.4	2.8
IEA-8	5.1	7.1	15.4	1.7

Source: Energy Policy, vol. 29, no. 2, p. 86

The problems of data sufficiency worsen with more detailed examination. Key elements of the data are simply not available to the public. When data can be gathered and summed, their usefulness is dubious due to differences in data collection and reporting systems, boundary conditions relating to the scope of activities addressed, difficulty of interpretation, and other key methodological differences. As the table below demonstrates, a simple summing of public data can show aggregate consumption in the countries from which some data is available, but not much more than that. Again, the differences among nations and between the minerals businesses in those countries make meaningful comparisons between nations difficult, if not impossible. Thus anyone who claims to know how much energy the mining and minerals industries are using is at best naïve, and all published figures purporting to provide that figure are unsupportable.

Type and Quantity of Fuels Consumed for Selected Commodities, Worldwide (1997)

Commodity	Coal	Fuel Oil	Gas	Gasoline	Electricity	Total	
	1,000 st	1,000 bbl	Bcf	Mil gal	Mil kWh	Tbtu	GJ*10^3
Coal	253	9,075	1.2	33.7	11,355	103	108,750
Potash, Soda Ash, & Borate	1,712	Withheld	25.2	0.3	1,317	69	72,359
Iron	Withheld	911	34.3	1.4	6,234	62	65,503
Copper & Nickel	-	3,058	1.8	3.1	7,779	47	49,154
Lead & Zinc	Withheld	Withheld	Withheld	0.1	462	2	1,688
Gold	Withheld	3,655	Withheld	13.1	4,480	38	40,293
Silver	-	Withheld	Withheld	0.1	168	1	633
Phosphate Rock	Withheld	424	0.7	1.4	2,933	13	14,134
Crushed Rock	43	4,011	5.4*	14.7	4,628	48	50,419
Total	2,008	21,134	68.6	67.9	39,356	-	-
Trillion Btu	45	124	70.7	8.5	134	382	402,934

Source: Rocky Mountain Institute compilation of USEIA data. Data set includes only available data for United States, Australia, Canada, China, South Africa, Chile, Indonesia, India, Peru, Mexico, Russia, Gabon, Kazakhstan, Namibia, Niger, and Uzbekistan.

And yet, at some level the data insufficiency problem may be a red herring. Mining and minerals businesses know their own energy consumption patterns and prices, and can make shrewd guesses about competitors. Careful analysis of energy consumption by these businesses can produce reams of pages and hundreds of perspectives on this energy use. For example, Western Mine Engineering, Inc. sells comprehensive cost estimating data to the industry. The following table summarizes some of the archetypical estimates provided by Western Mine Engineering:

Energy Costs as a Percentage of Total Operating Costs – US Data

Facility Type	Ratio/Process/ Products	Output	Electricity	Diesel	Total energy
		Tonnes per day	Percentage		
Surface	Stripping ratio 1:1	1000 tpd	0.3	6.4	7
	Stripping ratio 8:1	1000 tpd	0.4	7.7	8
	Stripping ratio 1:1	8000 tpd	2.4	7.3	10
	Stripping ratio 8:1	8000 tpd	2.1	8.7	11
Hydromet mill	Cyanide leach	2000 tpd	na	na	27
Underground	Room and Pillar Adit	8000 tpd	na	na	6
	Room and Pillar Shaft	8000 tpd	na	na	5
Flotation mill	1 concentrate product	1000 tpd	0.0	27.5	28
	1 concentrate product	8000 tpd	0.0	28.5	29
	3 concentrate products	1000 tpd	0.0	24.5	25
	3 concentrate products	8000 tpd	0.0	28.4	28

Source: Western Mine Engineering Costs Models

The issue of public availability of data seems closely related to the issue of attempting to characterize the industry generally as a "big" user of energy and to assign a number to the amount of energy used in the industry. Research by the authors revealed a great many assertions about energy use in the mining and minerals industries, ranging from a few percent to as much as ten percent of global energy consumption. For example, an extract from the book *Stuff–The Secret Lives of Everyday Things,* by John Ryan and Alan Durning of Northwest Environment Watch (USA), states that:

> [A] computer's 1kg of copper began as copper sulphide ore, mined from the Chilean Andes. If the ore contained 0.9 percent copper (the global industry average), making my computer required excavating 127kg of ore and at least 136kg of other rock lying on top of the ore. The ore was pulverised, mixed with water and chemicals and boiled to obtain pure copper. Boiling also produced sulfur dioxide (S02), which causes acid rain. Worldwide, the SO2 emitted in copper production is equivalent to one-quarter the SO2 emissions of all industrial nations. Though my computer contains less copper than my car (18 kg) or the pipes and wires in my house (even more), it was enough to have a big impact. Mining, crushing, grinding and smelting the 1kg of copper required the energy equivalent of 275 litres of petrol. Mining and producing metals accounts for about 7 percent of global energy consumption.

(Emphasis added)

The initial assertions have a rationale and can be checked, but the italicized assertion is imponderable and would be difficult to document to primary sources. Efforts at gross simplification in this sphere seem largely driven by a desire by many to target the mining and minerals industries as deserving of great attention in the global warming debate.
It seems true that the mining and minerals industries are relatively big energy users (as are several other industrial sectors such as buildings and transportation, for which much more detailed information is commonly available), and given that fossil-fuel use is closely related to greenhouse gas emissions—it is the single largest source—it is entirely appropriate to examine the potential for greenhouse gas reduction strategies in the sector. But whether the usage figure is 10% of global energy use, a number that looks high, or 5%, a number that might be more nearly correct depending on which activities are included, the important question is whether the industry enjoys any meaningful opportunities to reduce greenhouse emissions. As the discussion in the remainder of this chapter emphasizes, there are indeed a great many profitable opportunities to reduce energy use and greenhouse gas emissions in the mining and minerals industries. If key players aggressively pursue such opportunities, the sector's greenhouse gas emissions will not be an indicator of public relations problems so much as a measure of opportunity for profit and competitive advantages.

Because energy use cumulates and compounds at every step along the chain between the mining of raw ore and the ultimate use of a product by an end consumer, energy efficiency strategies have diverse social and business aspects. For example, the pursuit of efficiency at the mine is primarily an issue of economic competitiveness, and given the abundant opportunities that exist, are generally a low-cost opportunity for enhancing profits. End-use efficiency, such as the increased use of compact fluorescent lightbulbs, offers greater society-wide benefits because each unit of increased efficiency is leveraged against every upstream use of energy. (For example, efficient lighting saves on energy in manufacture of light bulbs, generation of electricity, transmission of electricity, labor for replacement of bulbs, and all the energy associated with mining component metals and minerals.) Changes in end-use efficiency also have upstream impacts on the mining and minerals industries due to changes in demand for particular metals and minerals, increased reuse and recycling, and improved end-use component durability. As a result, end-use efficiency is valuable throughout the product supply chain and should be explored even in the absence of highly detailed data.

2.2 How the Minerals Industries Use Energy

A review of publicly available data[6] of energy used in the mining industry for extraction, transportation, processing, and disposal reveals the following major relationships:

Energy consumption in the industry is tightly correlated to the amount of materials that must be handled. Therefore, techniques and technologies that reduce the quantity of materials handled can improve energy efficiency per unit of product delivered or value added. Materials handled versus production for metals and industrial minerals and coal vary widely: recovery ratios for coal are above 80% while precious metals are roughly 20%.

- Energy used in mining operations accounts for approximately 3–7% of the mining and minerals sectors' total energy use, but represents about 17 percent of the total cost of supplies. About one-third of energy requirements are met by electricity, one-third by fuel/diesel oil, and the remainder by coal, natural gas, and gasoline.
- Energy requirements vary widely for each mined commodity and depend upon the type of ore being mined, whether it is underground or surface, and whether it must be smelted.
- Underground mining operations require significantly greater amounts of energy than surface mining operations because of the increase in hauling requirements, ventilation, water, and pumping.
- The majority of energy used in surface mining is diesel fuel for haulage.
- Electricity is a major source of energy for underground mining, where the ore must be hoisted to the surface and for ventilation.
- The majority of electricity is used in milling and processing operations
- Within the excavation process (roughly one-third of mining energy demand), removal accounts for about one-half of energy use, haulage one-quarter, and drilling, blasting, ventilation services, and in-mine processing the remainder.
- Within the processing stage (roughly one-third of mining energy demand), comminution (crushing and grinding) account for an estimated 85% of energy requirements. Smelting/refining account for 10% and separations and agglomeration the remainder.
- Energy use tends to increase with declining ore grade and with finer mineral grain size.

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[6] Sources include data published by the US Energy Information Administration, International Energy Agency, US Department of Energy, National Mining Association, World Bank, and others.

Case Study—Local and Regional Importance of Mining Industry—Western Australia

The relative importance of the mining industry varies significantly from country to country, and even within regions of a particular nation. Western Australia is one example of a region where mining plays a significantly greater role. What follows are two key perspectives on Western Australia that demonstrate the apparent conflict between objectives for the mining and minerals industries, and for the broader interests of sustainability and sustainable development. As the discussion in this report demonstrates, however, there are abundant opportunities for satisfying both sets of objectives and interests.

Western Australia accounts for 26% of Australia's A$40billion in annual resource exports. Western Australia produces 13% of the world's iron ore, 39% of its diamonds, and 10% of its gold. And while mining represents 5% of the Australian national economy, it is 20% of the economy of Western Australia.

Western Australia is also therefore subject to global economic fluctuations to a high degree. Faltering global industrial activity led to a 23% decline in capital spending in Australia in 1998 alone, and the rate of decline in commodity prices outstripped production increases and cost reductions. As a result, the Western Australia Chamber of Commerce in one year lowered the statewide growth predictions by more than one percentage point for the period following the economic slowdown. The Western Australian mining industry is highly impacted by a host of global factors, including globalisation, diversification, increasing competition for mineral exploration investment dollars, increasing competition in the mining products industry, environmental concerns, and the progress of technology development. At home, the minerals industry in Australia has been affected by issues dealing with the rights of indigenous peoples. With long-run economic forecasts being generally positive, the issue facing a minerals-intensive regional economy like that in Western Australia is whether the state can weather rapidly changing global economic cycles. Overall, the nation of Australia maintains a high percentage of global expenditures on mining exploration (some 17.5% in 1999–98), but this fraction faces erosion due to competition from developing countries moving to expand their role in the mining and minerals industries.

(The information above was drawn from a speech by the Honourable Senator Nick Minchin, Minister for Industry Science and Resources, Commonwealth of Australia, presented at a Conference on the Future of Mining, Kalgoolie, Western Australia, 20 August 1999.)

In late 2001, the Sustainability Policy Unit of Western Australia issued a consultation paper for the State Sustainability Strategy for Western Australia under the signature of the Premier, the Honourable Geoff Gallop. The consultation process invites a broad range of input in the development of a sustainability strategy for Western Australia, and includes the following discussion of issues particularly applicable to that state:

A focus on Western Australia

The primary challenge is to recognise that our economic prosperity cannot indefinitely rely solely on the utilisation of our abundant natural resources. The volume of material, energy and water that an economy needs to function is an important indicator of sustainability. The Western Australian economy uses a large amount of materials, energy and water for every unit of economic production. Preliminary analysis by Curtin University and the Department of the Premier and Cabinet has found that Western Australia has a very large total 'ecological footprint'. [Ecological footprint is the total resource and waste impacts calculated on a per person basis and converted into a standard for comparison using amount of land required.]

On average each Western Australian effectively uses between 17 and 31ha of land to maintain their standard of living, which is greater than the national average. To be sustainable we should be aiming to reduce the total ecological footprint of our economy by at least half over the next 10-20 years.

Environment Western Australia 1998: State of the Environment Report concluded that the most important environmental issue was our high consumption lifestyles. Western Australians have some of the highest rates of resource consumption in the world. For example, we use more energy, water, and emit more carbon dioxide per person than almost any other society other than the United States, and the rate at which we are eroding our biological resources is also one of the highest globally. Patterns of production and consumption are fundamental causes behind the priority environmental issues identified in the State of the Environment Report such as the loss of biological diversity, salinity and greenhouse gas emissions. We need to find ways of reducing this ecological footprint whilst improving the quality of life for everyone.

Very often the environmental issues facing society are directly related to social problems, such as population drift from rural communities to coastal cities, the state of the health system, youth suicide and the disadvantages experienced by Aboriginal peoples in Western Australia. Any distinction between social and ecological health is artificial and prevents the discovery of solutions that address both sets of problems.

The last thirty years have witnessed the global economy steadily transforming itself into a single marketplace, where sustainability factors, such as knowledge, technology and innovation, are increasingly becoming the major drivers of growth and employment.
Western Australia's economic strength has always been underpinned by the production of minerals (more recently, oil and natural gas) and agricultural products. All of these commodities are subject to international price fluctuations determined by production, competition, trade barriers and monetary exchange rate changes that have been largely outside of the State's control. Accordingly, a major challenge we face is the need to diversify our industrial base, particularly our export capability and our ability to value-add to raw materials. Our resources and agricultural industries also can be building blocks for a range of sustainable industries. This challenge is especially pertinent with regard to small and medium sized businesses that may not necessarily have the capacity, resources or expertise to adapt to the new economy by themselves.

Changes in the global economy associated with new technologies also present us with both an opportunity and a challenge, requiring an ability to adapt and innovate in times of technological change. Many of the emerging economic opportunities are dominated by the services sector where knowledgebased skills and a high level of education are the most important factors. WA is contributing to this transition through its education and training sectors. We need to work out how to help them grow and prosper for a sustainable economy.

The promotion of innovation is a major factor in achieving sustainability. The Government's Innovate WA Strategy has been recently launched to strengthen our long-term competitiveness by establishing Western Australia as a global leader in innovation-related activities. In particular, this Strategy will need to focus on a range of issues across the triple-bottom line, such as:

- reversing the decline in R&D activities in this State;
- achieving higher school retention rates;
- encouraging greater participation in science at a tertiary education level;
- providing leadership, research capacities and comprehensive industry plans for industries that offer a high growth potential; and
- developing infrastructure for innovation strategically.

All of this can be used to help the sustainability agenda as innovation in eco-efficiency (and other aspects of sustainability) is one of the new global challenges for industry. [Eco-efficiency involves dramatically reducing the amount of materials, energy and water that is required to produce goods and services.] The drive to eco-efficiency and sustainability should stimulate local innovation and economic activity while securing a healthy environment and a vital, diverse and fair society.

A report by the Department of Training outlines job opportunities in six areas that are all part of the sustainability agenda:

- Earth repair (restoring land damaged by society)
- Environmental survey (generating knowledge of the environment and its protection and management, for example using satellite data)
- Resource renewal (increasing eco-efficiency, i.e. in the use of materials and water and recovering and preventing waste)
- Sustainable energy (renewable energy and energy efficiency)
- Sustainable communities and cities (transport infrastructure, planning, urban design and building design)
- 'Clean and green food' and sustainable agriculture (organic farming, low input agriculture, agriculture based on ecological principles)

The State Sustainability Strategy will recognise the need for long term social and economic change, and will use the challenges of sustainability to stimulate innovation and social and economic development.

2.3 The Role of Price in Commodity Businesses

In the steel, chemicals, computer, and financial services industries—all loosely described as having evolved into "commodity markets"—leading companies are prospering by providing highly integrated packages of services. These experiences are instructive for the mining and minerals processing industries as well.

These packages of products can be significantly enhanced when integrated with a successful end-use, least-cost business approach that looks not only at the producers resource efficiency, but also at the needs of the customer and helps customise the product to meet their needs better. In this light, resource efficiency is not only a way to reduce production costs and gain competitive advantage; it is also an ideal way to build closer relationships with customers by helping them enhance their competitive position.

A disciplined focus on energy efficiency and end-use, least-cost planning offers at least three important benefits to companies in commodity-based industries:

- Reduce production costs
- Build closer and more interdependent relationships with customers
- Better understand new technologies and techniques that will propel a company to the forefront of industrial innovation

2.3.A. Helping Customers Become More Competitive

In the competitive global markets of the 1990s, pure price competition has given way to sophisticated bundling of products and service attributes to respond to customer needs. Price competition is a limited short-term strategy appropriate only at certain times of the product life-cycle. Prices are only one component of the buying decision, and in mature commodity-type markets, often not the most important one.

Helping customers become more competitive is the primary basis of a sustainable competitive advantage in a commodity market—helping the customer reduce costs, increase revenues, enhance product design or characteristics, etc. Understanding customer opportunities and needs is critical to developing the ability to provide mass individualisation, for example, by turning a commodity market into a specialty market to enrich customers with solutions derived from commodity-type products.

During the 1990s, the telecoms, airlines, natural-gas and electricity providers, PC OEMs, and credit-card companies learned the lessons that the US "Big Three" auto manufacturers learned the decade before: that special offers and discounts attracted few, if any new buyers. They merely "churned" existing customers, cut profit margins, and diminished their reputations.

For example, in the 1970s and early 1980s, US Steel nearly collapsed as the result of a defensive marketing strategy it pursued when confronted by lower-cost competitors. The firm tried to protect market share in low-margin markets instead of investing in high-margin, high-value-added markets.

US Steel is one of America's industrial success stories. At the end of the Second World War, US Steel was the world's largest supplier of steel and earned spectacular profits for its shareholders. Then in the 1970s, in a period of less than a decade, it nearly collapsed. Popular explanations focus mainly on relative cost structures and technological leadership. However, beginning the 1970s, US Steel greatly underpriced its products in an effort to maintain market share that was being eroded by aggressive global competitors, primarily in Japan. US Steel, convinced that the Japanese strategy of attacking the undefended low end of the market would lead in turn to the loss of their higher-value markets, made a strategic miscalculation that ignored a very simple truth: discounting commodity-type products in a competitive market requires a substantial profit cushion. For the Japanese, this cushion came from their domestic steel market. The price left US Steel with no earnings to plow back into customer service, R&D, and improvement of the product itself.

2.3.B. Market Intelligence

Companies in a broad range of industries that have taken energy efficiency and business innovation seriously as part of their core operational strategy are prospering in the industries and creating decisive competitive advantage. Leading companies in commodity-type industries are investing large amounts of money in market research, segmentation studies, psychographic profile analysis, and other sophisticated analytic techniques. These investments have advanced the understanding of customer buying behaviour considerably and enabled sophisticated tactical marketing. But they have also accompanied some celebrated mistakes and oversights when market research focused only on current products in defined markets and missed opportunities that were beyond the scope of the research.

Whilst new and more sophisticated techniques in market research have greatly enhanced the understanding of customer buying behaviour and underscored the importance of market orientation on business performance, they have not helped give a fuller picture of the attributes of market-driven organisations, such as the role of company culture and information utilisation, or the importance of the proper environment for innovation and product development.

For instance, the fax machine is American in invention, technology, design, and development. Yet not one fax machine offered for sale in the US today is American-made. The American companies that invented the fax machine did not put it on the market because market research convinced them that there was no demand for such a gadget. Bell Labs made the classic mistake of attempting to do market research on something not in the market. They reportedly asked people, "Would you buy a telephone accessory that costs upward of $2,000 and enables you to send, for approximately $1 per page, the same letter the post office delivers for 25 cents? The answer, predictably, was "no." Sharp and Panasonic endeavored to understand their customers' needs—they looked at the market for what the product does, not the market for the product, and they now dominate the industry. To be sure, the special requirements imposed by the Japanese system of writing helped create a robust domestic market, but with faxes as with photocopiers and personal computers, the original inventors of the technology proved utterly unable to envisage its markets.

The 1999 book *Natural Capitalism*[7] by Hawken, Lovins, and Lovins contains hundreds of case studies about leading companies that are increasing shareholder value and creating decisive competitive advantage by incorporating resource efficiency into their core strategy for understanding the future of their markets and the processes vital to compete in them.

2.3.C. Customer Relationships and Value Added

Customers, whether retail customers or businesses, do not want more choices. They want exactly what they want—when, where, and how they want it—and innovative companies are finding ways to make it possible.

Business paradigms that predominate today—those revealed through firms' strategies and organisational structures—are functions of an older, more capacity-constrained information environment. As that environment changes, so too do the paradigms, strategies, and structures that evolved with it. In particular, two major trends can be identified.

- The emergence of knowledge or information itself as an asset in its own right, often with significant market value to enhance commodity products.
- The blurring of current boundaries and the redefinition of traditional conceptual categories—between the firm and the outside world as well as within the firm itself.

The combination of mass customisation and one-to-one marketing binds producer and consumer together in a dependent relationship—an ongoing connection that becomes smarter as the two interact with each other, collaborating to meet the customers needs over time.

In this type of relationship, individual customers teach the company more and more about their preferences and technical needs, giving the company an immense competitive advantage. The most customers teach the company, the better it becomes at providing exactly what they want—exactly how they want it—and the more difficult it will be for a competitor to entice them away. Even if a competitor were to build the same capabilities, a customer in such an interdependent relationship with the company would have to spend a great deal of time and effort to teach the competitor what the company already knows.

2.3.D. Product Development

Product development is neither a science nor an art; it is a practice. It is a practice that is highly dependent on institutional structures that can either promote creativity and innovation or retard it. As in all practices, knowledge, structure, and process are the three key elements of success.

Companies in commodity-based markets that are successfully designing and marketing new products do not credit individual initiative and insight for their success. Rather, they credit a company culture and institutional structures that create the proper environment, provide

[7] Hawken, P. G., Lovins, A. B. & Lovins, L. H. 1999: *Natural Capitalism,* Little, Brown, New York, NY.

the necessary tools and funding, and engender a work ethic that promotes individual entrepreneurship. This is an important distinction. At the foundation of an "institutionalised entrepreneurial process," as 3M calls it, is a culture that puts great faith in the ability of the individual, and creates the proper environment for him/her to succeed. Companies like 3M, Intel, DuPont, US Steel, IBM, Bank of Boston, MBNA, Proctor & Gamble, are all exemplars of companies that have moved beyond simple production cost minimisation strategies and re-examined their upstream and downstream relationships and changed the way they utilize all resources for competitive advantage.

The structural doctrine that most managers rely on today is about allocating resources, assigning responsibilities, and controlling through management. The objective of the entrepreneurial organisation is to shape the behaviours and attitudes of people and create an environment that enables them to take initiative, to cooperative, and to learn. These philosophies of organisation and management are built on different assumptions about motivation and behaviour.

2.4 Cost Drivers and Market Prices

The mining and minerals industries use substantial, though poorly characterized, amounts of energy to obtain, process, purify, and transport their products. As noted in the text, there are vast differences between different mineral commodities, ambiguities in reporting conventions and system boundaries, changes in energy use over time and space, joint products, and other uncertainties that make it unfruitful to try to define this industry's energy use with any precision. However, other things being equal, energy use tends to increase with declining ore grade. For example, a 1972 study by Oak Ridge National Laboratory[8] estimated total direct energy inputs of 54 MJ/kg for copper from 1.0% sulphide ore in place in the 1940s, nearly doubling to 98 MJ/kg as the ore grade fell to 0.3% in the 1980s, when just mining and beneficiating ore containing 1 kg of copper took about 50 MJ. The typical comminution energy for typical nonferrous ores three decades ago, ~50–80 MJ/kg ore, implies total production energy on the order of 10 GJ/kg metal if ore grade declines to 0.001%. For comparison, burning 1 kg of typical coal yields 29 MJ, so metal from a 10^{-5} "ore" would embody the energy of hundreds of times its mass in coal. At such low grades, extractive technology, powerful though it undoubtedly is, would be hard pressed to sustain the declining real costs tracked for decades by Barnett and Morse in their classic Resources for the Future book *Scarcity and Growth* and its sequel.

The physical principles of grinding ore to liberation size are clear, but their implications are sometimes overlooked by minerals economists. One anecdotal example suggests that resort to the underlying physical principles can be illuminating. In the 1970s, a professor at the Royal School of Mines in London privately shared with one of us (ABL) his intriguing unpublished analysis of the relationship between the smoothed average market prices of nearly all metals (other than silver and gold) and the physical parameters that drive the cost of their extraction and processing. Surprisingly, he had been able to predict metal prices

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[8] Bravard, J. C., Flora, H. B. & Portal, C. 1972: "Energy Expenditures Associated with the Production and Recycle of Metals," Oak Ridge National Laboratory Report ORNL-NSF-EP-24, November.

quite closely—often within a factor of two—over a crustal-abundance range exceeding five orders of magnitude, from three purely physical variables:

- the average crustal abundance of the metal typically being mined—a surrogate for the amount of host rock to be moved and processed and the overburden removed to obtain it;
- the average grain size of that typical ore mineral—a surrogate for the investment and energy requirements of comminution and beneficiation; and
- the Gibbs free energy of the metal in its typical mineral—a surrogate for the investment and energy requirements of smelting.

The remarkably close relationship he reported between long-run smoothed metal prices and these physical parameters—despite the distortions of by-product and co-product relationships, sometimes uncompetitive market conditions, etc.—suggests a gratifying degree of competitiveness and economic efficiency linking prices to production costs for at least most of the dozens of metals examined. (Unfortunately the analysis itself was never published, its author may no longer be alive, and in any case it deserves updating—a worthy research project.)

Among the uncertainties in how far these physical parameters will continue to dictate the energy required to extract metals is limited knowledge of whether biological techniques, biomimicry, or conceivably in time nanotechnology may be able to evade some of the brute-force physical processes now used, notably comminution and smelting.[9]

Technological improvements and breakthroughs have the potential to change the energy per unit of product parameters. But it should be noted that the pace of technology development, adoption and commercialisation can be quite long indeed. Most new technologies require decades to achieve significant market penetration, and the size and scope of the mining and minerals industry will contribute to even longer periods for adoption. Finally, the great diversity within the mining and minerals industries poses further challenges. For some products, the greatest energy consumption is in extraction and transport, and in order to fundamental alter the energy equation, significant technological leaps in these areas would be required. For others, the key energy consumption stages are in processing and refining—involving entirely different technologies.

2.5 Mining and Minerals Industries as Drivers of Energy Investments

The mining and minerals industries are not simply price takers in energy markets. In fact, the attributes of these industries give them considerable influence on how energy investment decisions are made, especially by electric and gas companies. While a detailed

[9] More conventional improvements might also prove attractive. For example, Hitachi in 1995 commissioned a 1 T/h Tokyo pilot plant for separating municipal solid waste. By using liquid nitrogen to embrittle bulky mixed trash, including large white goods, it reduced comminution energy from 24 to 5 kWh/T. We have not researched whether cryogenic embrittlement makes sense for mineral comminution.

treatment of the energy markets and regulatory arena around the world is not appropriate here, and the ultimate issues are highly site-specific, a few general points can be made:

- Mining and minerals industry operations, especially in production and processing, are often very large energy loads. As a result, facility managers often have a real choice in whether to "build or buy" their energy supplies. A great many mining and processing operations self-generate their own electricity, are therefore dependent on bulk fuel sources, and enjoy an option to sell wholesale energy to the electric grid if interconnection is available and the price is right. In many cases, large industrial customers of utilities have been offered "load retention rates"—discounts—as compensation and incentive not to self-generate.
- Mining and minerals industry operations typically have relatively flat load profiles, meaning that their level of use is fairly constant over periods of operation. Under traditional regulatory tariff-allocation systems, driven primarily by peak pricing, mining and minerals operations enjoy relatively low prices per unit of delivered energy.
- Mining and minerals operations that buy their energy supplies typically take their energy at the gas or electric transmission level. The lower service price due to reduced distribution costs further reduces costs. The cost differentials are typically addressed in regulatory tariff proceedings, in which industry representatives often participate, especially in the cost allocation phase.
- Much of the environmental emissions associated with production and processing are embodied in the energy used in these processes. One highly effective strategy for reducing emissions imputed to the mining and minerals industry is to press electric service providers to use low-emissions generation, such as natural gas or even windpower (which in good US sites is contracting at prices lately edging below $0.03/kWh at the busbar). Almost every nation has considered or is considering policy to increase use of renewable and less-polluting fuels for electricity generation. Examples include the "Non-Fossil Fuel Obligation" in the United Kingdom, the "Renewable Portfolio Standard" under consideration in the United States Congress and currently adopted in several US states, the development in recent years of large natural gas-fired generation in India, the deployment of barge- and skid-mounted natural gas turbines in Central America, and similar initiatives around the world. Both developing and industrialised nations have actively pursued these strategies, for reasons including minimization of capital investment requirements, development of domestic "manufactured energy" industries, reduction of pollution, and technological and commercial self-sufficiency. For the mining and minerals industry, the advantage to such broad-based initiatives is the leverage in cooperative development and cost-sharing that accompanies electric industry-wide transitions.
- Deregulation or liberalisation of electric utility and gas utility businesses was largely driven by industrial customers seeking to take advantage of improved price performance for new (primarily gas) technologies. As champions of liberalisation, mining and minerals industry customers can help accelerate generation or supply stock turnover. However, retail choice often creates pressure for other legislative and regulatory responses, including "wires charges" to fund public benefits, "exit fees" to protect revenue streams, and "stranded cost" allocation schemes. These may in some cases trigger a decision to leave the grid.

- Mining and minerals industries operations are often a key component of local and regional economic activity. As such, they exercise strong influence on economic regulators charged with protection of the public interest, and upon commercial businesses operating in the same region or who are part of the industries' supply chains. This influence can be demonstrated in proceedings that approve or pass into tariffs new generation and delivery systems.
- Mining and minerals industry operators can also exert influence on tariffs and services for individual customers. For example, because labour costs are often a greater fraction of operating expenses than energy, mining and minerals industry support for residential energy efficiency programs could actually help to control energy cost inflation and concomitant wage pressure. Some industrial firms have even given away residential energy and water efficiency programmes and financing to their workers as a high-leverage way of increasing employees' disposable income.

3 Sustainability Trends and Their Impacts on Mining and Minerals Activities

In Section I.2, we introduced the major trends and drivers impacting the energy industry. Embodied within and influencing several of those is the growing impact of pressure to address sustainability—the ability to meet environmental, economic, and social needs both today and in the future. These underlying forces are impacting the mining and minerals industry as well, and just as they are contributing to change in the energy industry, they are impacting the large energy-using mining and minerals industries.

3.1 Definition of Sustainability

Eleven of the twelve largest American companies at the beginning of the twentieth century were not around to see the beginning of the twenty-first. Only General Electric—the fifth largest US corporation today and the ninth largest worldwide—has continued to prosper. Survival is not impossible in the midst of rapid technological change, but it requires business insight and foresight into the changing nature of scarcity, and an understanding of where the opportunities lie for vastly enhancing resource productivity and corporate profitability.

Sustainability is a broad and sloppy term used by many to promote narrow and parochial interests, and by others to promote broad and sweeping campaigns to prevent governments or industries from behaving in certain ways they find disagreeable. In a larger context, however, a growing number of companies have demonstrated that sustainability does not need to imply restrictions, deprivation, or austerity, but rather strategies to produce greater value from the more efficient and restorative use of resources. In this sense, sustainability is not a response to a threat, but rather a severely practical and meticulously applied desire for durable prosperity.

The debate over energy and the environment is often cast in similar terms: how should a company or industry behave in a resource constrained—or carbon constrained—environment?, as opposed to how can a company or industry create decisive economic advantage through the more efficient and restorative use of resources?

The philosophy that sustainable growth has to be focused on a *functionality* not a product, leads to the next major step toward sustainable growth: namely to improve the value of our products and services per unit of natural resources employed—that is, to raise resource productivity across the board.

3.2 Drivers for Sustainability

The mining and minerals industry will continue to be confronted by challenges presented by the use, and interaction with, four major categories of resources or associated environmental concerns: water, energy, climate modification, and transportation technologies. These key areas of concern are explored in greater detail below because of the important issues of energy use they raise in the mining and minerals industries.

3.2.A. Water

We live on the Water Planet. Three-fourths of the earth's surface is covered by water. Yet fresh, clean water is scarce and getting more so. Of all the water on earth, less than 3% is fresh, and all but 3/1000^{ths} of that freshwater is locked up in glaciers and icecaps or is too deep in the earth to retrieve.[10] The fresh water available in rivers, lakes, and accessible groundwater is increasingly becoming polluted. Despite more than a half-million square kilometres of reservoirs capable of storing nearly 6,000 cubic kilometres of water—a redistribution of natural water flows that has measurably changed the orbital mechanics of the planet[11]—individual well-users, fertile farming regions, and even whole cities of the size of Mexico City or Beijing are short of water and getting more so. Such water scarcity has already changed the global patterns of grain trade. Water tables are retreating on every continent, with 70% of the pumping to irrigate crops. As shortages turn from local to regional to larger, water is becoming a significant source of international conflict—a trend five millennia old.[12] Global climate change could intensify the droughts that have sporadically devastated and desertified subcontinental areas. In most parts of the world, substantial increases in the supply of water appear impractical or uneconomic: no supply-side strategy alone could keep pace with the present rate of population and demand growth.[13]

Mining is often water-intensive, and like any industry expecting to use substantially more fresh water, it will probably be competing with other uses and users. This conflict is sometimes said to be entirely avoidable by desalination—the last resort for those lacking water but rich in money and energy. However, this technique provides only 2/1000^{ths} of the

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[10] UN Commission on Sustainable Development, *Comprehensive Assessment of the Freshwater Resources of the World*, 1997, UN, NY

[11] Gleick, P. H. 1998: *The World's Water 1998-1999: The Biennial Report on Freshwater Resources,* Island Press, Washington, D.C., updated at www.worldwatch.org, at 70, citing B. F. Chao, B. F. 1995: "Anthropogenic impact on global geodynamics due to water impoundment in major reservoirs," *Geophys. Res. Letts.* **22**:3533-3536.

[12] Gleick, P. H. 1998: *The World's Water 2000–2001*, Pacific Institute, Oakland CA, at 182–191.

[13] Postel, S. L., Daily, G. C. & Ehrlich, P. R. 1996: "Human Appropriation of Renewable Fresh Water," *Science* **271**:785–788.

world's freshwater use, mainly because of its discouraging economics.[14] The minimum energy theoretically required to desalt one cubic metre of seawater is 2.8 MJ—the energy contained in a mere 80 millilitres of oil. However, the best large-scale desalination plants operating in the mid-1990s, though about twice as efficient as typical plants, used about 7–10 times the theoretical limit, with apparently limited practical opportunity for further improvement. At that rate, desalinating enough seawater to grow enough protein-rich crops and efficiently-converting livestock to feed a person could use about as much energy as that person now uses for everything else.

Desalination plants are also extremely capital-intensive. In 1994, a cubic meter of desalinated water in the Middle East, which has about half the world's desalination capacity, cost $1–4, sometimes up to $8, despite some of the cheapest energy in the world. The lowest reported US contemporary prices are around $0.65/m^3. For comparison, for a cubic metre of water desalted for free by the earth's hydrological cycle, western US farmers were paying $0.01–0.05, and urban users typically around $0.30. Commercial desalination ventures have an uneven history. Santa Barbara, California, ordered a desalination plant in 1990 as "insurance" during a prolonged drought, which ended just as the plant was finished. It has never run, but its cost and that of a $600-million extension of the State Water Project so burdened local water districts with debt service that water prices more than trebled, demand skidded by two-fifths (enough to displace the desalination plant[15]), and efficiency efforts were halted in an attempt to boost revenues and avert a "death spiral" of rising prices and falling revenues. Parts of the plant have now been removed and sold.

However, desalination is no longer the only option for water users with more money than sense. Surprisingly, technical advances had made it feasible by the late 1990s to tow bags of fresh water through the oceans from water-rich to water-poor areas, and several firms were undertaking small-scale pilot transactions that may prove less costly than desalination,[16] though they do not create new water supplies and are still not cheap.

Water is akin to energy in some ways—valuable but widely wasted natural capital, subject to similar policy errors:

- focusing on supplying more rather than a balanced portfolio of supply and more productive use;
- supplying the highest-quality water for every task (such as flushing toilets and washing roads with drinking water);
- seeking gigantic scale for new projects rather than the right size for the task; and
- depleting nonrenewable supplies rather than learning to live comfortably within our income.

But there are also key differences:

- Energy doesn't get polluted as water does—easy to do, hard to undo.

[14] Gleick 1998, Ch. 5.
[15] Gleick 1998 at 32.
[16] Gleick 1998 at 200–205.

- We get a free daily increment of energy from the sun, but other than perhaps a gentle drizzle of interplanetary ice pattering on the upper atmosphere, the earth isn't getting topped up with more water.
- Renewable energy arrives far more reliably and evenly than the fickle and inequitably distributed supply of rainwater.
- And because water is a matter of life and death, both literally and economically, many people in arid areas will kill for it. Water in most societies flows to those with political and economic power: in the Western United States, water is said to flow uphill toward money. However, water for drinking and other directly vital needs can often outbid other water uses.

For example, Postel *et al.* 1996 estimate that the fraction of the earth's accessible water runoff appropriated for human use could rise from 54% in 1995 to over 70% by 2025. But increasing scarcity implies rising prices that will shift allocations. For example, Reisner 1986/93[17] estimated that enough water to meet the needs of Los Angeles' 13 million people was being used to irrigate California pastures for feeding livestock. In the mid-1980s, the pasture was worth $0.1 billion, while Southern California's economy was worth $300 billion, so the cities can easily outbid the farmers. In that region,[18] a million cubic metres of water used in high-tech industries can support 13,000 jobs, while using the same water to grow grass for livestock supports only six jobs. Mining too would obviously suffer from such a comparison.

Most forms of mining are both energy- and water-intensive, so it is important to understand how these two kinds of resource use often interact. That is, not only do water and energy hold similar policy lessons, but delivering one tends to require the other too.[19] For example:

- Water is heavy, so pumping it up from wells and over mountains is the biggest use of electricity in California. That state's Water Project, as authorized in 1959, originally planned 148 pumping stations, 40 power stations, 22 reservoirs and dams, and 620 miles of aqueducts. It would have consumed as much electricity as Maine or Wyoming use, just to pump water around. This more than 12.4 TWh/y would have been two-thirds more energy than could have been recovered as the water ran back downhill. Where those who pay for the water must pay directly for its pumping energy, the economics can quickly become hopeless—as when a west Kansas rural electric cooperative went broke building and trying to run the Sunflower coal-fired power plant, meant to supply energy to enable farmers to pump Ogallala groundwater waster—the plant itself to be cooled by groundwater. The managers failed to foresee that at the electricity prices they'd have to pay for pumping, the farmers couldn't afford the water. Similarly, the US Army Corps of Engineers wanted to pump the Missouri River uphill to recharge aquifers in and beyond West Kansas, even though there was no legal crop that farmers could grow with that water to earn enough to afford just the pumping energy. The 1968 Texas Water plan would have needed seven Chernobyl-sized (1-GW_e) power plants to pump water about 1 km up from the Mississippi River to a region of West Texas. The

[17] Reisner, M. 1986/93: *Cadillac Desert: The American West and Its Disappearing Water,* Penguin Books, New York, NY.

[18] Gleick 1998 at 25

[19] Gleick, P. H. 1994: "Water and Energy," *Ann. Rev. En.* **19**:269-299.

North American Water and Power Alliance would have replumbed western North America—damming the 800-km-long Rocky Mountain Trench near Banff and Jasper National Parks, and diverting the major rivers of Alaska, the Yukon, and B.C. to supply water to all of Canada, the western and midwestern US (pumping over the Rocky Mountains as needed), and northern Mexico. This nearly trillion-dollar project did not pass the giggle test and was ultimately abandoned, but it illustrates how far some people are willing to go to put water where it isn't.

- America's 60,000+ water supply plants and 15,000 wastewater treatment plants use 3% of US electricity, and would use even more if national wastewater quality standards were universally met. Heating water uses about 6% of US electricity. Thermal power stations use 39% of all US freshwater withdrawals—equal to irrigation, and more than triple all community and municipal water supply systems. In 1990, US thermal power plants were two-thirds cooled by freshwater, and consumed about 2% of the saltwater and 2.7% of the freshwater they withdrew. A coal-fired power plant using once-through cooling evaporates water weighing about ten times as much as the coal it burns. (The plant is typically sited near cooling water because it's cheaper to move the coal than the water.) Dry-climate cooling towers use about 2.5 times more water than power plants in moist regions use. Hydroelectric reservoirs typically lose even more water per kWh to evaporation and seepage.
- In the American Southwest, more groundwater than coal is mined for the slurry pipeline that carries coal from Black Mesa to the Mojave Power Plant in southern Nevada. Water recovered from the pipeline at the power plant provides only 1/7 of its cooling. Extracting and processing coal, oil, uranium, and other fuels can also consume large amounts of water and contaminate even more. In some countries, matters are far worse: for example, in Poland two decades ago, when it was the world's fifth largest coal-mining country, severe air and water pollution was contributing to economic shrinkage,[20] coal-mining consumed a fifth of all steel (up >150% since 1978) and nearly a tenth of grid electricity, the average depth of mines was increasing by 2–4%/y, more difficult mining conditions were cutting labour productivity in the worst mines to a sixth of the British or West German norm, social and administrative costs were high and rising, and land was already so scarce that some mines "transport waste rock and coal washing refuse as far as 80 km for disposal."[21] Coal exports for hard currency had to virtually cease in the 1990s in order to fill domestic needs as coal quality and accessibility declined. In any event, the economic benefits of the exports were illusory because they greatly speeded the shift from high- to low-quality coal (high sulfur, high ash, high cost, more global warming)—more precisely, to water-mining with poor coal as a minor byproduct.

The only financially and logistically feasible foundation for sound water policy, virtually worldwide, is to use water in a way that saves money. Fortunately, powerful technologies

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[20] Chandler, W.U., Makarov, A.A., & Zhou, D. 1990: "Energy for the Soviet Union, Eastern Europe and China," *Scientific American*, September, pp. 120-127.

[21] Sitnícki, S., Budzinski, K., Juda, J., Michna, J., & Szpilewicz, A. 1990: *Poland: Opportunities for Carbon Emission Control,* Battelle Pacific Northwest Laboratory, Richland, WA, May.

and implementation methods[22] can enable water's benefits to flow adequately, even bounteously—providing, as South Africa's farsighted Constitutional water policy seeks, "some, for all, forever." The key is to apply to water the policy lessons learned from energy: to use the resource very efficiently, so desired end-use services are provided at least cost; provide the right quality and scale for the task; choose the best buys first; let markets work; be fair; and reward least-cost outcomes.

3.2.B. Efficient Energy Use

Overview – End-Use Efficiency

US industry uses one-third of its total fuel consumption in the form of electricity. Three-fourths of that electricity runs motors.

Typical drive systems in oil refineries, chemical plants, chip fabs, and general manufacturing can often be retrofitted to save about half the energy between the meter and the input shaft of the driven machine, with after tax ROI approaching 200%/y.[23] The savings are that cheap (around $0.005 per saved kWh) because a premium-efficiency motors has 18 benefits, not just one, and retrofitting the right seven improvements in the right order can capture 28 more as free by-products.

This doesn't count improvements in the equipment that the motors are driving; but those improvements are often even bigger and cheaper, and should be done first so as to make the motors smaller. For example, as described below, two changes in the design mentality of a standard industrial pumping loop recently cut its pumping power by 92% whilst reducing its capital cost and improving its performance in all respects: the changes simply replaced skinny, long, crooked pipes with fat, short, straight pipes. A new geometry has nearly doubled the efficiency and increased the reliability of even the lowly sewage pump; another has about quintupled the efficiency of the bubble diffusers used in wastewater and chemical plants, and perhaps akin to those used in selective flotation.

Case Study – Georgia Quarry Reduces Maintenance Requirements and Energy Costs

The Lithonia quarry, one of 10 quarries operated by Blue Circle Aggregates in Georgia, produces 1.8 million tons of aggregate and manufactured sand for construction and road building each year. Excavating, moving, screening, and processing these materials consume approximately 4 million kWh annually and create a demand of about 500 kW. Based on an assessment conducted by the Energy and Environmental Management Center (EEMC) at the Georgia Institute of Technology, the Lithonia quarry implemented motor system upgrades. Implementing the motor system upgrades has reduced yearly energy consumption at the quarry by nearly 250,000 kWh and demand by 81 kW, resulting in cost savings of over $21,000 per year. These energy and demand savings are

[22] Hawken, Lovins & Lovins 1999, Ch. 11; Vickers, A. 2001: *Handbook of Water Efficiency and Conservation*, www.WaterPlowPress.com, ISBN 1-931579-07-5

[23] Lovins, A.B. *et al.*, 1989: COMPETITEK, *The State of the Art: Drivepower*, RMI, republished as E SOURCE, *Drivepower Technology Atlas*, 1999, www.esource.com; Fickett, A. *et al.*, 1990: "Efficient Use of Electricity," *Sci. Amer.* **263**(3):64, September.

6.2% and 16% of their respective annual figures.

Motor System Upgrades

Motor	HP	kW Savings	kWh Savings	US$000 Savings
Upgrade 1: Reduce Horsepower of Water Pumps				
Water Pump #1	50	20.1	60,400	$ 5,260
Water Pump #2	75	28.0	89,900	7,320
Water Pump #3	15	9.8	29,500	2,570
Upgrade 1 Totals	140	57.8	179,800	$ 15,150
Upgrade 2: Lower Hydro-Cyclone Elevation				
Upgrade 2 Totals	N/A	13.1	39,300	$ 3,400
Upgrade 3: Replace Four Motors with Energy-Efficient Motors1				
Crusher	200	2.4	7,218	$ 629
Pump #2	150	2.4	7,296	636
Pump #3	200	2.4	7,218	629
Pump #6	140	2.6	7,718	673
Upgrade 3 Totals	690	9.8	29,450	$ 2,567
Grand Totals	**837**	**80.8**	**248,640**	**$21,117**

Savings based on 3,000 hours of operation per year and replacement upon motor failure.

Upgrade 1: Reduce Horsepower of Water Pumps

The greatest energy savings resulted from reducing the capacity of three large water pumps. The quarry has two water sources—a quarry pit and a stream some distance away. The EEMC found that the quarry pit could provide all the necessary water for quarry operations. Therefore, reducing the use of the main pump from the stream and two additional circulation pumps reduced power requirements by 140 horsepower.

Upgrade 2: Lower Hydro-Cyclone Elevation

The second system upgrade reduced pumping costs by physically lowering part of the 10-element hydro-cyclone unit at the quarry by 80 feet. This upgrade cost approximately $5,100 and resulted in annual monetary savings of $3,400—a simple payback of 1.5 years.

Upgrade 3: Replace Four Motors with Energy-Efficient Motors

The third recommended upgrade includes replacement of four standard efficiency motors with high-efficiency models upon burnout. The EEMC completed the economic evaluations for this upgrade using MotorMaster+.

The EEMC further recommended that Blue Circle Aggregates change their motor policy to specify that all motors operating more than 3,000 hours per year be replaced with high-efficiency motors upon burnout. Doing so would have an average payback of about 2.4 years.

Source: US DOE *Energy Matters* Newsletter (May 1999)

Authors' Note on the Motors Case Study

This case study describes a fairly standard approach to motors. It captures a useful but relatively modest saving with an acceptable payback of a few years. However, this achievement falls well short of the highly integrated, comprehensive, whole-system approach first analyzed by Rocky Mountain Institute and the Electric Power Research Institute in 1989. Its best current summary is in the Drivepower Technology Atlas (and some parts of the *Space Cooling Technology Atlas* dealing with piping, pumps, ducts, and fans), both parts of the Electronic Encyclopedia CD-ROM published semiannually by E SOURCE, www.esource.com. A brief summary is at www.natcap.org/sitepages/ pid27.php, Appendix 5D.

Obstacles to efficient energy use

Most economic theorists assume that almost all energy-efficiency investments cost-effective at present prices have already been made. Actually, huge opportunities to save money by saving energy exist, but are being blocked by scores of specific obstacles at the level of the firm, locality, or society. Even if environmental, energy security, and climate change were not a concern, it would be worth clearing these barriers in order to capture energy-efficiency investments with rates of return that often approach and can even exceed 100% per year.

Focusing private and public policy on barrier-busting can permit businesses to buy energy savings that are large enough to protect the climate, intelligent enough to improve living standards, and profitable enough to strengthen economic vitality, employment, and competitiveness.

Eight classes of regulatory, organisational, and informational failures, perverse incentives, distorted prices and investment patterns, and similar barriers are costing the US economy about $300 billion every year and the world several orders of magnitude more. This waste pervades even well-known and well-managed companies that have been saving energy for decades. Some alert corporate leaders, however, are now starting to break through these barriers to enrich their shareholders by combining careful attention with far-reaching innovations in design and technology. Many examples illustrate how each of the obstacles to such energy-saving practices can be turned into a lucrative advantage.

Summary – Barriers to Energy Efficiency

A few years ago, the CEO of a Fortune 100 company heard that one of his sites had an outstanding energy manager who was saving $37 per square metre per year. He said, "That's nice—it's a nearly 100,000-square-metre facility, isn't it? So that guy must be adding $3.5 million a year to our bottom line." Then in the next breath, he added: "I can't really get excited about energy, though—it's only a few percent of my cost of doing business." He had to be shown the sums to realise that similar results, if achieved in his 9-odd million square metres of facilities worldwide, would boost his corporation's net earnings that year by 56%. The energy manager was quickly promoted so he could spread his practices across the company.

In mining, as in most process industries, many obstacles inhibit cost-effective energy savings. Some come from inept public policy, such as the common practice of rewarding distribution utilities for selling more energy while penalizing them for cutting customers' bills. Some come from perverse commercial practice, such as rewarding engineers and architects for what they spend, not for what they save. Some reflect management deficiencies at the level of the firm, such as:

- neglecting energy as a relatively minor factor cost (in operations where it is), even though any savings in energy, as in any overhead, go straight to the bottom line
- judging energy savings by their simple payback instead of discounted-cashflow metrics (four-fifths of all US firms do this)—and hence not noticing that the hurdle rate set (such as a two-year simple payback) often corresponds to an aftertax return many times the marginal cost of capital
- making seemingly small purchases by first cost only, not lifecycle cost
- not fairly comparing marginal investments on the demand side with those routinely undertaken on the supply side
- uncritically following old design and operational habits ("infectious repetitis")
- not measuring how systems actually work and using that information to drive continuous design improvement
- optimizing by isolated department rather than the whole enterprise
- not rewarding individuals or organisational elements for the savings they achieve, but instead penalising them
- not making energy efficiency anyone's primary responsibility or reflecting it in personnel performance evaluations
- supposing that the sum of individual decisions yields rational behaviour for the organisation

Collectively, these and other market failures—some 60–80 kinds in all—cause most of the highly profitable efficiency that is available in the world's industrial firms to remain unbought. Both these obstacles and the business opportunities that each one can be turned into are catalogued Lovins & Lovins 1997, at pp. 11–20.

Capital misallocation

- Energy is only 1–2% of most industries' costs, and most managers pay little attention to seemingly small line-items, even though small savings can look big when added to the bottom line. Surprisingly many executives focus on the top line and forget where saved overheads go; and without managerial attention, nothing happens.
- Most manufacturing firms tend to be biased toward investments that increase output or market share and away from those that cut operating costs.
- About four-fifths of firms don't assess potential energy savings using discounted-cashflow criteria, as sound business practice dictates; instead, they require a simple payback whose median is 1.9 years. At (say) a 36% total marginal tax rate, and using the common end-of-year convention, a 1.9-year payback means a 71% real after tax rate of return, or around six times the marginal cost of capital.

Organisational Failures

- Old habits die hard. Why make changes when the status quo is comfortable?

- Schedules conquer sensible design. Intense schedule pressures combine with design professionals' poor compensation and prestige, overspecialized training, and disintegrated processes to yield 'commoditised', lowest-common-denominator technical design.
- In most firms, the design process is linear—require, design, build, repeat—rather than cyclic—require, design, build, measure, analyse, improve, repeat. No measurement, no improvement.
- Little measurement, hence no improvement. Few firms carefully measure how their buildings and processes actually work. Their design assumptions are therefore untested and often incorrect.
- Departments can't or won't cooperate. Often capital expenditures are made from one budget and operating expenses from another with totally separate financial and operational targets.
- If you save, the bean counters simply cut your budget some more. Institutional or personal rewards for cutting energy costs are rare, even in the private sector. It's equally hard to prime the investment pump so savings from one project can help pay for the next.

Regulatory Failures

- Almost every utility in the world is rewarded for selling more energy and penalized for cutting customers' bills.
- Just "meeting code" wastes money and incredibility opportunity. Choosing low cost bidders and minimizing first costs can often sacrifice after-tax returns on energy savings of 100+%/y.

Informational Failures

- Lack of adequate information. If you don't know something is possible, you can't choose to do it.
- "Hassle factor" and transaction costs prevent efficient microdecisions in day-to-day operations.
- Information is viscous; it sticks to those who have it, but seldom gets to those who need it
- Value-chain risks and risk aversion. Manufacturers often hesitate to take the risk of developing and making new energy-saving products, because of limited confidence that customers will buy them in the face of all the obstacles listed here.
- Distribution Logistics. Efficient equipment often isn't available when and where it's needed—as anyone knows who's tried to replace a burned-out boiler, furnace, motor, etc. on short notice.
- Litigation risks (especially in the US) lead to inefficient defensive behaviour and can inhibit innovation.

Perverse Incentives

- Architects and engineers get paid according to what they spend, not what they save.
- Split incentives. One person choosing the capital equipment, another responsible for the energy expenses are ubiquitous (builder/buyer, purchasing/operations, landlord/tenant).

False or Absent Price Signals

- Energy prices are often badly distorted by government subsidies.
- Energy price signals are often diluted by other costs. Few firms track energy costs as a line-item for which profit centers are accountable. Most billing systems give no end-use information that lets customers link costs to specific devices.
- Tax asymmetries distort energy choices – for example, energy purchases are deductible business expenses, but investments to save energy get capitalized.
- Absent-minded business models—for example, data-center developers' charging tenants only by floor area, not by measured wattage, even though most big costs are watt-dependant.

Incomplete Markets and Property Rights

- There is no market in saved energy. Saved energy, "negawatts," aren't a fungible commodity subject to competitive bidding, arbitrage, secondary markets, derivatives, and all the mechanisms that make efficient markets in commodity energy, metals and agricultural products.
- Few tradable property rights in reduced or avoided depletion/pollution or reduced uncertainty of energy demand, so the market can't adequately express the value.

The Role of Energy Prices

Energy price does matter, but ability to respond to price matters even more. The last time the United States saved energy very quickly—expanding GDP 19% while shrinking energy use 6% during 1979–86—the main motivator was costly energy. Yet similar success can now be achieved by substituting high skill and attention for high prices. During 1996–99, the US saved energy nearly as fast as during 1979–86, despite record-low and falling energy prices!

Another example equally perplexing to economists: During 1990–96, Seattle, with the lowest electricity prices of any major US city, saved peak electric load twelve times as fast, and annual electric use 3,640 times as fast, as Chicago, where electricity tariffs averaged twice as high. The key difference: Seattle began to create an efficient, effective, and informed market in energy productivity, whilst the Chicago utility discouraged electricity savings that would (due to perverse regulation) reduce its profits.

And another example: a worldwide survey by DuPont a few years ago revealed that its European chemical plants were no more energy-efficient than their US counterparts, despite long having paid twice the energy price. This is because all the plants were designed by the same people in the same way using the same processes and equipment. There's little opportunity for behavioral change in a chemical plant, so relative prices had little effect.

Retired GE Chairman Jack Welch said of American industry, "Our productivity is at the beginning stages. There's so much waste. There's so much more to get, it's unbelievable. And somehow or other people think all these things are finite." Singapore engineer Eng Lock Lee, reflecting on decades of experience in wizard-class efficiency improvements, likens the potential to a recent cosmological discovery: "Low efficiency is like dark matter—90% of the universe is made of it. We know it's out there but sometimes it is hard to detect––it warps space-time and shapes the universe and sucks in money like crazy." Practitioners often find that the more that the industry-pervading waste is corrected, the more new opportunities emerge to save even more resources, even faster and cheaper—especially electricity, which is the costliest and most climate-affecting form of energy. Many of the most striking opportunities come from simple changes in design, as the following example illustrates.

Systems Thinking

Pumping is the biggest use of electric motors. Leading American carpetmaker Interface was recently building a factory in Shanghai. One of its processes required 14 pumps. The top Western specialist firm sized them to total 70.8 kW. But a fresh look by Interface/Holland's engineer Jan Schilham, applying methods learned from Eng Lock Lee, cut the design's pumping power to only 5.3 kW—a 92% or 12-fold energy saving. This redesign also reduced the system's capital cost, and made it more compact and quiet, easier to build and maintain, and more reliable, durable, and controllable.

These astonishing results required two changes in design. First, Schilham chose big pipes and small pumps instead of small pipes and big pumps: friction falls as nearly the fifth power of pipe diameter. Second, he laid out the pipes first, then installed the equipment, not the reverse: the pipes are therefore short and straight, with far less friction, requiring still smaller and cheaper pumps, motors, inverters, and electricals.

These two changes in design mentality—optimising the pipe size for lifecycle whole-system cost, and laying out the pipes before the equipment—cut pumping energy by twelvefold while reducing total capital cost. But then Schilham found more benefits. The straighter pipes also allowed him to add more thermal insulation, saving 70 kW of heat loss with a two-month payback. Further big benefits included lower size, weight, and noise, which could often bring knock-on savings in construction; clean layout for easy maintenance access, but less maintenance required; and longer life (because pipe elbows weren't being eroded by fluid turning the corner). Had these benefits been properly analysed, it's quite possible that the even fatter pipes resulting might have saved more like 98% than 92% of the pumping energy.

Such radical savings at reduced capital cost are not confined to pumping. Major energy savings are available in valves, ducts, dampers, fans, motors, wires, heat exchangers, insulation, and most of the other design elements, in most of the technical systems that use energy, in most applications, in all sectors. Virtually all energy uses are designed using rules-of-thumb that are wrong by about three- to tenfold. Substituting economically rational whole-system design would therefore save much of the energy used by industry, probably including many applications in the mining and minerals industries, whilst reducing capital costs.

These benefits derive from artfully integrating components into systems. But even at the level of simple components, careful scrutiny of actual market prices for equipment reveals that many technical devices—motors, valves, pumps, rooftop chillers, etc.—show no correlation whatever between efficiency and price. A typical (1800-rpm 60-Hz TEFC) 75-kW (100-hp) American asynchronous motor, for example, can be cheaper to buy at 95.8% efficiency than an otherwise identical 91.7%-efficient model.

But if you don't know that—if you assume, as economic theory predicts, that more efficient models always cost more—then you probably won't shop for it. That can be costly. If the motor runs continuously, each one-percentage-point gain adds about $50 per horsepower to the bottom line, so not choosing the most efficient 100-hp motor can reduce present-valued profits by $20,000. Many process-industrial facilities have hundreds of such motors, which are less efficient than even mediocre new models. Again, the key is not so much adopting new technologies, though they're important, as using proper recipes for combining the best available technologies in the optimal manner, sequence, and proportions.

Some of the recipes are embarrassingly obvious. Proven examples abound in every kind of business:

- Properly choosing office equipment and commercial and household appliances has saved over two-thirds of their energy use with the same or better service and comparable or lower cost. Some energy savings in this sphere can exceed 98%.
- Skilled retrofits have saved 70–90+% of office and retail lighting energy, yet the light quality is more attractive and the occupants can see better. In many cases, the better lighting equipment more than pays for itself by costing less to maintain.
- Motors use three-fifths of all electricity, and even in the US, more primary energy than highway vehicles. This use is highly concentrated: about half of all US motor electricity is used in the million largest motors, three-fourths in the three million largest, many of which are in mineral processing facilities. Since big motors use their own capital cost's worth of electricity every few *weeks,* switching to the best premium-efficiency motors can pay back quickly. A comprehensive retrofit of the whole motor system typically saves about half its energy, as noted earlier, and pays back in around 16 months at a $0.05/kWh tariff.
- The chemical industry saved nearly half its energy per unit of product during 1973–90 by plugging steam leaks, installing insulation, and recovering lost heat. Now it's discovered that better catalysts and matching heat to the required temperature ("pinch technology") can often save 70% or so of what's left, yet pay back within two years. Next-generation industrial plant design, now moving from the chemical industry into semiconductors, is uncovering 50–75% savings with lower capital cost, faster construction, and better performance. Applications suited to microfluidics can even achieve orders-of-magnitude savings. Early adopters will prosper.

Many of these examples illustrate a new design concept: wholesystem engineering can often make it cheaper to save a large than a small fraction of energy use. Integrating the design of an entire package of measures so they do multiple duty (such as saving on both energy and equipment costs), or piggybacking on renovations being done anyway for other reasons, or both, can enable designers to "tunnel through the cost barrier." Good engineers think this is fun. Most economic theorists assume it's impossible. We'll explain in a moment why it's both possible and practical.

The Secret is Proper Planning

By the time the design for most human artifacts is completed but before they have actually been built, about 80–90 percent of their life-cycle economic and ecological costs have already been made inevitable. In a typical building, efficiency expert Joseph Romm explains,

> Although up-front building and design costs may represent only a fraction of the building's life-cycle costs, when just 1 percent of a project's up-front costs are spent, up to 70 percent of its life-cycle costs may already be committed. When 7 percent of project costs are spent, up to 85 percent of life-cycle costs have been committed." That first one percent is critical because, as the design adage has it, "All the really important mistakes are made on the first day.

To think differently—to use a different design mentality—on that first day, we can make no better higher-leverage investments than improving the quality of designers' "mindware"—assets that, unlike physical ones, don't depreciate but, rather, ripen with age and experience. Senior building-services engineer Eng Lock Lee offers the following example. A typical colleague may specify nearly $3 million worth of heating, ventilating, and air-conditioning (HVAC) equipment every year—enough to raise a utility's summer peak load by a megawatt. Producing and delivering that extra megawatt conventionally requires the utility to invest several million dollars in infrastructure. If better engineering education were ultimately responsible for the equipment's being made 20–50 percent more efficient (a reasonably attainable and usually conservative goal), then over a 30-year engineering career, the utility would avoid about $6–15 million in present-valued investments per brain, without taking into account any of the savings in operating energy or pollution. This returns at least a hundred to a thousand times the extra cost of that better education. The savings would cost even less if good practitioners disseminated their improved practices through professional discourse, mentoring, or competition, so that educating just one engineer could influence many more. In addition, a good engineer's lifetime designs can improve comfort for perhaps 65,000 office workers, whose 30-year present-valued salary totals about $36 billion. If increasing their comfort will increase their productivity, as has been widely observed, then society can gain perhaps a million times more benefit than the additional cost of the better engineering education.

Many architects, engineers, and other designers, however, are not being well taught. J. Baldwin, long the technology editor of Whole Earth Review, was told on his first day in design school that

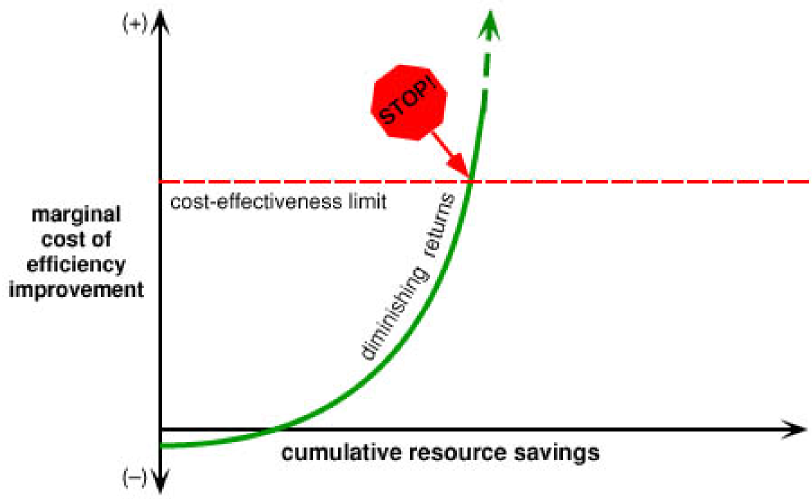
design is the art of compromise.

Design, he was instructed, means choosing the least unsatisfactory tradeoffs between many desirable but incompatible goals. He believed that this formulation described "a political technique masquerading as a design process," and he realized it was wrong. His inspiration came as he gazed out the classroom window and saw a pelican catching a fish. For the past 3.8 billion years or so, nature has been running a successful design laboratory in which everything is continually improved and rigourously retested. The result, life, is what works. Whatever doesn't work already got recalled by the Manufacturer. Every naturalist knows from observation that nature does not compromise; nature optimises. A pelican, nearing perfection (for now) after some 90 million years of development, is not a compromise between a seagull and a crow. It is the best possible pelican.

A pelican, however, is not optimized within a vacuum. It exists in an ecosystem, and each part of that ecosystem, in turn, is optimized in coevolution with the pelican. A change in the pelican or in any aspect of its ecosystem could have widespread ramifications throughout the system, because all its elements are coevolving to work optimally together. For the same reason, an engineer can't design an optimal fan except as an integral part of its surrounding cooling system, nor an optimal cooling system without integration into the building around it, nor an optimal building without integration into its site, neighborhood, climate, and culture. The greater the degree to which the components of a system are optimized together, the more the tradeoffs and compromises that seem inevitable at the individual component level becomes unnecessary. These processes create synergies and felicities for the entire system—rather than, as commonly assumed, compromises and tradeoffs. And this in turn exposes a core economic assumption as a myth.

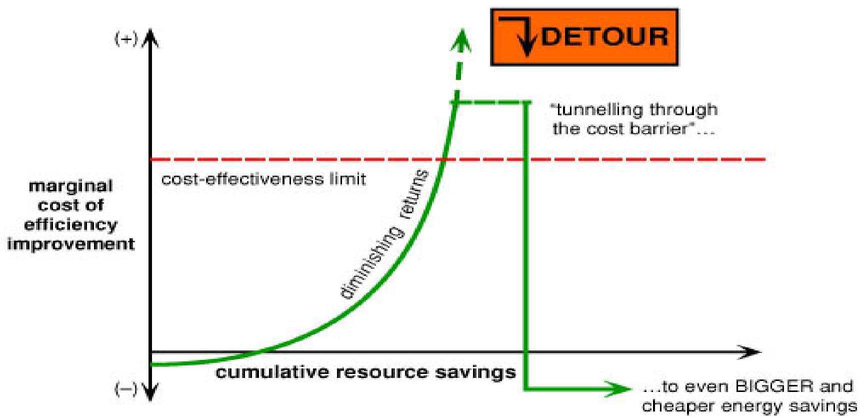
Tunneling through the Cost Barrier

Economic dogma holds that the more of a resource you save, the more you will have to pay for each increment of saving. That may be true if each increment is achieved in the same way as the last. However, if done well, saving a large amount of energy or resources often costs less than saving a small amount. This assertion sounds impossible, and indeed, most economic theorists can "prove" it won't work. Blissfully unaware of economic theory, however, intelligent engineers put it into practice every working day as part of an approach called whole-system engineering.



If you build a house, you'll be told that thicker insulation, better windows, and more efficient appliances all cost more than the normal, less efficient versions. If you build a car, you'll be told that lighter materials and more efficient propulsion systems are more expensive options. These statements are often true—but at the level of single components incrementally improved and considered in isolation. On the cost-versus-savings graph shown above, as you save more energy (that is, as you move from the lower left end of the curve toward the right), the cost of saving the next unit of energy initially rises more and more steeply. This is called "diminishing returns." When you've struggled up to the limit of cost-effectiveness, you should stop additional outlays of money, because they're no longer justified by their results. This part of the curve illustrates the common principle that better usually costs more—a principle that has taken a death grip on our consciousness.

Actual engineering practise, however, presents a different possibility. Only recently noticed is an additional part of the curve further to the right (see the graph below): There, saving even more energy can often "tunnel through the cost barrier," making the cost come down and the return on investment go up. When intelligent engineering and design are brought into play, big savings often cost even less up front than small or zero savings. Thick enough insulation and good enough windows can eliminate the need for a furnace, which often represents an investment of more capital than those efficiency measures cost. (Rocky Mountain Institute's headquarters did this in 1983, growing 27 passive-solar banana crops with no furnace in a 2200-m elevation climate that can get as cold as –44°C.) Better appliances help eliminate the cooling system, too, saving even more capital cost. (That has been done in other houses up to +46°C.) Similarly, a lighter, more aerodynamic car and a more efficient drive system work together to launch a spiral of decreasing weight, complexity, and cost. (That is the approach of the Hypercar™ vehicles discussed below.) The only moderately more efficient house and car do cost more to build, but when designed as whole systems, the superefficient house and car can often cost less than the original, unimproved versions.



There are two main ways to achieve this more-for-less result. The first is to integrate the design of an entire package of measures, so that each measure achieves multiple benefits, such as savings on both energy and equipment costs. The second method is to piggyback on improvements being made anyway for other reasons, such as renovation of aging equipment, renewal of deteriorating building facades, or removal of such hazards as CFCs, asbestos, and PCBs. These two practices, which can also be combined, rely not on some arcane new technology but on well-known engineering fundamentals rigorously applied. A well-trained engineer will be guided by the following three precepts:

- The whole system should be optimized.
- All measurable benefits should be counted.
- The right steps should be taken at the right time and in the right sequence.

Most engineers would agree with these principles in the abstract but have actually been trained to do something different. Perhaps the scheme is too simple. (As broadcaster Edward R. Murrow once remarked, "The obscure we always see sooner or later; the obvious always seems to take a little longer.") Tunneling through the cost barrier requires not a change in what we know but a shift of what we already know into new patterns. That shift can ultimately reach the scale of an industry, city, or society, but it must start at a more immediate and fine-grained level: at the building or factory, the mine or mill, and even earlier, at their constituent systems and subsystems.

Special Issue. Energy, Efficiency, and the Demand for Copper

The interaction between mining and energy goes both ways: mining uses energy, but saving energy may also stimulate mining. As one of us (ABL) pointed out to the Copper Development Association in 1992, many technologies that use energy more efficiently tend to use more copper.

Very efficient use of electricity will somewhat decrease electricity suppliers' relatively small purchases of copper for their generators, transformers, etc. However, it will also open up major market opportunities and economic arguments for using more copper; help attract important public-benefits financial incentives to electricity-saving devices that use more copper; make electric utilities into potential partners to collect scrapped motors and ballasts, thus increasing recycling; and somewhat increase the stocks of fabricated copper (*e.g.*, utilities may pay motor suppliers to carry stocks of premium-efficiency models prespecified for customers' replacements). Moreover, copper producers and fabricators can cut their operating costs by becoming more efficient in their *own* use of electricity.

The main opportunities to market more copper to help save electricity include:

Motors (mainly asynchronous): Promptly replace most operating motors in industry and commerce as part of a ~35-measure retrofit package, mentioned above, saving roughly half of the motors' electric input with an aftertax return on investment approaching 200%/y (*i.e.*, saving electricity at a levelized cost equivalent to about US$0.005/kWh net of saved maintenance costs). The new motors will be premium-efficiency models using at least 20% more copper per kW than the old motors, but may offset this by being generally smaller in order to match their size to their load (most existing motors are oversized). More importantly, aluminium-wound motors will be scrapped and replaced with copper-wound motors—a huge recycling opportunity. In the longer run, asynchronous (induction) motors will increasingly be replaced by switchedreluctance and other synchronous DC types that have no rotor winding and are typically 1–2 frame sizes smaller than the original asynchronous machine. This will decrease copper use per motor but accelerate the turnover of the motor stock and the displacement of aluminium-wound motors.

Interior distribution wiring: Wire diameter will typically be about doubled to cut resistive losses by ~75% from their current ~6±2% in many large buildings. The extra copper typically pays for itself in less than a year in a new installation, and can even make sense to retrofit.

Pipes: Since friction falls as roughly the 4.83 power of pipe diameter, and each unit of friction saved in the pipe saves about ten units of fuel, cost, and pollution at the thermal power station (by avoiding compounding losses in between), there is a very strong economic incentive for specifying larger pipe, as illustrated in the Interface case above. Meanwhile, fittings will favour sweet bends, smoother fittings, low-pressure-drop valves, and other details that minimise friction; this could slightly increase copper use, though it may be decreased more by reducing the number of fittings.

Heat exchangers: Much bigger heat-exchange surfaces for close approach temperatures (0.5–1 C° rather than ~ 6 C°) would roughly triple copper use per unit of, say, space cooling, unless heat-transfer coefficients were meanwhile greatly increased by a transverse electric field in a nonconductive heat-transfer fluid ("hydroelectrodynamics"). However, more efficient lights, motors, ballasts, and glazings should meanwhile cut the amount of cooling and air-handling required by a factor of about two to four. Since some of those devices, notably the motors, should also use more copper, the net effect on copper use may be slightly positive.

Lighting: Magnetic ballasts are quickly shifting to high-frequency electronic ballasts, and in the future should emphasize continuous-dimming models. Wiring within the ballast will shift from aluminium to copper, though the amount of wire will greatly decrease as solid-state electronic designs replace transformer-type inductors, freeing up large metal stocks to be recycled. Net wiring size may be about the same (fatter wire but lower current thanks to more efficient lamps, fixtures, etc.), but there will be somewhat more control wiring (if it doesn't go wireless) and wiring between adjacent luminaries sharing ballasts.

These shifts offer marketing opportunities for the copper industry, if firms understand the technologies, policies, and implementation of electric efficiency, use copper's advantages as a marketing tool for capturing "negawatts," and become valued trade allies of implementing utilities, energy service companies, and other implementing organisations.

The relationship between copper and energy efficiency has several other parallels, including those involving gold, platinum, titanium and other special use metals and minerals.

3.2.C. Climate Modification

Overview

The vast majority of end-use electric energy is generated from fossil fuels. The generation of energy from fossil fuels results in a wide range of environmental impacts. Primary among these are direct impacts to the atmosphere—pollution products such as carbon dioxide, sulfur dioxide, oxides of nitrogen, heavy metals, and particulates. Local and regional impacts associated with these pollutants can be quite severe, and are frequently subject to national and local regulatory schemes. The most vexing, most controversial, and most ubiquitous issue associated with fossil fuel use, however, is climate modification. This section focuses on that issue. It should be noted emissions of greenhouse gases as a result of fossil fuel combustion is also a fairly reliable indicator of other pollution issues. For example, coal and petroleum combustion create the greatest amount of CO_2 emissions, but are also a major source of SO_2, NO_x, and particulates pollution. On the other hand, renewable energy systems such as wind turbines and solar panels directly produce neither CO2 nor other air pollutants. Finally, there are potent greenhouse gases emitted as a result of other industrial processes beside fossil fuel combustion. The mining and minerals industries generally create a wide range of environmental and climate impacts, dealt with in other parts of this study. In a carbon-constrained world, the business environment in the mining and minerals industries could change as a result of two fundamental factors: changes in the physical environment due to climate change itself, and changes in the energy market due policies to reduce carbon emissions from fossil fuel use. Of these two factors, the latter is likely to be by far the more important matter for the mining and minerals sector.

Climate change can be expected to change the physical environment in many ways. The most influential changes will be those related to biological systems and habitats. Agriculture and forestry, therefore, will be far more vulnerable to disruptive and costly changes than mining. The climate change impact most likely to affect mining would be possible shifts in the hydrological cycle, causing regional increases or decreases in precipitation. Warming is also expected to increase rainfall and decrease snowfall generally. Localized impacts of these changes are very difficult to predict, and there is no reason to assume that they will either favorable or detrimental to mining overall. However, increased volatility in the price and availability of hydroelectric power could have a dramatic effect on electrometallurgy.

International efforts to mitigate global climate change will necessarily focus on reducing fossil fuel use. Carbon constraints on the supply side will increase energy costs, although the magnitude of this effect will depend on the degree of success achieved in cost-effectively reducing demand through end-use energy-efficiency improvement. Energy cost increases could come in the form of carbon taxes, purchases of emission permits, or simply higher costs of low-carbon energy sources. The likely magnitude of such increases is widely projected to be in the range of 10–50%. At the high end, this could have a major impact on mining firms' cost structure and competitiveness. However, these projections rest on theoretical economic models that have previously (e.g., for US SO_x reductions) proved too pessimistic by an order of magnitude, partly because they seldom allow for any technological improvement. In general, once policy has set a framework that says lower emissions will be rewarded, technologists and entrepreneurs figure out far more competitive ways to reduce emissions than the theorists had initially assumed from historic price elasticities reflecting unincentivised behaviour.

In a carbon-constrained world, whether subject to regulation, trading, or carbon taxes, mining firms that are able to improve energy efficiency would gain an advantage. Operations located in industrialised countries subject to emission limits would at first seem to be hurt compared to those in developing countries not yet subject to limits, at least in the next decade or two. Developing country operations that improve energy efficiency could earn carbon offset credits, which they could sell or use to offset emissions from their firm's emissions in industrialized countries. In global operations, whether or not one is operating in a Kyoto Protocol Annex One country will become much less important than might at first appear.

What seems to underlie most concern about the difference in implications of Kyoto for industrialized and developing countries are implicit assumptions about the path of economic development, and the timelines along which economic development occurs. That is, it is often assumed that today's developing countries are simply at an earlier stage on exactly the same path followed by today's highly industrialised nations. And so, the assumption goes, absent stringent controls these countries will increase their greenhouse emissions to the same level as the industrialised countries.

This assumption is flawed in several respects besides the obvious fact that mining and minerals industries players are increasingly global in reach, and therefore will increasingly recognise the abundance of profitable investments in efficiency in developing countries. Moreover, the demand for less capital-intensive economic development in the developing countries will continue to increase demand for efficient, right-sized, competitive energy and industrial opportunities.

Often, the arguments are founded on in observed data about elasticity of demand for mining and minerals products. It is axiomatic that developed countries exhibit relatively low elasticity of demand for mining and minerals products. That is, a one-unit increase in spending power leads to less, often considerably less than one unit of increased demand. And for developing countries, it is often noted that when incomes grow by one unit, demand for mining and minerals products grows by more than one unit. However, as accurate as these observations may be, they tell us nothing about the shape of the curve through successive improvements in disposable income in developing countries. Increased demand for mining and minerals products may start out at a GDP or income elasticity factor greater than one, but this increased demand may be quickly tempered by improvements in efficiency that also typically accompany increased income. This reduction in the slope of increased demand over time is in fact more consistent with the observation of reductions in elasticity of demand for the wealthiest people and countries. The implications for the mining and minerals industries are several. First, increases in demand that accompany increased wealth are largely a temporary phenomenon, a time period made shorter by instantaneous worldwide communications and distribution of best-practices experience. Second, the rate at which efficiency improvements overtake elasticity response is probably accelerating, shortening the mineral demand stimulus of increasing wealth. Finally, because consumption is a poor metric for prosperity, an industry focused exclusively on increased consumption is likely to face a disquieting encounter with customer focus on value and efficiency. The mining and minerals industries probably have a better future serving improved efficiency than serving mere increases in demand.

A sobering example comes from China's U-turn on coal policy. In 1996, nearly 1.4 GT of coal was mined in China, and this was officially forecast to reach 2 and then 3 GT—a key underpinning of many global climate projections. However, though the latest data remain fuzzed by a two-year reporting lag, coal-mining and -burning in China began to drop steeply in 1997. By some authoritative estimates, coal output may already have reached 0.9 GT en route to a planned 0.7 GT. Instead, China is shifting rapidly to a modern natural-gas infrastructure (well into installation in 5–6 major cities), to renewables (including modern Danish windfarms in Mongolia), and to end-use efficiency (energy/GDP elasticity halved in the '80s, nearly halved again in the '90s, and far more still to come). China's motives were straightforward. Its energy investments had been unbalanced, technologically somewhat backward, and increasingly onerous. Building coal-based power infrastructure cost far more and took longer than doing the same thing with natural gas, distributed renewables, or efficiency. Hauling coal bottlenecked the development process by tying up at least 40% of winter railway capacity. And of course burning the coal had created the sort of public-health emergency one would expect from running what may be the world's second-largest economy on 1920s Pittsburgh technology.

The speed, decisiveness, and early success of China's about-face on coal policy suggests caution in projecting other mineral demands of national development, in China or elsewhere. Nor is China the only such example. In the 1990s, many developing countries reduced their carbon intensity more than OECD countries—in percentage and even in absolute terms—not to protect the climate but to further their own development goals. One need only imagine, for example, what a truly modern policy for the transport or buildings sectors could imply in reduced demand for cement, aggregate, steel, etc. to see that much of the infrastructure we see around us, and consider the pinnacle of modernity, is not at all what would be built using clean-sheet design and least-cost strategies. (*Natural Capitalism* provides a range of examples.) If developing countries, for their own reasons, leapfrog to a development process based on elegant frugality—as their poverty gives them strong incentives to do—their mineral demand elasticities could probably fall rather quickly to or even below those long considered the sole province of advanced economies.

Industrial Responses to Climate Change

The Kyoto Agreement continues to occupy the center of the international conversation on the dangers and costs of addressing issues associated with global climate change. As an executive of a mining firm that uses fuel, electricity and energy services in their industrial and commercial operations, their response to this news could be one of the following:

- ignore the agreement as lip-service to environmentalists that will never be enforced?
- mount an intense lobbying effort to convince national policy makers not to ratify the agreement?
- corner the nascent market in carbon emission credits to offset one's firm's emissions?
- identify low-cost reduction options and explore ways to limit the risk of future limits?
- begin to invest massive resources in shifting technology to non-fossil energy sources?

Answering this question could involve the commitment of a significant share of such a firm's labor and financial resources over the next decade. The implications of that answer, right or wrong, could involve the continued growth and success of the firm, or perhaps large and burdensome costs. The right answer is not yet clear, and it is probably not the same for every firm or other organization that addresses the question.

Ultimately, the response will be based on the organization's perception of both the degree and the timing of regulation of emissions. The level of activity in the mining industry has been very low, but some actions by companies in the energy industry are illustrative. Activities have ranged from inter-company trades of emissions offsets, to increased implementation of energy efficiency measures, to purchases of land for carbon sequestration. British Petroleum developed a six-point strategy for addressing climate change, the main one being a goal of reducing emissions by 10 percent by 2010 from a 1990 baseline. With support from the Environmental Defense Fund, BP has also developed a pilot program for 12 business units to trade carbon offsets with each other.[24]

In October 1998, General Motors, British Petroleum, Monsanto and the World Resources Institute announced the creation of an affiliation called "Safe Climate, Sound Business." This initiative aims to address climate change through emissions reductions, sequestration and increased support for climate change research. They have developed a seven-point agenda to address climate change, through individual and joint action:

1. Climate performance measurement and reporting;
2. Early reductions through efficiency, offsets and trading;
3. Strategic business ventures and alliances;
4. Purchasing decisions and leverage;
5. New global investment criteria;
6. Education;
7. Dialogue.

Some companies appear to view the response to climate change as a necessity, as with any other environmental responsibility. Others see an aggressive response as a necessity for continued business itself, and perhaps even as an opportunity. Bob Shapiro, Chairman and CEO of Monsanto, noted:

As a life sciences company, we create technologies to improve agriculture, nutrition and human health. All of these require healthy ecosystems. Over the years, business enterprises have found creative solutions to tough technological problems, and businesses can play an important role in reducing threats to our ecosystems. We believe that agricultural practices which sequester carbon can be an important part of the solution.[25]

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[24] British Petroleum, "Where BP Amoco Stands on Climate Change," (date unknown), from www.bpamoco.com/about/policies/climate.htm, (downloaded January 29, 1999).

[25] Bob Shapiro, Chairman and CEO, Monsanto Company, Press Release, "Industrial Leaders and Environmental Group Announce Actions to Address Climate Change: Automotive, Agriculture,

Monsanto believes that climate change may affect their core business – products for agricultural production – by changing the ecosystems in which their customers operate. They also see potential to address climate change through that business, as plant life is a natural sink for carbon.

Most companies that are acting are taking similar approaches: trying to address climate change through activities related to their core business. In this way, the investments in reducing GHG emissions may have ancillary benefits to their operations and customers.

Specific actions and plans of some companies regarding climate change are presented in the table below:

Table 1. Climate Change Actions by Companies

Company	Climate Change Actions	Emissions Reduction Targets
BP Amoco[26]	New technologies; internal trading system; 50 emissions reduction projects in 1999.	10% below 1990 levels by 2010
General Motors[27]	Advanced propulsion technologies; electric vehicles; tracking emissions; Green Lights and Energy Star Programs.	No target
Monsanto[28]	Measuring and tracking emissions; promotion of conservation tillage; Green Lights Programs and green buildings; energy efficiency in facilities.	No target
TransAlta Corporation[29]	Power plant efficiency improvements; end user efficiency programs; purchasing renewable power; GHG Offset RFP; cogeneration projects.	1990 levels by 2000 (already achieved)
Shell Oil[30]	Improve operations efficiency; stop continuous venting of gas by 2003 and continuous flaring by 2008; provide lower carbon-content fuels; renewable energy; support for early action; utilize flexible mechanisms proposed at Kyoto.	10% below 1990 levels by 2002
Various Electric Utilities, including SCE&G, Austin Electric, PSE&, others[31]	As part of DOE's Climate Challenge, members agree to take specific actions to reduce or sequester emissions, through efficiency, investment in heat pump technology, electric vehicles, and forestry projects.	1990 levels by 2000

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and Energy Companies Propose Emission Reduction Steps," Washington, DC (October 27, 1998). Contact: Dianne Herndon, Monsanto, 314-694-2915.

[26] World Resources Institute, "Safe Climate, Sound Business: An Action Agenda," (date unknown), 1709 New York Avenue, NW, Washington, DC 20006, www.wri.org/wri, pp. 8-9.

[27] *Ibid,* pp. 9-11.

[28] *Ibid.,* pp. 11-13.

[29] TransAlta Corporation, "Climate Change Management, (date unknown), from www.transalta.com, (downloaded February 19, 1999).

[30] Royal Dutch/Shell Group, "Taking Action on Sustainable Development: Climate Change," (date unknown), from www.shell.com/values/content, (downloaded February 19, 1999).

[31] William L. Fang , "The U.S. Climate Challenge Program: Voluntary Government-Utility Partnerships to Mitigate Greenhouse Emissions," paper presented at the *IEA/OECD Workshop on Voluntary Approaches for Mitigating CO_2 Emissions*, Bonn, Germany, (October 30-31, 1995), Associate

As seen from the table, there is considerable variation on actual emissions targets. In fact, only a handful of companies – such as BP and Shell -- have set specific targets. Other programs, such as the U.S. EPA's Climate Wise Program, and the Business Environmental Leadership Council of the Pew Center on Global Climate Change (formed in 1998), are encouraging companies to take actions that will reduce emissions. The Pew Center's group, which includes Air Products and Chemical, Enron, International Paper, 3M, Sun Co., and Weyerhauser, does not require members to make quantitative commitments, nor does the Climate Wise Program. Some therefore question how meaningful these programs are.[32]

When reviewing actions such as the above, one must ask: what is motivating these companies to spend money on emissions reductions? Is it altruism? According to Amory Lovins, "many smart companies are already behaving as if the U.S. Senate had ratified the Kyoto Protocol. They're becoming very clever in finding new ways to turn climate protection into profits, and are committed to doing so vigorously."[33] Lovins refers to some of the potential benefits of aggressively tackling climate change: dollar savings from energy efficiency; superior service from efficient technologies; the potential to sell carbon allowances in the future. This appears to be true, at least for the supposed "winners." However, are these benefits also motivating the "losers" to take urgent action, or is it something else?

Potential "Losers"

The "losers" are relatively easy to identify: they are the large fossil-fuel producers and users, in particular the coal and petroleum industries. They represent a united and powerful opponent to any form of emission limits, with very few exceptions (notably British Petroleum and Shell). Other industries, such as electric utilities, most of which rely heavily on coal-fired generation, also oppose the prospect of heavy-handed regulation. However, some such companies are showing increasing interest in "flexibility mechanisms," with the hope that emission limits could be made less painful by using economic mechanisms such as joint implementation rather than a rigid regulatory regime.

The primary goal of potential "losers" in formulating a climate strategy is risk mitigation. If profits depend on either the sales of fossil fuels or carbon-intensive products, such as mining and minerals, GHG limits could be a threat to that bottom line. Thus, leading firms are studying how they can reduce or offset the emissions associated with their purchasing decisions, their operational activities or their products sold. They are also entering into business ventures and alliances to facilitate this transition and to diversify into low-carbon technology areas.

A risk mitigation strategy can involve mostly study of options and analysis of internal business practices. The decision whether to take immediate action on a carbon strategy depends partly on the perceived need for direct experience to develop and improve practices.

General Counsel, Edison Electric Institute, Washington, D.C., from www.ji.org/iuep/ieabonn.shtml, (downloaded February 19, 1999).

[32] "Technology to Cool Down Global Warming," *Chemical Engineering,* (January 1999), p. 41.

[33] Amory B. Lovins, "Lovins: Smart Companies Aren't Waiting Around for Climate Treaty Ratification," *WorldWatch*, v. 12, No. 1, (January/February 1999), p. 7.

It also depends on the perceived benefit in terms of regulatory positioning. By initiating "early action," in advance of any mandatory reduction measures, some companies hope to demonstrate the "win-win" advantages of relying on "flexibility mechanisms" such as carbon offsets and emission trading in place of the traditional command-and-control approach.

Some industries, particularly the electric utilities, have had negative experiences with command-and-control regulations, and they perceive that more market-based mechanisms would make the process of emission control less painful, if it is indeed inevitable. Thus, while some firms will choose to fight any sort of emission limits or regulations, others accept the eventuality of limits and are working to influence the regulatory structure to be as flexible as possible, which could reduce the cost of compliance with future limits.

Potential "Winners"

The potential "winners" are a diverse group. The few pure beneficiaries of emission limits, such as renewable energy companies, are generally so small that they represent relatively little economic or political clout at present. Others, such as diversified technology companies, have both potential liabilities in their present carbon emissions and potential assets in technologies that could help reduce future emissions. Their potential as "winners" lies less in their ability to reduce their own emissions than in their potential to capture new markets in the relevant technologies. Yet others, such as engineering and environmental consulting firms, have the opportunity to assist those companies with liabilities to reduce their emissions.

While some firms resist the idea of any new emission charges or regulations, others consider such measures inevitable in the medium to long run. From the latter perspective, there is a clear business advantage in being among the first to develop and deploy low-carbon technologies. Dependence on continued weak emission standards may be a risky, if not obsolete, long-term strategy if it assures that a firm will be the last, not the first, to penetrate important future markets.

A primary goal of the "winners" is to capture market share in the technology areas that will be favored under GHG emission limits. These technologies include renewable energy sources, natural gas conversions, fuel cells, energy-efficient equipment, vehicles, building systems and industrial processes, methane recovery measures, certain forestry and agricultural practices, energy and land-use monitoring systems, and others. Many of these technologies are commercially available but not widely used today, while others are still in development.

As the discussion of global GHG emission limits becomes more serious, the winners will become more aggressive in identifying and developing the technology areas where they expect to have an advantage in a carbon-constrained market. Since most of the European countries have already begun to accept such limits, their industries are working to capture early markets for these technologies, and this competition will gain strength. On the other hand, these markets could be early export targets for firms that are strong enough to overcome the local competition.

Accelerating the development and deployment of low-carbon technologies may require a shift in corporate resources compared to the "business-as-usual" direction. This could be accompanied by a shift in the value or at least the perception of some types of assets. Equipment, processes, intellectual property, even land that is useful for low-carbon technologies could become more valuable. Similarly, emission-intensive assets could lose value.

No-regrets Strategies for All Players

Although aggressive emission reductions would be very expensive if implemented within a short period of time, there is also a wide range of reduction measures that have the potential to be cost effective. For example, energy cost savings from energy-efficiency improvements and other measures can provide an attractive rate of return while reducing emissions. Most facilities have at least some such "no-regrets" opportunities that can be exploited in the near term. Other cost-effective "no-regrets" measures can be designed into new facilities and equipment in the future.

In addition to energy cost savings, implementing energy efficiency and other emission-reduction measures can improve a firm's competitive position, making it less vulnerable to future energy-price fluctuations or emission limits. Another "no-regrets" benefit of "early action" is the self-education gained from the experience. This experience provides an opportunity to test, evaluate and improve the technologies and practices being used, both for direct emission reductions as well as buying carbon offsets and emission trading.

Finally, an important aspect of most emission-reduction measures is the opportunity to promote the firm's public image, since most of the relevant measures, from energy efficiency to tropical reforestation, have local environmental benefits in addition to GHG reductions. Public relations have clearly been a primary objective of many of the carbon offset transactions completed to date, as the market value of carbon would not otherwise support such investments at present.

Carbon Market Toolkit

If mining and minerals firms want to undertake some sort of "early actions," or at least prepare themselves to respond efficiently if regulatory limits develop in the future, there are a number of rather simple and inexpensive measures they can take. These include short-term measures to educate themselves and understand the potential markets, their own starting position, and their potential risks and opportunities in those markets. In addition, long-term options such as buying carbon offsets or implementing new technologies might be identified, evaluated and tested with an eye toward the future.[34]

Short-term Measures

The immediate measures that a firm could take to prepare for making carbon emission reductions or trading carbon offsets include the following:

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[34] See also, Energy Information Administration, U.S. Department of Energy, Greenhouse Gases from Major Industrial Sources, IV The Aluminum Industry, 2000.

Emission Accounting and Auditing The first step in reducing the energy consumption and resulting emissions from a facility is to perform a detailed energy audit and metering study, which will provide the basis for emission accounting and identify potential cost-effective reduction measures.

Internal Baselines Based on the results of detailed facility audits and more general company-wide analysis, a firm can construct a historical record of its emissions, indexed to such parameters as production, sales or value added, facility occupancy, weather, etc., in order to demonstrate the baseline level of emissions and to identify reduction measures that have already been taken.

Market Screening An analysis of the nascent carbon offset market, with frequent up-dating, can identify which project types, locations and technologies are capable of providing reliable offsets, with a high probability of being certified and verified, and what costs are reasonable for such offsets.

Long-term Measures

The long-term measures for which a firm might want to prepare, in anticipation of the imposition of emission limits and the emergence of carbon trading markets, include the following:

- Carbon Offset Acquisitions. The fastest and most flexible response to a potential carbon emission limit would be to purchase carbon offsets, domestically or internationally, to reduce a firm's emission liability and the need to implement expensive reduction measures in a short time.
- Carbon-neutral Products and Labeling. A number of industries, such as forest products, are beginning to develop auditing and labeling standards with the goal of being able to certify products as being carbon-neutral, i.e. causing no net emissions, either via low-carbon production technology and/or purchase of sufficient carbon offsets to compensate for the remaining emissions.
- Technology Selection. In the longer term, carbon emission limits, if agreed to internationally and imposed domestically, would require fundamental technology change toward cleaner, more efficient conversion of energy resources, both in the production of a firm's products and in the operation of those products from the time of sale until disposal.

Another Alternative

One of the problems inherent in any emission-trading regime is that the initial allocation of credits, allowances, or obligations has powerful implications in terms of the distribution of benefits and costs. In economic theory, the allocation does not influence the total cost, and thus the economic efficiency of the trading regime.[35] In reality, however, assigning an implicit value to billions of tons of CO_2 emitted annually involves the reallocation of billions of dollars worth of economic value and wealth. Thus, debate between the "winners" and the "losers" over initial allocations and baselines is bound to be intense.

Special Issue Public/Private Cooperation on Minerals/Climate Issues: The Conventional Approach

Australia

Australian light metals industry members have cooperated with the Australian Department of Industry, Science and Resources on a "Light Metals Action Agenda." The background paper developed for the Action Agenda notes that while the aluminium industry in Australia accounts for 16% of all electricity consumed in that country, the alumina industry was very low in energy intensity by world standards and was within 2% of world's best practice. Australian smelters, it was reported, had average electricity consumption 3% lower than world average, 5% lower than USA average, and 6% better than the European average.

The Australian aluminium industry has participated in the Greenhouse Challenge Program and achieved an 8.9% reductions in emissions per tonne of product between 1990 and 1999. For aluminium smelting, the comparable figure was 22%, including emissions from externally generated electricity. One company, Comalco, claims a 34% reduction in greenhouse emissions since 1990 at the same time that production increased by 57%.

The Action Agenda backgrounder also reports that the industry has and will continue to work in recycling in order to take advantage of a 95% savings in energy over that used to make primary aluminium.

The paper reported that greenhouse gas emissions were also an issue in the magnesium industry. First, a great deal of energy is used to produce magnesium. In addition, the gas sulphur hexafluoride is a greenhouse gas and is commonly used to prevent oxidation of hot metal. The industry and government have been cooperating in the development of alternative gases and processes and these options are being deployed today.

Source: Light Metals Industries Action Agenda, Background Paper on Aluminium, Magnesium and Titanium Issues. Light Metals Action Agenda Team, Coal & Minerals Industries Division, Department of Industry, Science and Resources, Canberra, Australia.

The Minerals Council of Australia commissioned the Allen Consulting group to conduct a study of impacts of Kyoto Protocol compliance on the rural and regional Australian economies. The study builds on an effort conducted by the Victoria government. The industry study found that:

[35] See, for example, W.J. Baumol, and W.E. Oates, *The Theory of Environmental Policy*, second edition, Cambridge University Press, Cambridge, 1988; and W.E. Montgomery, 1972. "Markets in Licenses and Efficient Pollution Control Programs," *Journal of Economic Theory*, vol. 5, pp. 395-418.

The study demonstrates that meeting Australia's obligations under the Kyoto Protocol would come at a high cost, particularly in some parts of rural and regional Australia. According to modelling conducted by Monash University using their MMRF-GREEN model, some regions will experience falls in employment of over 10 per cent and tens of thousands of jobs will be lost in non-metropolitan areas. Moreover, job losses experienced in country areas will be relatively more long lasting than those in the cities. While these impacts are moderately reduced if permits are sold by the Government rather than grandfathered, the regional employment reductions generated by the imposition of a mandatory emissions trading system on the Australian economy are significant regardless of the method used to distribute emission permits.

Because the economic implications for Australia of meeting our Kyoto targets are substantial, Australia should only consider ratifying the Kyoto Protocol if its COP6 negotiating conditions are met, including:

- unfettered use of flexibility mechanisms;
- full credit for reductions in land clearing emissions and sinks; and
- a clear path for the inclusion of non-Annex B countries in a GHG abatement program.

At present, final resolution on these matters has not been reached. The modelling conducted in this study made the assumption that Australian negotiators would be successful in achieving the first two of these conditions. As discussed earlier, the major modelling results also make a realistic set of assumptions about land clearing emissions—that we will achieve 100 per cent for these emissions and that Australia would reduce land clearing emissions to 60 Mt by the Kyoto commitment period.

Successful incorporation of the third condition—the inclusion of developing countries in emissions reduction targets—was not included in the MMRF-GREEN modelling, but does nevertheless have considerable potential to lessen the economic impact of Kyoto, as evidenced by the modelling of the alternative scenario by ABARE. Australia competes with non-Annex B countries both in international commodity markets and as an investment location. Enhancing the equity and efficiency of the Protocol by incorporating non-Annex B countries, therefore, can be expected to reduce Australia's economic burden substantially. Maintenance of this principle during COP6 and subsequent negotiations will therefore be critical from Australia's viewpoint.

One important implication arising from this study is that if the Kyoto Protocol is ratified and comes into force in its current form, a major structural adjustment policy will be needed in rural and regional areas of Australia. The employment impacts of Kyoto will be substantial, and government policies should ensure that there is adequate compensation for the inevitable structural adjustment that will occur once the Protocol comes into force. Inclusion of non-Annex B countries in targets under the Protocol can be expected to reduce, although not remove, the need for such compensation.

However all indications are that the Protocol is unlikely to come into force as it currently stands. Debate on greenhouse policy internationally is increasingly focused on concerns about the targets and timeframes mandated by the Kyoto Protocol, and the United States in particular appears concerned about the economic costs involved. International negotiating positions around each of three principles listed above are diverse and strongly held. Arguably the most critical of the three—the inclusion of developing countries—has the potential to stall negotiations completely.

If the Protocol is not ratified and does not come into force, Australia should work with other nations to develop a modified Kyoto approach. Such an approach should aim to correct the three major flaws in the current Protocol by:

- incorporating non-Annex B countries in emission reduction targets;
- including a major aid/technology transfer program for non-Annex B countries; and
- placing major emphasis on technological change, with a global R&D program, in order to reduce global GHG abatement costs.

The modelling conducted for this study by ABARE showed that such a policy package can produce moderately better climate change outcomes than Kyoto and at reduced economic cost. [The authors would comment, however, that ABARE's past climate/economic modeling has diverged notably from the structure and findings of modern efforts elsewhere.]

Finally, it is important to note that this study does not challenge the need for action and takes no position on the issue of the scientific basis for action on global warming. However it is also critical to broaden our understanding of the alternatives to the Kyoto approach that can achieve the Protocol's goals in a more equitable and efficient manner. Australia has an opportunity to work with other countries in the development of a fairer and more practical approach to addressing climate change.

United States of America

According to the US Department of Energy, the US mining industry uses 2.4 EJ of energy per year—over 3% of all industrial use, or approximately 1% of total national energy use. Coal and uranium generate more than 75% of US electricity supply. In the course of a lifetime, the average US resident will use nearly 1,600 tonnes of minerals, metals and fuels. And average of nearly 21 tonnes of new minerals, including 3.4 tonnes of coal, are used for each person in the US each year. The US mining industry is a US$39.5 billion business, with $19.9 billion in coal, $12.4 billion for metals, and $27.1 billion for industrial materials.

The US National Mining Association and the US Department of Energy's Office of Industrial Technologies have also collaborated on the development of a "Vision of the Mining Industry of the Future." In a summary document prepared by the National Mining Association, issues of technology, markets and greenhouse emissions, among others, were addressed:

Technology

Widespread use of emerging and yet to be developed technologies presents great opportunity. Concurrently, the industry will be required to generate sufficient returns to make these investments and attract a highly skilled interdisciplinary workforce that can apply and advance the use of technologies that are not traditionally associated with mining.

Historically, technology has been a critical factor in the mining industry's ability to reduce environmental impacts and occupational hazards while continuing to increase productivity and cut costs. Technology will enable the mining industry to maintain its international competitiveness and locate, measure, and extract products from lower grade ores than those utilized in the 20th century.

As the mining industry moves towards the twenty-first century, the opportunity to apply emerging technologies to enhance production and resource performance and provide new products are critical to the industry's ability to serve the nation and achieve profitability. Once these technologies are developed and in place, they will allow the industry to use its energy, land, capital and labour resources even more efficiently during all stages of the mining cycle which will in turn, create a safer, less environmentally disruptive industry with higher quality output at lower cost. Satellite communications systems and information processing technologies are already reducing costs and minimizing environmental disruption associated with reserve characterisation and production. Automated machines reduce worker exposure to hazards while in situ processes contain the disruption associated with extraction and processing. Advanced processing technologies, based on biological processes and solvent extraction-electrowinning, are improving recovery rates and reducing the costs of mitigating environmental impacts.

A basic technology change that enables a 1 percent increase in metal recovery will equate to an additional $5 million in annual revenues for a mine with $500 million annual sales. It simultaneously reduces the amount of material extracted, processed, and disposed, which all have positive economic and environmental effects.

For coal, higher productivity and lower costs are the result of advances in longwalls, shearers and plows, blasting techniques, and haulage equipment. Coal technologies can remove up to 98 percent of the SO2 and up to 99 percent of the particulate matter. Coal conversion processes enable 10 times as much energy to be recovered as was possible 40 years ago.

Changing Markets

Markets are demanding low cost products that have high levels of performance and minimal environmental impacts. For the products of mining, shifts in markets have a range of effects. One that is common to all is the drive for more efficient use of natural resources. Optimisation of resources, whether it be through higher energy efficiency, increased recycling, or less intense use of materials, has become a driving force in mature economies. It is also evident in emerging economies as they adopt more advanced processes and products.

In a market based economy, competition from innovative substitutes drives progress. Coal and uranium are the fuels of choice for over 77 percent of US electricity generators and contribute to the relatively low electricity prices in the United States. To maintain and increase that share, these industries must continue to make their products attractive and increasingly affordable to the customer despite other alternative fuel sources. In materials markets, producers of plastics and other polymers, glass, advanced composites and wood are continuing to upgrade their products to compete for markets now held by metals and industrial minerals. The emergence of new technologies and their products-zero emission cars, advanced electronics and communications systems-will intensify the competition. The success of the US mining industry will be determined by its ability to compete in this evolving marketplace.

Advances in technology also create new markets for metals and industrial minerals. The consumption of zinc is now increasing, after years of decline, because its use as an anti-corrosive coating for metals has grown. Copper, with its high degree of conductivity and relatively low cost, has an opportunity to expand its markets. High efficiency motors, for example, contain larger volumes of copper and copper is also becoming the metal of choice for high performance integrated circuits. Gold is corrosion resistance and high conductivity make it an essential component in the growing market for sensitive electronics and other advanced products (i.e., airbags, satellites, scientific instruments). The spread of economic prosperity in developing countries and the world's growing population will further expand markets.

Environmental and Energy Efficiency Policies

Increasingly stringent environmental policies in the United States will put upward pressures on production, processing and product costs at the same time that international competition and alternatives to mining products will require that costs remain competitive. Environmental costs can be significant. For example, the cost of environmental compliance in the United States for metal mining, processing and fabrication was about 10 percent of total costs in 1990. Despite these costs, progress has been significant. Coal mining operators, for example, have reclaimed in excess of 2 million acres over the past 20 years, an area equal to that of Rhode Island.

Domestically, we can expect continued improvement in land use and management, environmental, and health and safety programs that have made the US mining industry the leader in environmental, health and safety performance throughout the world. The public is and therefore the political perception of the industry, as well as the scientific and technical information that affects our understanding of environmental and occupational risk, will drive the change. New approaches, such as voluntary strengthening of safety standards and other mechanisms for self regulation and stakeholder compacts, have the potential to play a larger role in the mining industry of the future.

Recent adoption of international treaties affecting the handling and disposal of hazardous wastes and products containing metals, long range transport of air pollutants and agreements addressing other environmental concerns presage an increasing global approach to environmental concerns and issues. Although CO2 is not a pollutant, international political agreements to reduce CO2 emissions could be a major factor in energy markets, especially markets that use coal. Climate change strategies that may affect the mining industry are likely to emphasize energy efficiency, methane emission control, reduction of carbon use and carbon dioxide sequestration. They will increase the need for energy efficiency in mining operations and in the processing and use of mining products. They would almost certainly raise the cost of mining products.

National Mining Association, *The Future Begins with Mining: A Vision of the Mining Industry of the Future*, September 1998. http://www.oit.doe.gov/mining/pdfs/vision.pdf

Implications

Among the most obvious elements of sustainability is reducing the gaseous emissions—such as carbon dioxide, methane, nitrous oxide, and halocarbons—that absorb infrared and thereby change heat distribution in the atmosphere, altering the earth's climate. This issue continues to be studied in depth by the Intergovernmental Panel on Climate Change and other official and unofficial bodies. Although the pace and pattern of climate change remain complex and unpredictable in detail, skepticism about whether this problem is real and serious is increasingly confined to the uninformed. The question for the mining and minerals industries is what climate change, and policy responses to it, will mean to their operations and strategy.

First, and most obviously, any energy-intensive industry will be wise to redouble its efforts to use energy more efficiently. New technologies and design techniques (*Natural Capitalism*; E SOURCE *Electronic Encyclopedia*) can typically yield much larger and cheaper savings than were available or even imagined a few years ago. These improvements typically also improve operational performance, and in new installations, often reduce capital cost; such side-benefits may be far more valuable than the direct energy savings. Systematic, comprehensive, and modern efforts to boost energy productivity will henceforth be a hallmark of every successful minerals-related firm. This requires management attention, appropriate reward structures, whole-system integrative design, and careful focus on turning each of the 60–80 known obstacles into a business opportunity.[36] A few examples from energy-intensive industries are presented above.

Second, increased radiative forcing of the atmosphere will change weather patterns and will tend to increase their volatility. This means more frequent and severe storms, droughts, and extremes of temperature; generally rising sea levels; and possible region-wide reductions in water availability. These potential changes should be part of the design basis of any new project.

The possibility of prolonged and severe drought—such as in 2000, had Brazil on a power emergency, and caused many Pacific Northwest aluminium smelters to be shut down—is a special risk to electrometallurgy. It is also a hedgable risk. The Northwest smelters that furloughed their workers because spiking hydroelectricity prices made smelting uneconomic were actually able to resell their cheap hydropower allotments at a substantial profit—more than they'd have made producing aluminium. They could also have handled this emergency more gracefully if they had hedged in the aluminium futures market with physical delivery, so they'd have ingot inventories to sell, meeting their shipment commitments, in the event of a hydropower drought. The carrying cost of those inventories could almost certainly be covered from trading profits on the electricity. Indeed, the entire scheme could be bundled together, perhaps in the form of now-popular weather insurance, by any of the financial services firms skilled at linking disparate derivative instruments into a coherent risk-management strategy. (We suggested this more than a decade ago, and understand it is now starting to receive due attention.)

Third, it is prudent to assume that after the successful 2001 Bonn follow-up to the Kyoto conference, the Kyoto Protocol will be duly ratified and will enter into force. Official trading of avoided or sequestered carbon will probably begin over the next few years for all but US businesses, placing them at a competitive disadvantage unless their government sets up a parallel regulatory scheme qualifying for inclusion, *e.g.,* by including CO_2 in emissions regulated under the Clean Air Act. It is also prudent to assume that, as with the Montréal Protocol to phase out chlorofluorocarbons, the Kyoto targets will be steadily tightened over the next few decades as new scientific and political developments warrant and require more aggressive action.

Carbon trading will be economically equivalent, more or less, to a tax on fossil-fuel carbon emissions. The amount of this tax cannot be known in advance, but can be better understood by examining transactions of private market-makers who, as traders do, are making their own rules rather than waiting for the official rules. Most private carbon trades are clearing at just a few dollars, and a few outliers at about $20–30, per tonne of carbon. For example, internal trading among more than 100 BP Group companies cleared through 2000 at an average of $7/T with a range of $3–17/T—fairly typical for large, technically competent organisations. Some analysts believe the unbought inventory of nearly free or better-than-free carbon sequestration (*e.g.* in forests and cropland whose biotic productivity turn a

[36] Lovins & Lovins 1997, at 11–20.

profit) and of better-than-free energy efficiency (because it's cheaper than buying the energy it displaces) is so large that a mature, large-quantity carbon market will clear at extremely low or even negative prices, as foreseen a decade ago.[37] There are also basic constraints on long-term equilibria in such markets. For example, at above about $25/T, coal-fired power plants tend to shut down in favour of combined-cycle gas plants, which emit only about one-fourth as much carbon per kWh. In the long run, successful carbon sequestration could also cap carbon prices.

What would a carbon tax or its trading equivalent mean for the minerals industries? For most, added to coal or to diesel fuel, it could in principle raise the energy-related fraction of their costs by a few percentage points—the sort of price change that occurs routinely in the normal random variation of world fuel prices. It will impel managers to increase energy productivity, but should not affect the fundamentals of the business. It can also almost certainly be offset, and more, by improved end-use efficiency, just as most industries in most industrialized countries offset the effects of the 1973 and 1979 oil shocks. And to those fearful of broad and major cost increases, as implied by the US National Mining Association statement just quoted, we would offer a reassuring lesson from history. Sustained higher energy prices, especially if preannounced and anticipated, are usually offset by efficiencies and innovations, as occurred with the shift away from ozone-depleting halocarbons. Indeed, the Japanese and German experience in the 1970s and 1980s was that when energy prices increased—by enormously more than any contemplated climate-protection regime might conceivably cause—this spurred industrial innovation on a broad front, contributing to those economies' competitive advantage into the 1990s. Alert mining and minerals companies may well find that if higher energy prices do occur, they could be a blessing in disguise, helping improve old habits and induce new ways of thinking about process design and equipment choice.

Sidebar: Examples of smart industrial carbon strategy

DuPont announced in 2000 that in this decade, it intends to increase revenues at an average rate of 6%/y; to raise its energy productivity at least that quickly, so that its energy use stays at worst flat; and by 2010 to get a tenth of its energy and a fourth of its feedstocks from renewable sources.

Similarly, STMicroelectronics, Europe's largest and the world's fourth-largest chipmaker, has set a goal of zero net carbon emissions by 2010, when it expects to be making 40 times as many microchips as it made in 1990.

These firms are neither crazy nor eleemosynary. Rather, they are rationally pursuing shareholder value. They understand that advanced energy productivity is the key to competitive advantage; that efficiency almost always costs less than the energy it saves; and that it is better to sell carbon emission permits to competitors than to have to buy them. They have also learned that well-executed energy efficiency often makes their plants work better. And in an industry like semiconductors, where competitive advantage depends critically on speed to market, it's important that superefficient chip fabs

[37] Lovins, A. B. 1991: "Least-Cost Climatic Stabilisation," *Ann. Rev. En. Envt.* **16**:433–531.

(fabrication plants) can be built and set up more quickly and cheaply than today's inefficient ones. Both DuPont and STMicroelectronics, and many other process firms like Dow and Shell, have already demonstrated these concepts. For example, surveys of eight ST fabs revealed straightforward retrofit opportunities to save more than half the energy used to provide chilled water and clean air, with aftertax returns typically in the 100–200%/y range (though only 59%/y in one case). As ST's noted chairman Pasquale Pistorio has noted, his early motto of "Ecology is free" has lately turned into "Ecology is better than free"—so we should be buying a lot more of it.

The very energy-intensive apparent exceptions—firms that smelt alumina, magnesia, and titania—normally rely (with a few exceptions, notably in Australia) on hydropower, which would not pay a carbon tax but might put a premium on it as a way of displacing coal-burning. Carbon taxation or other carbon-cost internalisation could also tend to shift marginal power generation from coal towards windpower, which is already widely competitive if fairly evaluated, so this too would not materially affect the cost, and should improve the price stability, of the smelters' power supply, because renewables yield constant-cost power, reducing financial risk. (Risk-adjusted discount rates to permit fair comparison between, say, wind and gas-fired electricity generation would have to roughly double the present value of the gas cost stream—a hidden cost of gas-price volatility that financial economics requires should be properly counted.)

The big unpleasant surprise for hydropower-dependent smelters would come from a quite different and unexpected direction—a series of technological and market innovations only peripherally related to climate. In brief, the shift to uncompromised, ultralight, ultra-low-drag, hybrid-electric vehicles, generally called Hypercars™, is already underway for many fundamental reasons—chiefly breakthrough performance at comparable or lower cost.[38] It may be further accelerated by current concerns about climatic and Middle East instability, but should succeed even without those driving forces. Such vehicles are ideally suited for direct hydrogen fuel cells because, needing only about one-third the normal amount of propulsive power, they make the fuel-cell stack small enough to afford and the compressed-hydrogen-gas tanks small enough to package conveniently in the vehicle (www.hypercar.com). But this then permits a transition to a hydrogen economy that is profitable at each step starting now and is starting to be adopted by major energy and car companies.[39] This strategy integrates the deployment of fuel cells in stationary and mobile applications so that each accelerates the other by building production volume and reducing cost. Recent developments can even make the marginal cost negative: for example C.E. Thomas' October 2001 paper to the Montreux Energy Forum showed that the investment per car for a miniature-natural-gas-reformed fueling infrastructure for fuel-cell cars is about half the investment per car *already* being made to sustain the existing gasoline infrastructure![40]

[38] www.rmi.org/sitepages/pid386.php, www.hypercar.com.
[39] Lovins, A. B. & Williams, B. D. 1999: "A Strategy for the Hydrogen Transition," Nat'l. Hydr. Assn., April, www.rmi.org/images/other/HC-StrategyHCTrans.pdf.
[40] Thomas, C.E. 2001: "Hydrogen Infrastructure: Less Costly Than Gasoline?," Aspen Clean Energy Roundtable VIII (Aspen), Montreux Energy Forum, October, www.h2gen.com.

How could the hydrogen transition affect hydropower? One of the several climate-safe long-run sources of hydrogen for which the transitional strategy will aggregate markets is electrolysis using renewable electricity. The resulting hydrogen will be extremely valuable when used to run vehicular fuel cells, which can turn it into traction 3–4 times more efficiently than a traditional Otto-engine driveline turns petrol into traction. As a result, hydrogen that competes at the wheels of the car with petrol at a nominal price as low as has prevailed in the US ($0.33/L or $1.25/USgal, cheaper than bottled water) would be equivalent to selling electricity for about $0.09–0.14/kWh. This is on the order of three to eight times the wholesale electricity prices discovered in competitive bulk markets—or than many countries' contractual prices for selling hydropower to smelters. That price spread far exceeds the markup needed to convert the electricity into hydrogen and then to pipeline and distribute the hydrogen to retail customers. There will hence be strong and ultimately irresistible pressure for the proprietors of hydroelectric dams to sell each electron with a proton attached—to sell hydrogen, not electricity—in order to maximize their asset value and current income. As old power contracts expire, if not sooner, smelters may therefore expect to face renewal power costs that are a large multiple of historic costs, because they will be competing with the opportunity cost of hydrogen production. This is a realistic prospect in essentially every major hydropower site except, perhaps, those so remote that shipping hydrogen by pipeline or cryogenic marine tanker is not a realistic prospect.

Two final surprises merit consideration. First, climate science is starting to reveal disquieting historical events in which climate has shifted very quickly—within a decade—between two metastable states. If this began to occur or even to seem likely (rather than merely possible), all bets are off about policy responses, and an alarmed citizenry may insist on precipitate action, whether wisely designed or not. Second, it is also possible that solutions may be starting to emerge more quickly than expected. While climate policy experts debate whether departure from business-as-usual growth in carbon emissions need occur in 2010, 2020, or beyond, few have noticed that in fact, in 1998, Gross World Product grew 2.5% but CO_2 emissions fell 0.5%. In 1999, GWP grew 2.8% while CO_2 emissions fell 0.8%. In 2000, GWP grew about 3.5%, and while we don't yet have reliable data on CO_2 emissions (China and the US take two years to report), growth in carbon emissions was much lower, with preliminary estimates ranging from 1.6% (BP) to 0.1% (a leading French consultancy to the IEA). The main causes are improved energy productivity and a shift away from coal, most dramatically in China.

Just as the private traders making markets in carbon consider routine the issues that diplomatic negotiators consider intractable, so the climate problems that economist theorists consider difficult seem straightforward to most practitioners of advanced energy efficiency. But their experience is largely missing from official climate discussions, from public policymaking, and from the broad climate debate in the business community. That omission may be making many business and policy leaders' views of potential climate solutions as overly pessimistic as their views of the climate science may turn out to be overly optimistic.

3.2.D Transportation Technologies: Hypercars & Metal Demand

Automobiles offer a useful example of potentially major shifts in demand for metals as new design approaches, materials, and manufacturing methods create discontinuous change. In 1994, for example, cars used about 70% of the United States' lead, 60% of its rubber, carpeting, and malleable iron, 40% of its platinum-group metals and machine tools, 34% of its total iron, about a fifth of its aluminium, zinc, glass, and semiconductors, 14% of its steel, 10% of its copper, and 3% of its plastics. The massflows of these materials are immense, with North Americans alone buying a new 1.4-tonne car about every two seconds. But new kinds of cars may, in this decade, bring astonishing change to a previously fairly stable materials slate. During model years 1984–94, for example, the average US production model became only 1% heavier and shifted its mass composition only three percentage points from iron and steel to polymers and light metals. But in an early family car of the new ultralight-hybrid variety generically called the Hypercar™, the mass of iron and steel could fall by about twelvefold—perhaps even more.

A closer look at this example illustrates how saving energy can decrease as well as increase the use of certain metals and other mined materials. Increasing pressures to improve automotive performance, safety, cleanliness, durability, price, and other attributes seems likely in this decade to stimulate a major shift from heavy metal autobodies to ultralight advanced-polymer-composite ones. Designed for very low aerodynamic and rolling resistance, such "Hypercars" derive unusual advantage from hybrid-electric propulsion (driving the wheels with electric motors but making the electricity onboard from fuel as needed). This is especially true if the electricity comes from direct-hydrogen fuel cells, for the reasons noted above—affordable fuel cells and compact hydrogen tanks, due to the roughly threefold reduction in the power needed to propel the vehicle. An uncompromised, production-costed, midsized sport-utility vehicle of this kind, with quintupled efficiency and many other important advantages, was designed in 2000 (www.hypercar.com). Detailed production costing and analysis confirms that it should be manufacturable at midvolume (about 50,000 units per year) at competitive cost. Industry-standard simulation tools show that this fuel-cell-powered 5-passenger vehicle, with up to 2 m^3 of cargo space, could accelerate 0–100 km/h in 8.3 second, haul nearly a half-tonne up a 44% grade, be at least as crashworthy as a normal SUV twice its weight (even if it hits one), drive 530 km on 3.4 kg of safely stored compressed hydrogen gas (or, with newer tanks, about 1,000 km on 6.5 kg), and cruise at 89 km/h on the same amount of power that today's SUVs of this class need just for air-conditioning. Manufacturing is expected to require far less—even an order of magnitude less—capital, parts count, and assembly effort and space, giving a strong advantage to early adopters who reverse the industry's dismal risk/reward profile.

An earlier proprietary study by The Hypercar Center at Rocky Mountain Institute examined in 1996 the implications of Hypercar vehicles for automotive consumption of key materials. Assuming for illustration a standard four-seat family car smaller than that five-seat sport-utility vehicle, the mass budget for this 521-kg-curb-mass vehicle uses slightly more than twice the noncomposite polymers of an average 1994 US production car; three-fifths less rubber; half as much glass; four-fifths less volume of operating fluids (fuel, oil, antifreeze, etc.); one-third less aluminium; indeterminately more or less magnesium and zinc die castings; four-fifths less platinum-group metal if powered by an engine hybrid, or only modestly less if using a direct-hydrogen fuel cell; about one-eighth more copper; 92% less iron and steel (including 84% less high-strength, 67% less stainless, and 95% less other steel and 97% less iron); and 64% less total mass of all materials.[41] The absolute content of iron and steel falls from 974 to 82 kg, while that of noncomposite polymers falls from 111 to 75 kg and that of polymer composites rises from a small but indeterminate amount to 152 kg.

These assumptions are all sensitive to design. For example, the more recent, and far more fully designed, 5-seat SUV version weighs more (currently 857 and targeted at below 800 kg), uses more nickel in its nickel-metal-hydride buffer batteries, and probably uses less copper because its signal-wiring harnesses are replaced with networks. Generically, however, it is clear that the Hypercar transition has important implications for the demand for many important metals.

More broadly, there is a clear trend from heavy to light materials for vehicles. The 1908 Ford Model T was made possible largely by a high-strength vanadium steel alloy that permitted certain critical chassis components to meet previously impossible production and performance requirements. Improved steel and fabrication methods for autobodies also shifted that market in the United States from over 85% wood to over 70% steel just during 1920–26.

The shift from aluminium to even lighter and stiffer (for example, aluminium-lithium, magnesium, and titanium) alloys has long dominated aerospace, where mass is worth the most to eliminate and can yield very large "mass decompounding" (snowballing of saved weight). In all, eliminating weight equivalent to a soft-drink can aboard a commercial airliner can easily save upwards of $20 per year worth of fuel. But this logic is starting to be extended much further, in ways that could in time altogether displace important metals markets.

Advanced polymer composites already dominate the marine and racecar markets and make up generally more than one-fourth of the mass of typical military aircraft and missile structure. At first, advanced polymer composites were used in commercial aircraft only for subassemblies—the DC-10's rudder, the 727's elevator, and the L-1011's aileron, as well as many interior parts such as partitions and overhead baggage compartments. By the 757 and 767, carbon-epoxy composites provided all flight surfaces, saving about 383 kg of mass and 2%, or about 380 kL, of fuel per aircraft-year. In the 777, which entered service in 1995, advanced composites made up most of the tail and many other components totaling 9% of structural mass—triple the previous percentage. But this can go much higher. For example, an advanced tactical fighter aircraft developed in the 1990s at the Lockheed Martin Skunk Works® was 95% carbon-fibre composites by mass, making it one-third lighter than its 72%-metal predecessor. Yet it was also two-thirds cheaper, because it was designed round optimal manufacturing methods for carbon-fibre composites, not for metal. The leader of that design team now leads Hypercar, Inc.'s product development and is applying similar logic to automotive design.

These radical developments could affect oil markets profoundly. If diverse vehicles as efficient as Hypercar, Inc.'s 2000 concept SUV made up the entire light-vehicle fleet, they

[41] Lovins, A. B. *et al.*, 1996: *Hypercars: Materials, Manufacturing, and Policy Implications*, Rocky Mountain Institute, www.rmi.org, at 145.

could save in the United States about eight million bbl/d of crude oil, as much as Saudi Arabia produces, or could save worldwide about as much oil as OPEC sells. Moreover, if designed to be plugged in as fuel-cell power plants when parked (around 96% of the time), they could provide electric generating capacity equivalent to about six to twelve times the capacity that all power companies now own.

Similarly, the widely accepted conclusion that systematic improvements can double the fuel economy of commercial aircraft would be conservative—at least a trebling would be feasible—using the sorts of composite-dominated airframe structure just described. Adding operational improvements and competitive route structures (breaking the "fortress hub" monopolies on slots and gates so that direct flights can bypass unwanted hub transfers) could make this more like a factor 4–5. And in principle, advanced "air taxi" services on the lines of the Cirrus or Eclipse aircraft, and accompanying business models, described in James Fallows's 2001 book *Free Flight* could probably approach a tenfold fuel saving. The effect of these changes on light-metal consumption is unanalyzed but may be unfavourable, since the new aircraft are composites-dominated. And of course public policies that stop mandating and subsidising sprawl, that allow all modes to compete fairly at honest prices, and that encourage vendors of vehicles and their fuels to switch to business models that minimise the use of those inputs in providing desired mobility services, could all substantially decrease demand for new roads, parking structures, and other infrastructure currently important to demand for construction materials.

Special Issue – Industrial Metabolism and Soda Cans

A striking case study of the complexity of industrial metabolism – particularly as it relates to mass flow of resources in the economy – is provided by James Womack and Daniel Jones in their 1997 book *Lean Thinking*, where they trace the origins and pathways of a can of English cola. The can itself is more costly and complicated to manufacture than the beverage. Bauxite is mined in Australia and trucked to a chemical reduction mill where a half-hour process purifies each tonne of bauxite into a half-tonne of aluminium oxide. When enough of that is stockpiled, it is loaded on an ultralarge ore carrier and sent to Sweden or Norway, where hydroelectric dams provide cheap electricity. After a month-long journey across two oceans, it usually sits at the smelter for as long as two months.

The smelter takes two hours to turn each half-tonne of aluminium oxide into a quarter-tonne of aluminium metal, in ingots ten meters long and one meter square. These are cured for two weeks before being shipped to roller mills in Sweden or Germany. There each ingot is heated to more than 450˚C and rolled down to a thickness of about three millimetres. The resulting sheets are wrapped in ten-tonne coils and transported to a warehouse, and then to a cold rolling mill in the same or another country, where they are rolled tenfold thinner, ready for fabrication. The aluminium is then sent to England, where sheets are punched and formed into cans, which are then washed, dried, painted with a base coat, and then painted again with all the specific product information. The cans are then lacquered, flanged (they are still topless), sprayed inside with a protective coating to prevent the cola from corroding the can, and inspected.

The cans are palletized, forklifted, and warehoused until needed. They are then shipped to the bottler where they are washed and cleaned once more, then filled with water mixed with flavored syrup, phosphorus, caffeine, and carbon dioxide gas. The sugar is harvested from beet fields in France and undergoes trucking, milling, refining, and shipping. The phosphorus comes from Idaho, where it is excavated from deep openpit mines—a process that also unearths cadmium and radioactive thorium. Round the clock, the mining company uses the same amount of electricity as a city of 100,000 people in order to reduce the phosphate to food-grade quality. The caffeine is shipped from a chemical manufacturer to the syrup manufacturer in England.

The filled cans are sealed with an aluminium "pop-top" lid at the rate of fifteen hundred cans per minute, then inserted into cardboard cartons printed with matching color and promotional schemes. The cartons are made of forest pulp that may have originated anywhere from Sweden or Siberia to old-growth, virgin forests of British Columbia. Palletized again, the cans are shipped to a regional distribution warehouse, and shortly thereafter to a supermarket where a typical can is purchased within three days. The consumer buys 350 millilitres of the phosphate-tinged, caffeine-impregnated, caramel-flavored sugar water. Drinking the cola takes a few minutes; throwing the can away takes a second. In England, consumers discard 84 percent of all cans, which means that the overall rate of aluminium waste, after counting production losses, is 88 percent. The US still gets three-fifths of its aluminium from virgin ore, at about 20 times the energy intensity of recycled aluminium, and throws away enough aluminium to replace its entire commercial aircraft fleet every three months.

3.2.E Energy Security

In the aftermath of September 11, it should be apparent that both dependence on Mideast oil and most of the world's fragile domestic infrastructure threaten our security. Replacing Mideast oil is essential, but we should not do so by increasing our reliance on vulnerable domestic sources, especially when we have more secure alternatives.

Extraordinarily concentrated energy flows invite and reward devastating attack. Nearly two decades ago, a Pentagon study *Brittle Power: Energy Strategy for National Security,*[42] found—and little has changed since 1982—that a handful of people could shut down three-quarters of the oil and gas supplies to the eastern coast of the US (without leaving Louisiana), cut the power to any major city, or kill millions by crashing an airliner into a nuclear power plant. Expanding centralized and vulnerable energy systems was not then and is not now the way to protect national security.

Energy security is both about decreasing reliance on Mideast sources for petroleum and also about the basic architecture of the energy infrastructure. Energy systems are not made secure unless they are designed to make large-scale failures impossible and local failures benign. Energy security starts with using less energy far more efficiently to do the same tasks. Then we must also move to obtain more energy from sources that are inherently invulnerable because they're dispersed, diverse, and increasingly renewable. And finally we must avoid increasing reliance on existing vulnerable systems.

[42] A.B.and L.H.Lovins, Brittle Power: Energy Strategy for National Security (Andover,Maas.: Brick House,1982)

This strategy doesn't cost more; indeed, it's already winning in the marketplace. For example, central power stations, no matter how well engineered, can't supply really cheap and reliable electricity. The power lines that deliver the electricity cost more than the generators, and cause almost all power failures. Onsite and neighborhood micropower is cheaper, eliminates grid losses and glitches, and harnesses waste heat, so savvy investors favor it.

It should now be obvious that for most of the world's transportation fuel to rely increasingly on the Mideast—home of at least two-thirds of the world's proven petroleum reserves—is a tragedy waiting to happen. It is also now obvious that we reduce this reliance by investing in the most quickly available and cheapest alternatives, buying the most solution with each year and every dollar, Euro, and yen. We don't need just another crude-oil source, but an inherently secure supply chain delivering useful transportation fuels all the way to customers.

Energy efficiency is the first rapid-deployment energy resource. Last year, America used 40% less energy and 49% less oil to produce each dollar of GDP than in 1975. Those savings are now the nation's largest "source"—five times domestic oil output. Most were achieved in just six years, during 1979–85, when GDP grew 16%, total oil use fell 15%, and Gulf imports fell 87%.

Modern efficiency technologies can put another billions of dollars a year back in industries' pockets. Saving energy is the fastest way to blunt OPEC's market power, beat down prices, and expand invulnerable sources' share of energy supply. For mining and minerals companies worried about the energy security – price as physical supplies – need to begin examining ways to obtain their energy services from more efficient, distributed and less vulnerable sources.

4 Sustainability and Competitiveness for the Minerals Industry

4.1 Natural Capitalism

The mining industry includes some of the world's oldest corporations, such as Stora Kopparberg. Its business model of finding, mining, upgrading, and selling tonnes of material is well proven. Yet quietly accumulating in many other industries are subtle pressures to reexamine this business model and to consider changing it radically.

Natural Capitalism describes a different way of doing business *as if* nature and people were properly valued, but without needing to know or signal their worth. Natural Capitalism is not about internalizing external costs by taxation or regulation. Instead, it is a way of making business more successful by productively using and reinvesting in all four forms of capital—not just money and goods, but also people and nature.

Natural Capitalism combines four operational principles:

- radically increased resource productivity, often using integrative design to make very large resource savings cost less than small or no savings—*i.e.*, making investments in resource productivity yield not diminishing but expanding returns;
- closed-loop production with no waste and no toxicity;
- a "solutions economy" business model that rewards both those steps; and
- reinvesting resulting profits in the scarcest form of capital—natural capital.

Early adopters are finding that these principles can together yield stunning competitive advantage, happier workers and customers, and improved short-term profitability. The book and a *Harvard Business Review* overview of its basic business logic can be downloaded free or ordered from www.natcap.org.

4.2 Resource Efficiency

Mining and minerals processing firms have long sought to increase their resource efficiency in order to cut costs. However, there may be considerable further scope for applying new design methods and technologies that achieve multiple benefits from single expenditures. The discussion above addressed the opportunities in drive systems, motors, pipes, pumping, and the general approach of whole-system design.

Another type of resource productivity—saving materials—can substitute for extraction and processing of virgin materials. Chapter 4 of *Natural Capitalism* discusses these opportunities in depth, and is summarized below.

Any improvement that provides the same or a better stream of *services* from a smaller flow of *stuff* can produce the same material wealth with less effort, transportation, waste, and cost. Such improvements in resource productivity are rapidly and profitably reshaping industrial economies in four main ways:

- New methods to manufacture goods are saving both energy and materials.
- Making *different goods*—smaller, lighter, more durable, more valuable, and smarter products—reduces the energy and materials used per unit of industrial output by nearly as much as the technical improvements in the manufacturing process do.
- An ever-growing share of the economy involves producing and selling not material things at all, but information and other services.
- The services people desire that used to be obtained by buying a product are increasingly being delivered as flows of services rather than as sales of goods. This may turn out to be the most significant way to reduce the flow of materials and implement truly closed loops, where the same materials are reused over and over.

In addition, highly resource-productive manufacturing—the first principle of Natural Capitalism—is being increasingly augmented by closed loops—the second principle—so that production is followed not by disposal but by resurrection in a never-ending loop. The end of this chapter will loop back to that theme.

Since 1972, perhaps as much as one-third of total US energy savings has been the result of the shifting composition of economic output—less cement, more cellphones, less iron, more insurance, less newsprint, more news. By 1990, US steel consumption per dollar of GDP was below its *1880* level and falling steadily. Many other major materials including copper, zinc, and nickel show similar trends. Leading the shift away from huge flows of raw materials, Japan cut its materials intensity by 40 percent just during 1973–84. But far more is yet to come. As the increasingly information-based economy switches from copper cables to optical fibers, the tonnage of phone lines will drop by 98 percent and the energy required to manufacture them by 95 percent. Spread-spectrum wireless, which may soon displace most landline communications, would then replace most of the fiber with a few microchips in your pocket.

The average new 1997 US car contained 212 fewer kg of iron and steel than did a new car in 1978, because of better design and stronger alloys. A Hypercar™ would have 889 fewer kg yet of iron and steel. It would be made of synthetics like carbon-fiber composites that are less energy-intensive, more durable, at least equally recyclable, and much stronger and lighter. If the composites' freedom from rust, fatigue, and dents enable such an autobody last, say, four times as long as a steel one, and each autobody uses three-fifths less energy to make, then the energy used to maintain a given fleet of autobodies decreases by about tenfold. And if more sensible land-use (and business models based on mobility and access, not cars and litres) lets people get the access they want with fewer cars, then the saving is even greater. Such direct savings multiply into indirect savings, too, because each stage of the industrial process, from the mine or wellhead to the junkyard or landfill, consumes energy to produce, process, transport, and dispose of materials. It also scatters waste, creates pollution, and costs money. Thus cars can adopt the hallmarks of the next industrial revolution, the same as those of microelectronics: smaller, faster, better, cheaper, delivering more service with less stuff.

The potential for saving energy, resources, pollution, waste, and money in the industrial realm would take many specialized books to describe, because its range of activities is so diverse and complex. The US chemical business alone comprises more than 30 industries producing over 70,000 distinct products in more than 12,000 factories. However, if considered in sufficiently general terms, the methods to increase industry's resource productivity can be classified into at least six main categories, which often reinforce one another:

- design mentality,
- new technologies,
- controls,
- corporate culture,
- new processes, and
- saving materials.

4.3 New Processes

Process innovations in manufacturing help cut out steps, materials, and costs. They achieve better results using simpler and cheaper inputs. In practically every industry, visionaries are improving processes and products by developing highly resource-efficient materials, techniques, and equipment. Even in iron- and steelmaking, one of the oldest, biggest, and most resource-intensive of the industrial arts, researchers have discovered ways to reduce energy use by up to about four-fifths with better output quality, less manufacturing time, less space, often less investment, and probably less total cost.

A particularly exciting area of leapfrog improvements is the potential to replace high-temperature processes with gentler, cheaper ones based on biological models which often involve using actual microorganisms or enzymes. Such discoveries come from observing and imitating nature. Ernie Robertson of Winnipeg's Biomass Institute remarked that there are three ways to turn limestone into a structural material. You can cut it into blocks (handsome but uninteresting), grind it up and calcine it at about 1,480°C into Portland cement (inelegant), or feed it to a chicken and get it back hours later as even stronger eggshell. If we were as smart as chickens, he suggested, we might master this elegant near-ambient-temperature technology and expand its scale and speed. If we were as smart as clams and oysters, we might even do it slowly at about 4°C, or make that cold seawater into microstructures as impressive as the abalones' inner shell, which is tougher than missile-nosecone ceramics.

Or consider the sophisticated chemical factory within every humble spider. Janine Benyus, in her 1997 book Biomimicry, contrasts arachnid with industrial processes:

> The only thing we have that comes close to [spider] silk . . . is polyaramid Kevlar®, a fiber so tough it can stop bullets. But to make Kevlar, we pour petroleum-derived molecules into a pressurized vat of concentrated sulfuric acid and boil it several hundred degrees Fahrenheit in order to force it into a liquid crystal form. We then subject it to high pressures to force the fibers into alignment as we draw them out. The energy input is extreme and the toxic byproducts are odious.
>
> The spider manages to make an equally strong and much tougher fiber at body temperature, without high pressures, heat, or corrosive acids....If we could learn to do what the spider does, we could take a soluble raw material that is infinitely renewable and make a superstrong water-insoluble fiber with negligible energy inputs and no toxic outputs.

Such biomimetic innovations could indeed displace significant flows of traditional materials. For example, Benyus asks how abalone self-assemble in seawater, at 4°C with no furnaces, an inner shell that is twice as tough as humans' best missile-nose-cone ceramics. As it happens, Sandia National Laboratory scientists figured that out in 2000.[43] A passive, cold-dip-and-dry process can within seconds deposit hundreds or thousands of silica layers, interleaved with rubbery biopolymer, onto a substrate, yielding a transparent coating up to seven times as tough as the silica. This could in principle replace glass for toughened

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[43] Sellinger, A. et al., 1998: "Continuous self-assembly of organic-inorganic nanocomposite coatings that mimic nacre," *Nature* 394, 256 – 260, 16 July.

windows, and might displace, for example, chrome or other hardcoats for metals and polymers. Many such advances in materials science, biomimetic and otherwise, are on the horizon.

Natural Capitalism continues with the even more radical potential of nanotechnology:

> Ultimately, there's every indication that large-scale, specialized factories and equipment designed for product-specific processes may even be displaced by "desktop manufacturing." Flexible, computer-instructed "assemblers" will put individual atoms together at a molecular scale to produce exactly the things we want with almost zero waste and almost no energy. The technology is a feasible one, not violating any physical laws, because it is exactly what happens whenever nature turns soil and sunlight into trees, bugs into birds, grass into cows, or mother's milk into babies. We are already beginning to figure out how to do this molecular alchemy ourselves: such "nanotechnologies" are doing surprisingly well in the laboratory. When they take over at a commercial scale, factories as we know them will become a thing of the past, and so will about 99 percent of the energy and materials they use. The impact of that technology will dwarf that of any of the technical proposals in this book. Yet until nanotechnology is widely commercialized, industry should continue to explore how to reduce the massive flows of materials in its conventional production processes. Even if the nanotechnology revolution never arrives, savings nearly as great can still be profitably achieved by focusing on the last and perhaps richest of our six near-term opportunities—materials efficiency.

Materials efficiency is just as much a lesson of biological design as the making of spider-silk: biomimicry can inform not just the design of specific manufacturing processes, but also the structure and function of the entire economy. As Benyus notes, an ecologically redesigned economy will work less like an aggressive, early-colonizer sort of ecosystem and more like a mature one. Instead of a high-throughput, relatively wasteful and undiversified ecosystem, it will resemble what ecologists call a Type Three ecosystem, like a stable oak-hickory forest. Its economy sustains a high stock of diverse forms of biological wealth while consuming relatively little input. Instead, its myriad niches are all filled with organisms busily sopping up and remaking every crumb of detritus into new life. Ecosystem succession tends in this direction. So does the evolution of sustainable economies. Benyus reminds us that "We don't need to invent a sustainable world—that's been done already." It's all around us. We need only to learn from its success in sustaining the maximum wealth with the minimum of materials flow.

4.4 Saving Materials

If everybody in society is to have one widget, how many widgets must we make each year? Just enough to accommodate the number that break, wear out, or are sent away, plus however many we need to keep up with growth in the number of people. A key variable in production levels is clearly *how long* the widgets last. If the widgets are something to drink out of, we need a lot fewer ceramic mugs than paper or plastic cups, because the ceramic lasts almost forever unless we drop it, while the throwaways can be used only once or twice before they fall apart. If we make the ceramic mug unbreakable—especially if we also make it beautiful, so people enjoy having and using it—then it can last long enough to hand on to our great-grandchildren. Once enough such unbreakable mugs were manufactured to equip everybody with one, or with enough, relatively few would need to be made in each subsequent year to keep everyone perpetually supplied with the service that mugs provide.

Of course, if the ceramic mug is replacing disposable single-use paper or plastic cups, it keeps on saving those throwaway materials—made of forests and natural gas, birds and bayous—continually, for as long as the durable product is used instead. Amory Lovins has carried in his shirt pocket since 1963 a simple folding cup: two rivets attaching two flat, oval pieces of stamped stainless-steel sheet that bend and snap into a curved cup shape. By now it has saved thousands of paper or styrofoam cups. It should last for at least a lifetime, then be indefinitely repairable by re-riveting. To be sure, half the fun of buying consumer goods is getting an ever-growing array of diverse items. But for most of what industry produces, this is hardly a consideration: Few of us collect washing machines, let alone steel billets or blast furnaces. In fact, washing machines not only cost money and take up space; they are used so relatively seldom, and repaired and remanufactured so little, that they are 10–80 times more materials-intensive, per load of wash done, than are semicommercial machines, like those shared by the occupants of an apartment house. Thus if even a modest fraction of people choose to share a washing machine, considerable materials flow can be avoided.

Items can be made even more economical if they're designed with the spare and elegant simplicity of a Shaker chair or a Ming vase. Good design needs less material to create a beautiful and functional object. Sculptural talent can be enhanced nowadays by computer-aided design, which calculates stresses and determines exactly how little material, artfully placed, will make the object just as strong as we want—but no stronger. Often this requires severalfold less material. Strength can also be put only where it's needed: If an object will tend to break in one inherently weaker place, then it would be wasteful to make it excessively strong in another place. Conversely, small changes in design can produce vastly better function. Surgical bone screws used to pull out or break frequently, requiring another painful and costly operation. Then computer-aided engineering revealed that just moving just a few percent of the metal from where it wasn't needed to where it was needed would make the screws hold tenaciously and hardly ever break.

Another area for savings is the efficiency with which the raw material is converted into the finished object. That factor depends on the manufacturing process: excess material needn't be removed to achieve the desired shape if all the material is *already* in the desired shape. "Net-shape" and "near-net-shape" manufacturing makes virtually every molecule of material fed into the process emerge as a useful product. Many processes implement scrap recovery to take back leftover material for reuse, but ideally, there will be no scrap because it will have been designed away at the outset.

Net-shape production unlocks a further profitable way to save materials: consolidating many small parts, each individually fabricated, into a single large part molded to net shape. A toilet float/valve assembly, made mainly of cast or machined brass parts, was redesigned from 20 to 3 ounces, 14 parts to one molded plastic part, and $3.68 to $0.58 production cost. A 13-pound steel tricycle with 126 parts was redesigned to a 3-pound, 26-part plastic version at one-fourth the cost. A windshield-wiper arm was reengineered from 49 parts to one, at lower total cost, even though it was made of $150/kg carbon-fiber composites. Since molded plastic parts produce a very low amount of manufacturing scrap compared to metals, these examples actually saved far more input materials than they saved weight in the finished parts: the avoided scrap amplified the direct savings from parts consolidation. Moreover, not only plastics and clays can be molded to net shape, but also metal parts, through techniques like hydroforming, semiplastic forming, plasma spray, and powder metallurgy. These are increasingly eliminating machining scrap by eliminating machining.

Eliminating scrap takes many forms. In a sawmill, three-dimensional laser measuring devices can "visualize" how to slice up a log into the highest-value combination of lumber with the least sawdust, just as computers in clothing factories design complex cutting patterns to waste the least cloth. In Shimizu's advanced robotic system for high-rise building construction, precut and preassembled materials are computer-controlled and delivered on a just-in-time basis to the jobsite, eliminating onsite storage, with its associated pilferage, damage, and weather loss, and reducing packaging and construction waste by up to 70 percent. The Swedish construction firm Skanska has a similar system for not delivering to the construction site anything that won't go into the building—thus saving not only materials waste but also, importantly, on transportation in both directions.

4.5 Improving Production Quality

A further key way to waste fewer materials is to improve production quality. The US metal-casting industry has only a 55 percent average yield; 45 percent of its castings are defective and must be melted down and recast. Nearly half the equipment, labour, and melting energy (which is over half the foundries' total energy) is thus wasted. However, available innovations could probably push yields to 80–90 percent, nearly doubling this industry's output per unit of capital, labour, and energy and cutting its waste of materials by two- to fourfold. This means less mining but happier customers.

Still another way to save materials is to make a given unit of product more *effective* in providing the desired service. In 1810, iron boilers for locomotives weighed 1,338 kg per kilowatt. Steel boilers cut this ratio by more than threefold by the mid-1800s. By 1900, it was 134 kg/kW; by 1950, with electric locomotives, about 33; and by 1980, with more advanced magnetic materials, about 19. Much of this 71-fold increase in the mass-effectiveness of the iron came from the process change from steam to electric traction. Similarly, stretchwrapping machines that enclose palletized goods in tough plastic film, to hold them in place and protect them, use 7.5 times less plastic film than shrinkwrapping, but need no heating and give better results.

Other examples of substituting quality and innovation for mass abound in modern life. In the US, aluminium cans weigh 40 percent less than they did a decade ago; Anheuser-Busch just saved 21 million pounds of metal a year by making its beer-can rims three millimetres smaller in diameter without reducing the contents. A new Dow process that eliminates varnishing, spraying, and baking can save 99.7 percent of the wasted materials and 62 percent of the energy needed for preparing aluminium beverage cans for filling. The mass of the average European yogurt container dropped by 67 percent during 1960–90, that of a beer bottle by 28 percent during 1970–90, that of a Kodak film canister by 22 percent. An office building that needed 100,000 tonnes of steel 30 years ago can now be built with no more than 35,000 tonnes because of better steel and smarter design. Interface's reduced-face-weight carpet, with lower pile height and higher density, is beautiful, *more* durable, and saves twice as much embodied energy as the factory that makes it consumes.

Following its philosophy that "sustainable growth has to be focused on a *functionality* not a product", and that *"The next major step toward sustainable growth is to improve the value of our products and services per unit of natural resources employed*"—that is, to raise resource productivity across the board—DuPont is "downgauging" its polyester film. Making it thinner, stronger, and more valuable lets the company "sell less material at a higher price. On average, for every 10 percent of material reduced there is a 10 percent increase in value and price. Our ability to continually improve the inherent properties enables this process to go on indefinitely." The next step is to recycle used film and other polyester products by "unzipping" their molecules. A 45,000-tonne-per-year methanolysis plant for this purpose is now being proven out in order "to keep those molecules working indefinitely, reducing the need for new feedstocks from natural resources." The same loop-closing process is underway in the carpet industry, whose products, 95 percent petrochemical-based, are now ending up in American landfills at the rate of nearly 5,000 tonnes a day.

Still another way to save materials is to improve the design not merely of the specific component but of the entire product or process that uses them—the essence of the design approach Buckminster Fuller called "ephemeralisation," doing the job with the merest wisps of material, optimally deployed. In J. Baldwin's words, "The less material used per function, the closer the design is to pure principle." Even less than Fulleresque versions can yield impressive results. For example, a Romanian-American engineer noticed that overhead cranes, a ubiquitous means of moving heavy objects around factories and dockyards, were made of very heavy-duty steel beams. This was necessary because the hoist-motor travelled along the whole length of the crossbeam, so when it was in the middle, its great weight would buckle any but the stiffest beam. He redesigned the crane so the hoisting motor was at the end of the crossbeam, where its force would be borne straight down the support frame or wall to the ground. A light pulley, not a heavy motor, moved along the crossbeam to do the lifting. Result: same lifting capacity, six-sevenths less steel.

4.6 Born-Again Materials

Ultimately, though, people get tired of even a well-designed and efficiently made object, or it gets irreparably destroyed or worn out. Repair, reuse, upgrading, remanufacturing, and recycling are then the five main ways to keep the gift of good materials and good work moving on to other users and other uses. Repair, which works better if the product was designed to facilitate it, returns failed goods to satisfactory service for the same or a thriftier owner. Reuse passes them to another user, or perhaps to a new life with a different purpose. Upgrading existing equipment is familiar with personal computers and sewing machines, both of which can replace "mutable software" when desired and interchangeable parts of "eternal hardware" when necessary; upgrading can be a service as valuable for the provider as for the customer. Remanufacturing might, for example, strip off the worn surface and design, replacing them with an attractive new finish and pattern, for the same or another purpose.

Industry is already rising to these opportunities. Remanufacturing worldwide is saving energy equivalent to the output of five giant power stations, and saving annually enough raw materials to fill a freight train 1,775 km long. More than 73,000 US remanufacturing firms, directly employing 480,000 people, generated 1996 revenues of $53 billion, "a value greater than the entire consumer durables industry (appliances, furniture, audio and video, farm and garden equipment)." The biggest remanufacturer in the United States, regularly rebuilding everything from radars to rifles to entire aircraft, is the Department of Defense. The second-biggest U.S maker of furniture, Herman Miller, has a special daylit factory devoted exclusively to remanufacturing into like-new condition every kind of furniture the company has ever made. Its larger rival, Steelcase, is one of many large firms battling with independent remanufacturers for the profits from remaking its own products.

Big benefits flow to both customers and manufacturers when products get reborn. "Disposable" cameras are affordable (and profitable) because Fuji and Kodak actually salvage them from photofinishers, remanufacture them, reload the film, and sell them again. IBM remanufactures its computers; by 1997 its 9,492-square-metre Asset Recovery Center in Endicott, New York, was recovering nearly 16,000 tonnes of computers and computer parts per year. The Italian firm Bibo shifted in 1993 from making throwaway plastic plates to charging for their use, then recycling them into new ones. Xerox's worldwide remanufacturing operations boosted profits by about $200 million over three recent years, $700 million over its whole history; its basic green-designed photocopier, with every part reusable or recyclable, was expected to save it $1 billion via long-term remanufacturing. The University of North Carolina's business school has even hired a professor of "reverse logistics"—"dedistributing" products back from customers for remanufacture.

Obviously, it's much easier to disassemble a product for remanufacturing or reuse of its parts if it was designed with that end in mind. Personal-computer software can now help designers minimize disassembly time and compare the manufacture and disposal impacts of design alternatives. For an increasing range of products in Germany, which pioneered the concept of "product responsibility"—you make it, you own it forever—factories producing everything from televisions to cars design them for easy disassembly and disposition, because otherwise the costs of assuming the post-user responsibility are prohibitive. The system, which is spreading across Europe and to Japan, raised the German rate of packaging recycling from 12 percent in 1992 to 86 percent in 1997, and during 1991–97, raised plastic collection by 1,790 percent, reduced households' and small businesses' use of packaging by 17 percent. By the end of 1998, some 28 countries had implemented "takeback" laws for packaging, 16 for batteries, and 12 were planning takeback requirements for electronics. Such lifecycle responsibility also creates unexpected benefits: BMW designed the Z-1 sportscar's recyclable all-thermoplastic skin to be strippable from the metal chassis in 20 minutes on an "unassembly line" mainly for environmental reasons, but that configuration also made repairs much easier. Or when Alpha-Fry Group in Germany felt burdened by the cleaning costs of returned jars for its solder paste, it switched to pure tin containers, which on return are remelted into new solder—11 cents cheaper per jar. Avoiding dissipation of materials that are costly to buy and toxic when dispersed is smart business: when Dow announced a $1-billion, 10-year environmental investment program, it was not just being socially responsible. It also anticipated a 30–40 percent annual return.

What if an item's options for repair, reuse, and remanufacturing are exhausted? Then it can be recycled to reconstitute it into another similar product. As a last resort, it can be downcycled—ground, melted, or dissolved so its basic materials can be reincarnated for a lower purpose, such as a filler material. (Thus do many recycled plastics, no longer pure or strong enough for their original purpose, end up as tent pegs and park benches.) Waste exchanges like the Internet regional exchange sponsored by Canberra (which aims to eliminate waste by 2010), or a private-sector initiative in the region around Brownsville, Texas, and Matamoros, Mexico, aim to match waste materials with potential buyers. Hard-to-recycle materials, like tires, drywall, plastics, insulation, glass, and biosolids, can even be disintegrated by intense sound waves into fine powders for easier reprocessing. Materials that don't now biodegrade can be replaced with compostable ones, like the 1.8 billion potato-starch-and-limestone containers that McDonald's is trying as replacements for polystyrene clamshells— replacements that also happen to cost no more and to need much less energy to make.

These options can shift with improvements in technologies and prices as innovations turn trash into cash. Henry Ford's original car factories had an entire section devoted to reclaiming wooden crates and pallets, many of which were made into autobodies. In 1994, Mitsubishi Motors in Japan, which ships about 2,800 cases of car parts each month to its German distributor, switched from throwaway cardboard and wooden boxes to steel cases which are emptied, folded down, sent back to Japan, reused for an expected ten years, then remanufactured or recycled. Three-fourths of all fresh produce in Germany is now shipped in standard reusable crates sold or leased by the International Fruit Container Organisation—another consequence of the 1991 takeback law. DuPont's Petretec process can indefinitely regenerate throwaway polyester film (four-fifths of its billion-dollar films business) into new film with the same quality as that made from virgin materials, but costing up to one-fourth less. Recycling old car batteries, which every state requires to be turned in when buying a new one, now provided 93–98 percent of all the lead for US lead-acid batteries. Most spectacularly, when Reynolds employee Daniel Cudzik invented in 1976 the aluminium-can pop-top that stays attached when the can is opened, that little tab—because Americans recycle over 100,000 aluminium cans every minute—"enabled the additional recycling of about 200,000 metric tons of aluminium since 1980." This equates to about 3 billion kilowatt-hours of saved electricity, and, if coal-fired, to pollutants including over 3 billion kg of carbon dioxide.

Some recycled materials, like old bricks, beams, and cobbles, can actually be worth more than new ones. Others can gain novel properties from reprocessing. "Environ" biocomposite, for example, is a decorative nonstructural surface-finish material, made from recycled paper and bioresin, that looks like stone, cuts like wood, is twice as hard as red oak, and has half the weight of granite but better abrasion resistance. When you apply these closed-loop principles to everything from packaging to the three billion tonnes of construction materials used each year, a substantial amount of reclaiming is at stake—and every ton not extracted, treated, and moved means less harm to natural capital.

What is the scope, throughout the industrial system, for combining *all* of these steps—product effectiveness and longevity, minimum-materials design and manufacturing, scrap recovery, reuse, repair, remanufacturing, recycling, upgrading, and materials savings through better quality, greater product effectiveness, and smarter design? Nobody knows yet. But many experts now believe that if the entire spectrum of materials savings were systematically applied to every material object we make and use, and if enough time were allowed for all the indirect materials savings to work through the structure of the whole economy, together they would reduce the total *flow* of materials needed to sustain a given *stock* of material artifacts or *flow* of services by a factor much nearer to one hundred, or even more, than to ten. This is in large part because smarter design can often wring more service from a given artifact, so all these savings won't just add; they'll multiply. And as each of those multiplying savings turns less green land into brown wasteland, less fossil fuel into climate change, less life into death, it will accelerate the restoration and increase the abundance of natural capital.

In short, the whole concept of industry's dependence on ever faster once-through flow of materials from depletion to pollution is turning from a hallmark of progress into a nagging signal of uncompetitiveness. It is dismaying enough that, compared with their theoretical potential, even the most energy-efficient countries are only a few percent energy-efficient. It's even worse that only one percent of the total North American materials flow ends up in, and is still being used within, products six months after their sale. That roughly one percent materials efficiency is looking more and more like a vast business opportunity. But this opportunity extends far beyond just recycling bottles and paper, for it involves nothing less than the fundamental redesign of industrial production and the myriad uses for its products. The next business frontier is rethinking everything we consume: what it does, where it comes from, where it goes, and how we can keep on getting its service from a net flow of very nearly nothing at all—but ideas.

Special Issue – Massflow

A considerable fraction of economic benefit, and essentially all environmental harm, is caused by movements and transformations of physical material. (Nonrenewable energy is converted from mined fuel, and toxicity comes from mined materials or transformations of them.) The massflow in modern societies is extremely large. To provide one average middle-class American family's consumption for a year in 1990 required a massflow exceeding 1,200 tonnes of material, including consumptively used water. Of that total, roughly 83% is extracted, moved, processed, and used or sold or disposed of by the mining and minerals industries. Those industries' relationship to issues of sustainability is thus intimate and ineluctable.

In 1990, the average American's economic and personal activities mobilized a flow of roughly 56 dry-weight kilograms of material per day, comprising 21 kg of fuel, 21 kg of construction materials, 7 kg of farm and 3 kg of forest products, 3 kg of industrial minerals, and 1.4 kg of metals of which 90 percent is iron and steel. All but the 10 kg of farm and forest products—about 83%—was mined. Net of 3 kg of recycled materials, that average American's daily activities emitted 19 kg of gaseous material into the air, add 21 kg to the stock of material artifacts, generated 6 kg of concentrated wastes, and dissipated 1.6 kg of nongaseous wastes into the environment in such scattered forms as pesticides, fertilizers, and rubber crumbs rubbed off tires. In addition, the average American's daily activities required the consumption of about 1,425 kg of water and produced more than 100 kg of wastes, mostly waste rock, from mining and other extractive activities. This is the equivalent of 256 million full truckloads of goods and materials per annum for every person in the country. The consequences of this vast massflow include habitat disruption, emissions, toxicity, and depletion of high-grade resources.

In sum, Americans waste or cause to be wasted more than 454 metric tons of materials per person per year. This figure includes: 1.6 million tonnes (770 million square metres) of carpet landfilled, 1.1 million tonnes of carbon dioxide emitted into the atmosphere, 9 million tonnes of polystyrene peanuts, 13 million tonnes of food discarded at home, 160 million tonnes of organic and inorganic chemicals used for manufacturing and processing, 320 million tonnes of hazardous waste generated by chemical production, and 1.7 billion tonnes of construction debris. The figure does not include wastes emitted as the result of extracting gas, coal, oil, and minerals, which would add at least another 15 billion tonnes per year, or 168 kg per person per day. Furthermore, these are merely domestic figures for material flows, and do not account for wastes generated overseas on Americans' behalf. For example, one large gold mine in Irian Jaya annually generates 180 kg of tailings and toxic waste for every man, woman and child in the US Only a tiny fraction of the 118,000 tonnes of daily material flow comes to the United States as gold; the rest remains in Indonesia as toxic tailings

Total annual wastes in the United States, excluding wastewater, now exceed 23 trillion kilograms a year. (A trillion is a large number: To count to 50 trillion at the rate of one per second would require the entire lifetimes of 24,000 people.) If wastewater is factored in, the total annual flow of waste in the American industrial system is 113 trillion kilograms. Less than 2 percent of the total waste stream is actually recycled—primarily paper, glass, plastic, aluminium, and steel. Over the course of a decade, 220 billion tonnes of American resources will have been transformed into non-productive solids and gases. Indeed, since only about 7% of the total massflow extracted gets into products—the other 93% is lost during extraction and manufacturing—and only about 1% of the original extraction ends up in durable products, more than 99% of the extracted mass goes to waste. This pervasive waste represents a vast business opportunity.

These are US numbers, but studies organized by the World Resources Institute and others in the past few years suggest that the corresponding figures for other industrialized countries are broadly comparable. Japan in 1990, for example, used about 52 kg of materials per person per day, close to the US estimate of 56, and put somewhat more building materials into domestic stock (7.7 tonnes per person-year in Japan *vs.* 6.7 in the US). Developing nations generally aspire to an economy like America's, but many are growing and industrializing much faster. Britain required more than a century to double its income in the first Industrial Revolution. Korea took fewer than 25 years. After the US began its industrialisation, 50 years passed before income doubled; in China, it required only nine years. The staggering rate of waste in the United States could therefore be quickly overtaken by the rest of the world, which has 21 times as many people, if historic development patterns were simply replicated rather than improved.

This passage is adapted from Chapter 3 of Natural Capitalism, which contains the references; the primary source is Wernick, I. K. & Ausubel, J. H. 1995: "National Materials Flows and the Environment," *Ann. Rev. En. Envt.* 20:463–492.

4.7 The Solutions Economy – Minerals Services

Even this excerpt from a longer and well-annotated discussion suggests that mining and minerals companies intending to sell ever more tonnes of their product may be disappointed in a global economy that is shifting perceptibly towards doing more and better with less for longer. It is not a sound strategy to want to sell ever more tonnes when customers wish to buy ever fewer tonnes. But the third principle of Natural Capitalism—the "solutions economy"—specifically rewards this shift, and may offer remarkable opportunities for rethinking the minerals value chain.

Traditionally, businesses made and sold material products (or, increasingly, dematerialized services). The less resource-efficient the product, the more raw material would be embodied and sold, and the more inputs the purchaser would need to operate it. The less durable the product, the sooner another could be sold to replace it. If customers had no alternative, this might work; yet clearly it rewarded the vendor for exactly the opposite of what the customer wants.

A solutions economy business model, in contrast, replaces the occasional making and selling of goods with a continuous flow of value and service—in a relationship that rewards both the provider and the customer *in the same way*, namely for doing more and better with less for longer. Its key feature is not changing the form of the transaction from selling an object to leasing a service, but rather aligning the provider's with the customer's interests. For example:

- Schindler prefers in Asia and Europe not sell its lifts (elevators), but rather to lease a vertical transportation service. That's because it considers its lifts more durable and efficient than competing ones, so if Schindler owns the lift and pays its [reduced] operating cost, it can more profitably and cheaply provide what the customer wanted—which was not a lift, but just the service of being moved up and down.
- Interface has developed a superior floor-covering material, Solenium®, that can be completely remanufactured into identical product with no loss of quality. It is now experimenting with a service-lease business model, in the belief that many customers don't particularly want to *own* carpet, but only to walk on it and look at it. Carpet tiles of this material can be leased, then automatically inspected and renewed monthly as needed. Replacing only the worn one-fifth of carpet tiles, not the entire area whether worn or not, cuts materials flow by fivefold. The lower materials intensity and greater durability of Solenium cuts materials flow by a further sevenfold—a total reduction of 97%. When enough worn carpet tiles have come back to the factory to justify remanufacturing, materials flow will fall by 99.9%. How can a conventional company that sells rolls of broadloom carpet compete with Interface, which will use 1,000 times less raw material and 10 times less capital to provide a better service at lower cost with higher margin—and a tax-deductible operating lease to the customer rather than an idle balance-sheet asset? It can't. This illustrates the stunning competitive advantage that natural-capitalist firms can gain.
- Dow would rather not sell solvents; it prefers to lease dissolving services. Afterwards the solvent is taken back for purification and reuse. The more cycles of reuse it goes through, and the less is lost each time, the more Dow can cut its price (gaining market

share and saving customers money) while increasing its margin. Dow Deutschland is even paid not for litres of solvent whose dissolving services are provided, but rather then square centimetres of parts degreased—so that if Dow can help the customer figure out how to keep parts from getting greasy in the first place, so no degreasing is required, Dow gets paid for that too: it is compensated for achieving sufficient customer intimacy to anticipate customers' evolving value needs.

Solutions economy business models are rapidly appearing in a great many industries, including petroleum and natural gas: a few utilities are providing comfort or water-heating services rather than selling fuel, most French commercial floorspace is heated by *chauffagistes*, and major aeroengine manufacturers lease "power by the hour"—thrust services—rather than selling engines, so the more efficient and reliable their engines are, the more money they and the airline both make. Major car and oil companies are examining business models that provide access and mobility, *e.g.* by integrating public-transport passes, door-to-door-delivered hire cars, backup taxis, and perhaps longer-range travel and virtual mobility (telecommunication) services, so that the more mobility and access it provides with the *least* vehicles and oil, the more money it and the customers both make. What might this approach offer to the mining and minerals industries?

Consider the following analogy. Xerox is sometimes considered the inventor of the solutions economy because it first (chiefly in England) began to provide photocopying services by the page rather than selling photocopiers. Xerox's European vans say "The Document Company" because Xerox understands that its customers want documents, not machines. Thus under the roof of such large firms as Germany's chemical-maker Henkel one can find outsourced printing and copying shops operated by Xerox and paid for by the page. But the next logical step is to realize that Henkel wants a mixture of presented information in different forms—not just hard copy but also onscreen. Xerox has therefore realized that it can and should be paid for helping Henkel use E-mail, groupware, and other software tools to displace some hard copy. The next step would be to realize that Henkel further wants a mixture of presented information and information that is *not* presented—that is filtered out—because it's unwanted and unnecessary. (As *Natural Capitalism* recounts, a simple experiment in providing such "nega-information" at Dow's European headquarters cut paperflow and increased productivity by about 30% in six weeks.) If Xerox provides this information, it should get paid for that too. The evolution of customer value needs is never-ending. But notice a basic business lesson of this progression: in a world using fewer tonnes of paper, one does not want to be in the business of selling tonnes. Rather, one should move around the table and sit next to the customer, so that fewer tonnes represent not a reduced *revenue* but a reduced *cost*.

Where is the world's largest high-grade copper deposit? Not in Papua New Guinea or Chile. By some reckonings, it's beneath the streets of Manhattan, as old signal cables (and in time, with distributed generation, perhaps power cables) become obsolete and can be mined. Unfortunately, they were not installed with retrievability in mind: a copper company sold tonnes of copper to a wire- and cable-maker, who sold the wires to a telecoms company. But if instead the copper company had leased a conductance service directly to the phone company, contracting with the cable-maker to provide its technical means, then the copper company would have had a strong incentive to install the cables retrievably so as to preserve its asset value; to use the copper with elegant frugality; and to ensure its durability. In principle, a "copper services" company could do the same thing with thermal-conductance services (just as one maker of refractory furnace liners leases the "refractory insulation service" of its materials) or with corrosion-protection services, as from roof flashing.

Copper-mining, like most metal-mining, is a very capital-intensive, long-lead-time business that is a price taker in a volatile market. This is a guaranteed recipe for pain. Integrating downstream to include a copper recycling company does not escape from these attributes. In contrast, a copper *services* company would earn a regular, noncyclic lease fee from the services its copper is providing—as power or signal conductors, as roof flashing, as a beer-brewing kettle, or whatever. Because that income has much lower risk than an income stream from selling copper, a dollar's present-valued lease income, on a risk-adjusted basis, is worth more than a dollar of copper sales income. The copper services company can still take advantage of continuing progress in the technologies of finding, extracting, and treating copper; but it is also poised to take far greater advantage of—not suffer a loss from—the faster-moving and far more promising technologies of increasing copper productivity. Naturally, this does require that the copper services firm, or its agents or affiliates, become familiar and indeed intimately involved with the ultimate customers who desire the copper services. But of course a main objective is to escape form the commodity-business trap; and inevitably that means getting closer to customers.

In the end, an apt (and thought-provoking) question for the mining and minerals industries is this: "Is it in the best interests of the industries to isolate themselves into ever more tightly-squeezed segments, ignoring the 'network' economies of servicizing, and remaining dependent on varying degrees of social, environmental, and economic subsidisation until countries can afford them no longer?" At the very least, it should be recognized that a company with a presence and influence in the production, processing, recycling, distribution, and redistribution aspects of the business enjoys more economic robustness. While recycling and remanufacture of their products promises interesting opportunities for the mining and minerals industries, it is not clear what the optimum recycling rate is with regard to reducing the energy intensity of the services that they can provide.[44]

The solutions economy—the third principle of Natural Capitalism, and arguably the most subtle and powerful of the four—appears to have profound implications for primary materials industries, including forest products and mining. It leverages the increasing power and popularity of advanced resource-productivity technologies into less extraction, less investment, less risk, less cost, and higher profit. The time would seem ripe for the mining industry—as the chemical industry has already done—to convene a working group to explore this approach. Rocky Mountain Institute is convening a seminar on it in 2002, *Lean Thinking* authors Womack and Jones are publishing a book tentatively called *The Solutions Economy*, and Walter Stahel at the Product-Life Institute in Geneva pursues pathfinding applications of this rich concept.

[44] See International Energy Agency, OECD, Greenhouse Gases from Major Industrial Sources, 2000.

5 Going Forward

For mining and minerals companies doing strategic planning regarding their future operations in minerals production and use, one of the most important considerations would be to study carefully the balance between energy use in extracting minerals, processing them, and their use in finished products. This is a unique range of considerations that can only be dome by companies working with industry downstream., as well as others.

In this regard, mining and minerals companies must also coordinate their activities carefully with NGO's. labour unions, academia, and consultancies to ensure that there is widespread understanding – and acceptance where appropriate – of the rationale for integrating energy concerns more directly into strategic planning regarding industrial development, environmental problems and costs, susta inability, and social concerns.

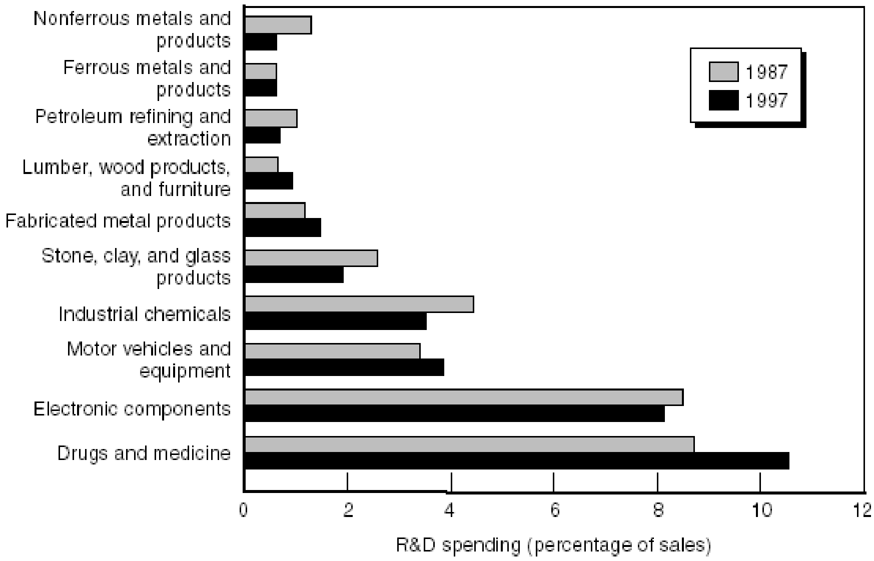
Special Issue – Research & Development

The Rand Institute conducted a survey of mining industry representatives in order to prepare a report on technology issues facing the industry. The following are extracts from that report. Authors feel this is a very representative summary of R&D priorities suggested for the industry.

Research and Development Funding and Alliances

According to industry executives, cuts in R&D by government and industry are likely to result in fewer fundamental or breakthrough technology innovations in the future.

Over the past three decades, many participants noted, mining concerns in the United States have scaled down or eliminated entirely their R&D operations—a function of trimmed profit margins and a broader business trend of focusing on "core competencies." This decrease is reflected in the low rankings of mining related industries in a comparison of R&D expenditures across industry sectors (Figure 2.4). In addition, dramatic cutbacks in federal funding for industry since 1988 have reduced budgets for advanced R&D in both academia and the private sector.[4] As a result, almost all mining companies said that their mining related R&D activities (if they reported having any) were largely confined to short-term and site-specific problem-solving. This has shifted the locus of technology research, development, and demonstration to technology providers.



SOURCE: National Science Board, *Science and Engineering Indicators 2000*, Arlington, VA: National Science Foundation, 2000 (NSB-00-1).

Figure 2.4—U.S. Nonfederal Industrial R&D Spending as a Percentage of Sales

As mining technologies become more complex and mining processes become more tightly integrated, the need for sustained, strategic alliances between equipment developers and mine operators is becoming more critical. Few organisations have the capability to combine metallurgy with machine design to develop advanced rock-cutting technologies, one industry executive noted. Similarly, the development of automated equipment requires coordination and collabouration among producers of machinery, communications and GPS, sensors and imaging technologies, and control algorithms. But funding from both the private and public sectors to catalyze and sustain such partnerships has been very limited in recent years.

Innovation often springs from insights gained through the technology buyer/supplier relationship.
You need everyone at the table to work things out,
said one manager about the ideal innovation environment. Yet one technology developer characterized the current situation as a "stalemate." According to several discussants, many operating companies are not particularly interested in alliances, risk-sharing, and pilot-testing new technologies. Several mining company representatives stated that they wanted to use only those technologies that already were proven on a commercial basis. Said one supplier,
Not too many of them want to be first at anything.
As if in response, another technology provider quipped,
We never send a new product out the door with 'Serial Number One' on it.

[4] National Science Board, *Science and Engineering Indicators 2000*, NSB-00-1, National Science Foundation, 2000. The principal source of federal funding for mining technology R&D was the US Bureau of Mines, which was abolished in the mid-1990s. The discussants, however, were divided on the practical technology implications of this act.

* * *

Adoption of New Technology

Table 3.1

Anticipated Availability of Selected Unit-Ops Innovations

Technology	Anticipated Date
Solid-state programmable blast detonators	2000
Six-unit miner-bolters	2000
Mechanical cutter for hard-rock applications	2003
Fuel-cell-powered underground equipment	2010
1000-ton-capacity haul truck	2020
150-cubic-yard-capacity shovel	2020

Source: RAND discussion participants.

Where feasible, underground and surface mines are replacing track and truck haulage with belt-haul conveyors, which have a lower operating cost . . . Coal companies in particular highlighted the increasing use and importance of conveyors. The conversion to belt haulage systems was listed as one of the top three current mine-site investment priorities of one major coal producer. Another coal producer argued that running belts through mined-out tunnels was more flexible and cost-effective than building and maintaining surface roads, and that it reduced labour costs in the mine. He described his company's operations as now having a tremendous amount of belt structure.

Table 3.2

Belt and Truck Haulage Costs

Method	Cost (cents per ton/mile)
Truck haulage	15–35
Conventional belt haulage	5–10
Automated belt haul and stacking	1–15

Source: Industry representative.

* * *

Upstream and Downstream Innovation

When asked to highlight critical technologies, operating-company participants often focused first on technologies in downstream activities (such as beneficiation and utilisation) rather than those in upstream activities (such as ore extraction). Several study participants were able to discuss in detail the benefits of monitoring and control technologies for optimisation of their processing plants, while the benefits of such technologies for optimizing ore production were sometimes viewed as less critical or "too soon to tell." Similarly, when discussing activities at the mine site, participants tended to focus more on haulage than on development, drilling, or blasting.

This disparity partially reflects the fact that minerals processing operations—downstream activities—have more in common with factories and refineries, where process optimisation technology has been in use longer, than do upstream activities. The bias toward downstream technology also can be understood from an economic standpoint for those commodities in which processing represents the bulk of the cost: The value of productivity gains tends to increase with the value of the product, and value is added as the product moves downstream through the various operations of a mine. *One* *manufacturer estimated that a 1 to 2 percent productivity gain in a metals-processing plant was equivalent in economic value to a 20 to 30 percent productivity gain in an underground mining operation. (emphasis added)* [But by the same logic, minor productivity gains downstream can leverage very large savings of activities upstream to deliver the previously wasted materials flow to the downstream user, and may therefore merit greater attention for their potential knock-on benefits than they have historically received.]

In the case of coal, producers and technology developers emphasized the importance of preparation plants and transportation: The industry is not production-constrained, and transportation can account for as much as 50 to 80 percent of the cost of coal. Thus, gains in product quality and transportation costs are usually viewed as more valuable than gains in extraction productivity. Downstream technologies also receive particular attention because of regulatory and community concerns. For example, technology to reduce emissions during coal utilisation was commonly cited by coal producers as an important avenue to sustain the market for high-sulfur Appalachian coal and, more fundamentally, coal in general. This downstream focus of the mining industry can help explain the incremental pace of technology innovation upstream at the mine site.

The incentive to innovate upstream operations may be increasing. As processing plants become more highly tuned—to meet higher productivity, emissions, or quality targets—the quality of feed materials becomes a more important determinant of plant performance. Similarly, the trend toward just-in-time delivery demands closer mine/plant integration to manage feed quantities. These two trends, in turn, are supported by the development of information technologies which are increasing the control over and the ability to link together unit-ops equipment. Drills and bulk explosives loaders, for instance, can be programmed to meet crusher demands. Finally, regulatory and community pressures (concerning aesthetics, noise, and land use, for example) increasingly challenge the basic character of mining operations, especially for aggregates, industrial minerals, and metals producers. This suggests that R&D and innovations targeted at upstream mining processes are likely to have higher payoffs in the future.

* * *

Over the past decade, the mining industry in the United States has shown greater productivity increases than other sectors such as manufacturing and construction. Yet many in the industry are concerned about mining's health and its long-term viability. Take the example of coal: Thanks to the introduction of new technologies, the number of labour-hours required to produce a unit of coal has dropped by a factor of eight since 1950, yet the industry suffers from overproduction, low market prices, and unfavorable profit margins. This suggests that conventional measures of success, which are geared toward perfecting methods of mass production, are no longer serving mining-industry decision makers well.

Source: Peterson, D. J., LaTourrette, T. & Bartis, J. T. 2001: "New Forces at Work in Mining: Industry Views of Critical Technologies." Rand Science and Technology Institute, report # MR1324, www.rand.org/publications/MR/MR1324.

5.1 Immediate Action

Recommendation # 1

Initiate sustainable industry sector studies, modeled on but improved from *Toward a Sustainable Cement Industry: Summary Report*, Battelle, November 2, 2001, commissioned by The World Business Council for Sustainable Development. The Sustainable Cement Industry report addresses the growing competitive opportunity afforded by a focus on the "triple bottom line," and establishes recommendations and action steps for implementation in the near and longer term. Recommendations address ecological stewardship, emission reduction, climate protection, resource productivity, regional development, community well-being, and employee well-being as well as business integration of sustainable development, innovation and cooperation.

Recommendation # 2

As noted above, detailed and authoritative estimates of this energy use are not available and that the right number defies easy and precise quantification. Broader coverage, greater consistency, and industry-wide discipline in collecting and disseminating energy use data in the mining and minerals industry should be a higher priority for government, industry associations, and trade groups.

Initiate an advisory body to address the lack of comprehensive, consistent, and regular data on the mining and minerals industry. Empower the advisory body to make recommendations to all the minerals and mining trade groups and associations on the mechanisms, activities, and coordinating organizations necessary to implement the recommendations of the advisory body.

5.2 Near-term

Recommendation # 3

Find several case-study mining and mineral processing operations suitable for a “charrette”—an intensive transdisciplinary roundtable design workshop (such as Rocky Mountain Institute has conducted in many other industries)—to explore the potential for breakthrough, rather than incremental, savings in energy, water, and other resources. For example, a marginal South African gold mine, where shaky economics are complicated by major pumping and air-handling costs, could seek the kinds of very large (even order-of-magnitude) savings that other industries have already demonstrated in similar applications. Past design efforts that have quickly identified very large and profitable but previously overlooked savings of electricity—for example, three-fourths in a chemical plant, or about two-fifths in an oil refinery—merit application to mining operations.

Recommendation # 4

Convene an industry task force to explore in what sectors and activities a “solutions economy” business model may offer advantages and merit closer consideration by individual firms. The task force should study closely the lessons learned from other commodity-type industries and make recommendations regarding the role of innovation, pricing and discounting, product development, and market research.

Recommendation # 5

Convene an industry task force or task forces to explore the broad implications of innovative transportation policies and technologies, of water constraints, and of least-cost climate policy for the sector. One of the most advanced case studies, that could be an examplar for the mining and minerals industry – is the cement industry that has been working with the World Business Council for Sustainable Development (WBCSD). Organise a small follow-on effort to the WBCSD cement study, examining innovative techniques it may have overlooked, and with the goal of making the cement sector climate-neutral or a net protector of climate.

Recommendation # 6

Convene an industry task force to review the strategic energy R&D portfolio for the mining and minerals industry, from basic research through applied research and demonstrations programs, excluding only the portions related to national defense. The findings should include rationale for national government support of R&D and review the priorities and management of industry programs, and recommend how it can be made more efficient and effective delivering value to industry companies.

5.3 Mid-term

Recommendation # 7

Convene an industry task force or professional conference to consolidate understanding of the potential for biomimetic solutions in displacing currently mined materials and in improving or replacing today's mechanical, abiotic mining and mineral processing practices. Institutionalise the permeation of biomimetic design perspectives into the design and operation of mining and mineral processing enterprises and activities. Please see discussion at IV.3 above.

Recommendation # 8

Demonstrate novel mineral processes that use little or no water, much as the pulp-and-paper industry has developed and the oil-refining industry is starting to apply. Any processes that can significantly reduce resource use and input cost, will increase profitability and competitive position within the industry.

5.4 Long-term

Recommendation # 9

Demonstrate biological *in situ* metal-recovery techniques that require little or no massflow of host rock or overburden. Many of these program specific R&D efforts should be developed from work described in recommendations above. This could, in theory, include phytomining. Although this recovery technique has been demonstrated for some metals (Ni, Zn, Cd), it is generally regarded as a technology that would be unable to meet more than a small fraction of demand other metals, e.g. copper.

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