

Meeting Societal Resource and Environmental Requirements for the 21st Century

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Energy, and the U.S. Geological Survey**

Background and position papers

**An introduction to the conference topics through the thoughts and
writings of participants and speakers.**

**Sagebrush Inn
Taos, New Mexico**

October 11-14, 1998

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Federal Lands and the Geosciences

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The geosciences have long played an important role in the development and management of the nation's public lands. For much of that time, the principle geoscientific contribution has been identifying and assessing natural resources, particularly mineral and water resources.

In recent years, however, that traditional role has been de-emphasized as land managers shift to an ecosystem management approach. This shift represents both an opportunity and a challenge for geoscientists, who must demonstrate anew to policy-makers the value and relevance of their work. We face this challenge on the state and local levels and in the federal arena.

Uncle Sam's Turf

Over time, federal public lands included as much as 1.7 billion of the nation's 2.3 billion acres. The federal government has gradually relinquished control of 1.1 billion of that expanse to states, tribes, and individual citizens. Federal public lands, however, still constitute 625 million acres, or 28 percent of the United States.

The majority of these lands are managed by the Department of the Interior through its Bureau of Land Management (266 million acres), Fish and Wildlife Service (87.5 million acres), and National Park Service (78 million acres). The U.S. Forest Service in the Department of Agriculture oversees 191 million acres. The remaining federal lands are controlled by defense-related agencies.

Federal lands have always been located primarily in the "west," although the definition of what constitutes western land has changed over time. The Northwest Ordinance of 1787 ceded title to all lands between the Appalachians and the Mississippi from the original 13 states, giving land and hence influence to a central government newly empowered by the Constitution.

For the next century, western expansion was accompanied by legislation designed to encourage settlement and development of newly acquired lands. One law from that period still on the books is the Mining Law of 1872, which codified the already common practice of staking ownership to mining claims. By the end of the 19th century, however, growing concern about over-expansion and the loss of pristine areas had led to the establishment of the first national parks and wildlife refuges and subsequent passage of the 1906 Antiquities Act barring private ownership of artifacts taken from public lands.

The Politics of Longitude

The tension between the development of resources and the preservation of pristine areas has intensified in recent years. Political debate over land-use policy tends to have a west vs. east flavor rather than breaking along party lines. History and geography have combined to create this longitudinal divide.

Mining law reform is a good example. Eastern Republicans such as Rep. Sherwood Boehlert (R-N.Y.) have opposed legislation introduced by western Republicans such as House Resources Committee Chairman Don Young (R-Alaska). Politicians from the more populous east (often joined by their West Coast colleagues) tend to view federal public land as communal property, whereas intermontane westerners see it as land held in common waiting for a specific need to be found for the use of it.

Over the past 30 years, preservationists have steadily gained ground. The amount of federal land available for mining declined from 75 percent in 1968 to just under 30 percent in 1994.

To see the preservation vs. development tension, consider the highly contentious debate over the Arctic National Wildlife Refuge. The Alaskan delegation in Congress and many others view this wilderness as empty space with a potential billion-plus-barrel oil reservoir beneath it, but Interior Secretary Bruce Babbitt and environmentalists refer to this same piece of land as the "American Serengeti" and last stretch of pristine arctic coast.

Both groups can point to scientific information that supports their views -- a reminder that science does not and cannot control land-use policy. But science can inform the debate. Policy-makers, however, will choose which scientific information they value as the foundation for their decisions.

Breaking with the Past

The traditional role for geologists with respect to public lands has been conducting resource assessments for minerals and hydrocarbons. These assessments are a required part of every forest management plan prepared by the Forest Service and every range management plan produced by the Bureau of Land Management.

Policy-makers saw the need for such assessments as a security issue -- ensuring adequate national reserves of oil and strategic minerals. Since the end of the Cold War, however, Washington has progressively lost interest in this issue. Despite concern raised over U.S. dependence on unstable foreign sources of oil and minerals, cheap gasoline and a perceived abundance of most minerals combined to push energy issues off the collective political radar screen in the recent election.

Protection of the environment, however, was a pillar of President Clinton's successful re-election campaign. The administration's much-touted accomplishments included two high-profile efforts to stop mining operations in Utah and Montana.

No wonder the traditional resource role of the geosciences has become suspect, and budgets have been slashed for conducting such assessments. Although the Wilderness Act of 1964 specifies that all lands withdrawn from use under the act are to be periodically surveyed for valuable minerals, such studies are rare because they are perceived as the first step toward future development. The exception is the collection of minerals data associated with cleanup of abandoned mine lands, an activity directly tied to environmental priorities.

Informing Ecosystem Management

The marginalization of geologists' traditional resource assessment role has been accompanied by a shift toward using ecosystems as the basis for managing federal lands. The environmental sensibilities of the Clinton administration are reflected in the decision to pursue ecosystem management as the principal land-use policy tool for federal lands.

Scientific input focuses necessarily on biologic resources, but geology and hydrology are critical to understanding why the biological resources are where they are and how the ecosystem functions. With nonrenewable resource assessments increasingly devalued, geoscientists must convince policy-makers of the broader utility of the information they provide.

The inclusion of the former National Biological Service in the U.S. Geological Survey has been seen by some as a threat to that agency, but this merger may be the best chance yet to educate biologists and policy-makers alike about the value of what geoscience can contribute to the new style of land management. As the importance of geoscientific information to understanding ecosystem processes becomes recognized, geoscientists may again play a central role in supporting public land-use policy. Perhaps this greater awareness will in turn lead to a new recognition of the ongoing need for resource assessment, allowing our profession to continue contributing to the many uses of the nation's public lands.

Resource Use and Sustainable Coastal Environments

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Position Paper for
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Coastal Environments under Stress

Coastal regions in the United States and around the world are under increasing pressure as a result of growing human populations, pollution from vast watersheds draining to the sea as well as direct discharges, loss of valuable habitats, increased demand for recreation, and over-exploitation of natural resources (renewable and non-renewable). Approximately 130 million people—more than half of the total U.S. population—reside within 80 miles of the coast. And, coastal populations are growing faster than the U.S. population as a whole. They are expected to reach 165 million by 2015 (NOAA, 1998).

After decades of experience with coastal zone management in which continued degradation of coastal ecosystems and resources has generally been the rule, there are efforts to integrate management approaches (including resource use and environmental protection) more effectively and meet “the challenge of sustainable coasts” (Heinz Center, 1998). In this position paper, I will briefly review why coastal ecosystems are particularly valuable, summarize some principles to guide sustainable management, and reflect on how these principles bear on the exploitation of an important non-renewable resource of the coastal zone, offshore and coastal oil and gas.

Valuable Ecosystem Services

My colleague Robert Costanza and his collaborators have estimated the economic value of the services nature provides in a paper published last year (Costanza et al., 1997) that generated considerable media attention and stimulated much debate within the environmental science and economics communities. They used a variety of methods to calculate the current economic value of 17 ecosystem services for 16 of the world’s major environments, ranging from grasslands to the open ocean. Services evaluated included a few that are traded in economic markets, such as production of raw materials and foods and recreation, and many others which are not, including the regulation of the atmosphere’s gas composition, natural waste treatment, and the provision of habitat and refuge for valued wildlife.

Costanza et al.’s mid-range estimate for the worth of these services is \$33 trillion per year, a figure about twice the globe’s gross national product (GNP) using conventional economic accounting. While there are those who would criticize this estimate as either deprecating the priceless of nature or exaggerating its strictly economic value, the point of their exercise was to underscore the fact that ecosystem services are indeed incredibly valuable, tend to be taken for granted, and often lose out to market-based considerations in decisions faced by society. As a result, actions are taken which impair these ecosystem services and we end up having to pay more to replace the lost services.

Notable in Costanza et al.'s estimates is the importance of the oceans and the environments around their margins, which together account for 68% of the value of services provided by all the world's environments. Even more striking is that coastal environments, including continental shelves, estuaries, seagrass beds, coral reefs, and tidal marshes and mangroves, comprise only 6% of Earth's surface but provide 43% of the biosphere's valuable services. Important coastal ecosystem services include those with which we are reasonably familiar, such as seafood production, habitat, recreation, and buffering the effects of floods and storms, and others of which the public is largely unaware, such as nutrient cycling.

Lisbon Principles of Sustainable Governance

As a contribution to the Independent World Commission on the Oceans, I participated with a group of scientists and policy experts in a workshop in Lisbon, Portugal, in 1997 that considered sustainable governance of the ocean from the perspective of ecological economics, i.e. managing human economic development while preserving essential ecosystem services. We recently published a viewpoint in *Science* that articulates the Lisbon Principles, embodying the essential criteria for sustainable governance (Costanza, et al. 1998). These principles are seen as forming an indivisible collection of basic guidelines governing the use of all environmental resources, including but not limited to marine and coastal resources.

Principle 1: Responsibility. Access to environmental resources carries attendant responsibilities to use them in an ecologically sustainable, economically efficient, and socially fair manner. Individual and corporate responsibilities and incentives should be aligned with each other and with social and ecological goals.

Principle 2: Scale-Matching. Ecological problems are rarely confined to a single scale. Decision-making on environmental resources should: [1] be assigned to an institutional level or levels that will maximize information about the relevant ecological system and recognize that ecological information needs to flow between them, [2] take ownership and actors into account, and [3] internalize costs and benefits. The appropriate scales of governance will be those that have the most relevant information, can respond quickly and efficiently, and are able to integrate across boundaries.

Principle 3: Precaution. In the face of uncertainty about potentially irreversible environmental impacts, decisions concerning the use of environmental resources should err on the side of caution. The burden of proof should shift to those whose activities potentially damage the environment.

Principle 4: Adaptive Management. Given that some level of uncertainty always exists in environmental resource management, decision-makers should continuously gather and integrate appropriate ecological, social, and economic information with the goal of adaptive improvement.

Principle 5: Full Cost Allocation. All of the internal and external costs and benefits (social and ecological) of alternative decisions concerning the use of environmental resources should be identified and allocated. When appropriate, markets should be adjusted to reflect full costs.

Principle 6: Participation. All stakeholders should be engaged in the formulation and implementation of decisions concerning environmental resources. Full stakeholder participation contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately.

Application to Coastal and Offshore Oil and Gas Resource Exploitation

Extensive oil and gas exploration, development and extraction have taken place in several coastal areas of the United States over the past 60 years. These regions range from the extensive coastal wetlands of Louisiana, to the continental borderlands of Southern California and lower Cook Inlet, to the coastal tundra and ice-covered nearshore zone of the Beaufort Sea (North Slope), and to the increasingly deep waters of the Gulf of Mexico (where exploratory wells have been completed in up to 2,800 m of water). During the last 25 years, coastal and offshore oil and gas development has been embroiled in controversy regarding its environmental impacts. As a result, most of the offshore region, the so-called Outer Continental Shelf, of the U.S. is under a moratorium prohibiting further leasing and exploration, under an Executive Order by President Bush that was recently extended by President Clinton.

Oil and gas development on the continental shelf has actually resulted in few demonstrable, long-term effects on the offshore environment (Boesch and Rabalais, 1987). Platforms do alter the environment by providing high-relief and hard substrates that attract fishes and result in biodeposition on the seabed by the attached fauna. Discharges from drilling and production activities in deeper waters have not resulted in contamination that could cause serious biological effects, particularly if they do not contain oily residues. There has been a remarkably small amount of oil spilled from offshore exploration and production, as a fraction of that produced. Despite that record, the fear of oil spills has been the most significant objection to OCS development by regional and national environmental opponents. Other significant concerns have been related to aesthetics (the disruption of ocean vistas) and collateral coastal impacts.

Indeed, impacts on coastal ecosystems as a result of both offshore and coastal zone oil and gas development have been more severe and longer-term than those in offshore environments (Boesch and Rabalais, 1987). These impacts include extensive modification and loss of coastal wetlands along the Gulf Coast due to canals dredged for well site access, pipeline transportation, navigation for the supply infrastructure and support facilities (Boesch et al. 1994). Physical alteration of Arctic coastal habitats has also occurred. Pollution, in the form of release of drilling fluids and cuttings and oily, formation waters, has also had more serious consequences in shallow, confined coastal waters that are less subject to dilution and dispersion of waste streams. Until recently, a significant amount of formation waters produced in offshore waters of the Gulf of Mexico was actually separated from the oil and discharged into estuarine waters for logistical reasons. Ironically, these estuarine discharges were subject to less stringent controls that they would have been if discharged into the less sensitive offshore environments.

To a large degree, the coastal impacts suffered and the opposition that now blocks future offshore development resulted from the lack of application of the responsibility principle. Until recently, corporate interests did not recognize responsibilities to mitigate or compensate for environmental impacts. The branches of government responsible for resource development have been not only separated from those responsible for environmental protection and renewable resource management, but also often incoherent and at odds with them.

There has also been considerable mismatch in the scale of decision-making. Permits for oil and gas exploration and development activities within the Louisiana coastal wetlands were considered one at a time: the economic value of the nonrenewable resource was thought to clearly outweigh the value of a few acres of wetland. But, this attitude failed to consider this issue at appropriate spatial and temporal scales. There were thousands of such permits and the cumulative effects of the wetland losses have been synergistic rather than just additive. Economic exploitation of the nonrenewable

energy resources over a 50-year time period accelerated the deterioration of these sinking deltaic wetlands and loss of the renewable resources they support by a factor of ten (Boesch et al., 1994). Yet, there were steps that could have been taken, at a cost of a mere fraction of the value of the energy resource produced, that could have substantially reduced this impact. We have also failed to understand and apply the scale-matching principle at the national government level as well. Few of the many billions of dollars of bid bonuses, rentals and royalties generated for the Federal treasury have been applied to reducing or mitigating the impacts—the costs and benefits have not been internalized.

While in the early days there was little cautionary control of coastal and offshore oil and gas development, one could argue that today, at least outside of the historically producing regions of the Gulf of Mexico, development of offshore oil and gas resources is frozen by precaution regarding potential environmental impacts. Carried to its extreme the precautionary principle will prevent actions for resource exploitation as long as there is any uncertainty or risk. The occurrence of an oil spill, however unlikely, is a risk that is just not worth taking, some would argue. Of course, scientific information should be used to quantify risk and uncertainty, but the degree of uncertainty one is willing to accept is a social and political and not a scientific decision (Boesch, in press). In that regard, I believe that the governmental agencies responsible for coastal and offshore oil and gas development have failed to develop a scientific community of expertise that is highly credible, because they viewed the acquisition of technical information as a procurement challenge rather than a cultural one.

One could argue that oil and gas development, with its substantial and long-term capital commitments, can not easily be subjected to adaptive management, in which management policies change as more information is gathered and integrated (Holling, 1978; Hilborn and Walters, 1992, Ludwig et al. 1993). Who would be prepared to make the massive investments if the ground rules are subject to change? However, adaptive management can be viewed in both the long-term strategic as well as the short-term tactical sense. How could environmental performance be monitored and results used to modify leasing policies and permit requirements over the long-term? How can flexibility be provided in operational permits that allow both more stringent and more liberal adjustments of requirements?

Full cost allocation sounds great in principle, but is difficult in practice. With no resource sector is this more true than with fossil fuels, where there are environmental consequences not only in the region of extraction, but also with regard to air quality and the global climate. Unfortunately, the global energy market does not reflect the full costs of the use of the commodity. To varying degrees in different countries, this is compensated for by high taxes that can then be used to offset non-market costs. In any case, we need to do a much better job in quantifying the full costs of energy extraction and consumption, including those falling on non-market, ecosystem services.

Particularly over the last 20 years, substantial effort has been expended by management agencies to engage stakeholders and other citizens through environmental impact statements, scoping meetings, etc. Perhaps because opposition had hardened by feelings that offshore oil and gas development was being forced on regions by the federal government, these efforts have not resulted in the kind of participatory decision-making embodied in the participation principle. Still, it should be clear that under present and future conditions, exploration and development could not proceed without effective public engagement and accommodation.

While the implied criticisms to a large degree deal with past practices and environmental management of coastal and offshore oil and gas development has certainly improved, the lessons still apply. We could still do much better if those managing and exploiting oil and gas resources, those entrusted with the stewardship of coastal and

marine ecosystems and resources, scientists trying to inform the process, and advocates kept the Lisbon principles firmly in mind.

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MEETING SOCIETAL RESOURCE AND ENVIRONMENTAL REQUIREMENTS FOR THE 21ST CENTURY

GLOBAL UNDISCOVERED NONFUEL MINERAL RESOURCES

Issues and Positions—Talking Points

By:

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- **Mining of nonfuel minerals is indispensable.**

Minerals are an essential source of new wealth that cannot be created from the sale of services. In fact, all of the material wealth of a nation is generated when the manufacturing and construction sectors create products from the essential raw materials provided by mining and agriculture. There is no other way.

Without nonfuel minerals for the construction, servicing, maintenance, repair, and replacement of the complex infrastructure and multitude of products that support our modern civilization, most of us would be dead or dying in a few months.

- **United States and world consumption of nonfuel minerals is growing.**

Charts showing this growth with time and population for total consumption (one chart) and for per capita consumption (second chart). Include projections into the future.

- **Americans want less mining in the United States.**

Mining of nonfuel minerals, whether by open pit or underground excavation, pumping from a drill hole, or even simple evaporation, is opposed by many, if not most, Americans, largely because of both real and perceived environmental effects. This opposition is reflected explicitly or implicitly in national resource, environmental, land-use, and fiscal policies. Examples include:

- Absence of a contemporary coherent national mineral-resource policy.
- Increasingly restrictive and expensive environmental requirements and litigation for exploration and mining, and for associated environmental mitigation, remediation, and reclamation.

- Continuing withdrawals and proposed withdrawals of public and private lands from mineral exploration, discovery, mining, and use.

In all, over the last 10 years, these lands comprise at least 200 million acres, most of which have never had detailed mineral surveys. This does not include increasingly restrictive resource management plans in place or under development by assorted land-management agencies for public lands still open to mineral development. Nor does it include continuing withdrawals of private lands resulting from ever expanding metropolitan areas. For purposes of comparison, the USGS and the USBM studied about 58 million acres in support of the USFS and BLM wilderness programs between 1964 and 1992.

- Efforts to restrict mining through revision of the Mining Law.
- Low and declining support for Federal minerals programs, including abolishment of the U.S. Bureau of Mines.

Although the value of primary processed materials derived from nonfuel minerals (360 billion in 1994) exceeds that of agricultural products from the nation's farms and forests (\$210 billion in 1994), Federal investment in minerals programs is substantially less than 2 percent of the investment in agricultural programs through the Department of Agriculture, even after excluding food and nutrition assistance. And, what is the likelihood that the USDA will be abolished?

Low public support of the minerals sector of the U.S. economy is unlikely to change barring an unpredicted and unlikely shortage of foreign supplies of nonfuel mineral resources, or an equally unlikely national security threat sufficient to restrict U.S. imports of minerals and mineral materials.

- **The United States is and will be increasing its reliance on imports of nonfuel minerals.**

Charts showing increasing overall import reliance for nonfuel minerals.

- **The world is becoming a smaller place for mining.**

While mining is being variously restricted in developed countries, large parts of the rest of the world also have been proposed, or by international agreement already are, off limits to exploration and mining. Examples include Antarctica; the Arctic Islands; a variety of fragile ecosystems often containing endangered plant and animal communities (e.g., tropical forests, old-growth temperate forests, wetlands, deserts, and alpine areas); marine coastal areas and wetlands, the continental shelves; ocean basins; and a

variety of other scenic and otherwise sensitive regions of the world that have been proposed or designated as international parks, etc.

At the same time, restrictions on mineral production in one region of the world can lead to mining in other unpredicted and even more environmentally sensitive locations. Parallels have been cited in international lumber trade.

- **What areas of the world are likely to contain recoverable deposits of undiscovered nonfuel minerals and how much is there? What are the likely and relative environmental effects of mining in these areas?**

What is the dominant land use in these areas? Are potential environmental effects local or global? Are there potential effects on the U.S. environment from mining in environmentally sensitive areas in foreign countries? Can these effects be greater than mining an equal amount of the same mineral commodity in the United States? What are the relative costs and environmental effects of mining nonfuel mineral deposits in one place and not another? Of mining one mineral-deposit type but not another type? Can these environmental effects be adequately predicted, prevented, mitigated, and remediated? Are mineral-rich countries willing to allow mining for export no matter how small the environmental impact? Will U.S. foreign policy and relations with a mineral-rich country permit us to import their mineral products? At a competitive cost?

If the United States is going to rely on foreign sources of nonfuel minerals, national leaders and policy makers will need to know the answers to these and many other questions. So will other governments, global financial institutions, environmental organizations, the mining industry, and others.

- **The USGS proposes to undertake a feasibility study of an effort to identify international cooperators and organize an international project to begin predicting the locations, and estimating the amounts, of the undiscovered nonfuel mineral resources in the world in national, regional, and global environmental and ecosystem contexts.**

This study will examine the feasibility of conducting quantitative global mineral-resource assessments of the continents using a variety of information from (1) all collaborators and clients regarding the needs for, and requirements of, quantitative global mineral-resource information, and from (2) the design and testing of prototype quantitative assessment methods applied to selected mineral commodities and mineral-deposit types.

The feasibility study will develop information required to design, evaluate, and undertake future quantitative global assessments of undiscovered mineral resources. These assessments will assist the United States and other national

governments, mining companies, and environmental organizations in discussing, planning, and maintaining the availability of essential mineral resources from areas of the earth most able to withstand the environmental effects of mining. Among the objectives of the feasibility study are efforts to:

- Define immediate and long-term goals for quantitative global mineral-resource assessments and establish minimum requirements for global-scale assessment products.
- Identify and begin discussions with countries and organizations involved in international mineral-resource studies and establish mutual collaboration on global mineral-resource assessments when possible. A workshop is planned to help facilitate this process.
- Build on the experience gained and lessons learned doing other large area resource assessments such as the USGS prototype national assessment of undiscovered gold, silver, copper, lead, and zinc in the United States, and the global assessments of oil, natural gas, and uranium.
- Design and test one or more methods for doing a quantitative global mineral-resource assessment for selected deposit types of strategic commodities, including both metallic and industrial minerals.
- Develop a prototype archive and library of worldwide commodity data, of maps showing areas determined to be permissive for the occurrence of undiscovered mineral resources, and of related regional geoscience data needed for global assessment activities. The feasibility of conducting timely global mineral resource assessments will be greatly enhanced if relevant data are available in common-format digital databases that can be manipulated using GIS technology.
- Locate and (or) develop global ecosystem and land-use maps and other environmental data bases for use with the global assessment to help identify and evaluate the relative potential environmental effects of mining among areas predicted to contain undiscovered resources, and thereby to plan for, prevent, and (or) reduce those effects.

Environmental Monitoring for Sustainable Use of the Planet

John Cairns, Jr.

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Environmental monitoring is an activity that is essential to maintaining human quality-of-life. Since human society depends on ecosystems to provide breathable air, potable water, food, fiber, building materials, pharmaceuticals, and genes, it is simple self interest to monitor ecological capital and the rate at which the interest on this ecological capital in the form of ecosystem services is produced. By integrating the many existing environmental monitoring programs, making their methods compatible, making their spatial and temporal scales complementary, and making the products of these investigations readily available, an explosion in understanding of the relationships between human society and natural systems will be possible. The boundaries of each individual effort will be extended by this coordination, and the confidence in each finding will be magnified. These efforts will enhance the ability to demonstrate the intimate links between environmental condition and human quality-of-life and provide essential quality control for ecosystem services.

HUMAN DEPENDENCE ON ECOSYSTEM SERVICES

Natural systems provide services that are essential to human society (Westman, 1978). Those few functions of natural systems that have been widely recognized as beneficial to human society are called ecosystem

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POPULATION AND ENVIRONMENT

services. If society's environmental literacy were sufficiently high, all functions of natural systems might be regarded as services. However, the benefits to human society of a few services provided by natural systems seem clear enough. Human society depends on (1) capture of solar energy and conversion into biomass, which is used for food, building materials, and fuel; (2) decomposition of wastes such as sewage; (3) regeneration of nutrients in forms essential to plant growth (e.g., nitrogen fixation); (4) storage, purification, and distribution of water (e.g., flood control, drinking water purification, transportation, etc.); (5) generation and maintenance of soils; (6) control of pests by insectivorous birds, bats, insects, etc.; (7) provision of a genetic library for development of new foods and drugs through both Mendelian genetics and bioengineering; (8) maintenance of breathable air; (9) control of both microclimate and macroclimate; (10) provision of buffering capacity to adapt to changes and recover from natural stresses such as flood, fire, pestilence; (11) pollination of plants, including agricultural crops, by insects, bats, etc.; and (12) aesthetic enrichment from vistas, recreation, inspiration.

Monitoring should have, as one of its primary objectives, the assurance that environmental quality control is adequate for these services to continue indefinitely. If monitoring and environmental quality control are not adequate, then sustainable use of the planet is impossible.

Quality control practices are well understood by members of industrial societies. Monitoring is common for the quality of blood given to patients in hospitals, for milk delivered to supermarkets, for gasoline used in cars, for bagels served on breakfast tables, and, of course, for beef made into burgers. Criteria have been determined for acceptable and unacceptable quality in these and other products. However, society is less used to setting similar quality control standards for complex multivariate systems that do not have clear cut boundaries such as ecosystems. Yet if sustainable use of the planet is a major goal, the quantity and quality of ecological capital and ecological interest must be determined so that future generations will inherit. If society depends on services provided by ecosystems, they should perform within certain boundary conditions. Going outside these conditions will affect the ecosystem's performance and, thus, the quality and quantity of their services. These concepts are challenging matters to define since society has not yet viewed its planet as an essential life support system. When this view has been considered, it has often been with poetic platitudes and much self-righteousness. Society must recognize that its life support system is now both technological and ecological, and that good management depends on optimizing the quality and quantity of both sets of services, without unnecessary sacrifice of either.

COEVOLUTION

While protecting ecosystem services seems a clear enough goal, complex interactions between human actions and environmental response occur (Cairns, 1994). Natural systems adjust to every action of human society—not always in the ways humans intended. The development of pesticide resistance is a key example. These changes in natural systems, in turn, require human society to adjust. Not only is the fate of ecosystems dependent on the actions of human society but the fate of human society is inextricably involved with the fate of ecosystems. In short, the dominance of human society over nature is not what it was once thought to be. The relationship is, in fact, more of a partnership. Each partner can benefit or harm the other. Such mutual modifications are analogous to the coevolutionary adjustments seen in pairs of species (e.g., hummingbirds and flowers).

However, the coevolutionary relationships that exist between species pairs are often accomplished by means of harsh penalties for those individuals or components that do not respond rapidly to changes in the other component. Thus, coevolution of human society and natural systems will be less unpleasant to humans if rapid information systems are developed to alert human society to needed changes.

A monitoring system can provide an early warning of deleterious change in ecosystems. However, this warning must be coupled with a sufficiently high appreciation for the dependence of human quality-of-life on ecosystem services. Without convincing links between environmental change and human quality-of-life, it will be impossible to influence human practices before the selective pressures of natural systems become too harsh. If environmental stewardship fails because of inadequate monitoring or the lack of will to take appropriate action, human society will suffer unpleasant consequences. Dobzhansky (1945) stated:

We like to believe that if we secure adequate data bearing on a scientific problem, then anybody with normal intelligence who takes the trouble to become acquainted with these data will necessarily arrive at the same conclusion regarding the problem in question. We like to speak of conclusions demonstrated, settled, proved and established. It appears, however, that no evidence is powerful enough to force acceptance of a conclusion that is emotionally distasteful.

Assuming that human society has faith in the results of the monitoring data, will it have the courage to prevent unfortunate consequences, or wait until the consequences make action imperative?

This, I suggest, is the context in which environmental monitoring for regional, national, and global needs should now be viewed. Everyone must abandon the polarizing views of human society's relationship with natural systems and substitute a relationship of one system coevolving with another. Monitoring should furnish information suitable for making policy and management decisions to optimize the multivariate coevolutionary systems which, together, constitute society's life support system. Monitoring should also furnish information about the linkage between environmental condition and human quality-of-life.

TECHNOLOGICAL VS ECOSYSTEM SERVICES

In my earlier writings on biological monitoring (e.g., Cairns et al., 1970a;b; 1977; Cairns & Dickson, 1973), I envisioned an environmental quality control system that would permit use of nondegrading environmental assimilative capacity of societal waste, thereby protecting the integrity of natural systems but simultaneously taking advantage of their services. This would permit the coexistence of a technological society with natural systems and permit humans to enjoy both worlds (Cairns, 1996). In theory, this relationship of keeping technology sufficiently restrained so that it does not imperil natural systems is still possible, but the outcome is more uncertain than it was when biological and environmental monitoring was in its infancy.

Before the agricultural revolution, during the hunting gathering period, one could reasonably state that the life support system for humans was essentially ecological. Since the agricultural revolution and subsequently the industrial revolution, increasing numbers of people have become dependent on technological services to deliver food and energy and to treat waste materials. Catastrophic disruptions, such as earthquakes, hurricanes, floods, and the like, have shown how much even temporary disruptions of technological services can affect the well-being of human society, especially locally. Disruptions in ecosystem services are less obvious when they are incremental, or ameliorated by an overlay of technological services. For example, the loss in flood buffering capacity along the Mississippi River is a sorely lost ecosystem service, but is only experienced directly once every 100 years.

Significant numbers of people believe that technological fixes can be found for any and all environmental problems. However, current estimates of the cost to replace all ecological services by comparable technological services are sobering. Avise (1994) estimated that the cost of replacing eco-

system services by technology and/or managed ecosystems in Biosphere 2 was a staggering \$9 million per person, per year. Achieving a balance between the provision of ecosystem and technological services will require both continual information about natural system condition and a willingness of human society to improve and, when necessary, restrain the delivery of technological services in order to prevent unacceptable levels of damage to the delivery of ecosystem services.

DEVELOPING ENVIRONMENTAL MONITORING POLICY OPTIONS

If human society acknowledges its dependence on an ecological life support system and simultaneously acknowledges that the system's capacity is finite and cannot indefinitely meet the demands of an ever-growing population, then five basic policy options for human society are possible (Cairns, 1993):

1. Continue environmental degradation and population increases until some sufficiently unpleasant selective pressure is exerted. Some would argue that there is already abundant evidence that crucial thresholds have been passed, but others deny this.
2. Develop a no-net-loss of ecosystem system services policy but do not attempt to regulate increases in population size or per capita level of affluence.
3. Exceed the standard of no-net global, regional, or national loss of ecosystem services but permit both population and levels of affluence to continue to increase.
4. Stabilize human population with concomitant no-net-loss of production of ecosystem services. This is essentially the definition of sustainable use of the planet if one does not equate increased affluence with increased energy consumption and increased production of material goods. Perhaps a more accurate term than *affluence* is *net resources used per unit of product produced* so that recycling would then not increase demands on resources even though affluence would increase.
5. Stabilize human population and its demand on resources and exceed a no-net-loss of ecosystem services. This is the only scenario in which things are environmentally better than they are now are. Options 4 and 5 both permit sustainable use of the planet as it is generally interpreted; options 1, 2, and 3 almost certainly do not.

Regardless of the option chosen, environmental monitoring will be essential to see if the option is compatible with sustainable use and to see if the systems are functioning as expected. For example, it is possible that

human society could still get sufficient ecosystem services with either half the ecosystem area or with a 50% decline in production of ecosystem services. If this is true, it is worth confirming. If it is not, the earliest possible warning would be highly desirable.

THE RISK-UNCERTAINTY PARADOX

Yet another consequence of the increasing scale of environmental problems is an increase in the uncertainty of the predictions of environmental outcome and consequences. Tolerance of scientific uncertainty and tolerance of risk are both proper subjects for debate before decisions are made in an environmental workshop. However, they are linked—acting with an intolerance of uncertainty often demands a high tolerance for risk. If the consequences are severe, one should be willing to act even in the face of high uncertainty. Impairment of ecosystem services certainly seems to fall in this category.

Traditional health and industrial monitoring systems produce both false positives and false negatives. In an environmental monitoring context, a false positive is a signal that some deterioration has occurred in the system when, in fact, it has not. A false negative is the absence of a signal when unacceptable changes in quality have occurred. The earlier use of sentinel species yielded false positives if the sentinel species was more sensitive to a particular toxicant than were the resident species and false negatives for some other toxicant for which the relative sensitivities were reversed. Reductions of errors can be accomplished by a better understanding of the system being monitored and by multiple lines of evidence. Integration of environmental monitoring programs will provide both. In addition, some attempt is being made to re-address the balance between false positive and false negative errors in risk assessments. Traditional scientific approaches control false positives at the expense of additional false negatives; this may be inappropriate in a risk assessment context (Shrader-Frechette, 1993).

ENVIRONMENTAL MONITORING FOR SUSTAINABLE USE

Developing a monitoring system so that ecosystem services essential to human society's well-being are maintained is quite a different activity than merely protecting natural systems for their own sake, although both activities are laudable. Acknowledging human society's dependence on

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Therefore, in order to achieve sustainability at some point, a balance must exist between ecological destruction and repair. Because the present rate of ecological destruction is unique in human history, now is the time to attempt to achieve a balance, while the quality of life is still reasonably high and some relatively pristine ecosystems are available to use as models. Of course, human error will always produce such destruction as accidental oil spills and other ecological catastrophes. In some cases, natural recovery will heal the damage; however, as sources of recolonizing species diminish and are more widely separated geographically, managed recovery or ecological restoration will be essential. The National Research Council (21) recommends beginning this process of restoration at a modest level for aquatic ecosystems.

Cairns (22) describes five options for human society regarding its relationship with the environment, only two (stabilize human population and exercise no-net-loss of ecosystem services, which would then maintain a status quo on ecosystem services per capita; and stabilize human population growth and restore ecosystems at a greater rate than destruction, which would improve ecosystem services per capita) of which are likely to result in sustainability. Both of these options would presently be regarded as visionary because they involve stabilizing the human population and level of affluence (which is not necessarily closely correlated with quality of life) and repairing ecosystems at the same rate as they are damaged or an even greater rate for a certain period of time.

Condition 4. Management strategies for sustainability must allow natural processes such as succession, evolution, predator/prey relationships, and the like to continue.

The machinery of nature has adjusted over literally billions of years to continual change. Although the changes in species composition may be imperceptible within human time frames, they are often quite dramatic in geological time frames. Ecosystem function (and delivery of services) may be relatively stable with regard to turnover in species within an ecosystem if there is substantial redundancy within the ecosystem (i.e., replacement species with similar function). However, the rate of change and increasing fragmentation of ecosystems might well negate the advantages of functional redundancy. The resiliency of natural systems is sufficient to overcome these changes, which are often (no pun intended) glacially slow. However, human-initiated perturbations (such as persistent toxic chemicals with no natural counterparts, habitat fragmentation on a large scale, and a very high rate of species impoverishment) have developed with such

rapidity that natural systems are unable to function as they normally would.

Goal 4. To devise a better balance in meeting short-term and long-term needs of human society.

Condition. Short-term human needs may not be met if doing so endangers the planet's ecological life support system.

The essence of sustainable use of the planet is to give a far higher priority to long-term needs than has been given in the history of human society. In essence, short-term needs might be denied or postponed if they endanger long-term needs. This is a difficult position to achieve and seems almost unthinkable in a society that insists on needs being met immediately. However, if some attention is not given to this issue, natural forces (23,24) will almost certainly adversely affect human society and deprive many individuals of perceived needs.

Sub-condition 1. If a world food shortage develops, grains will be shifted from domesticated animals to humans, rather than convert more natural systems to agriculture.

Converting more natural systems to agriculture is an example of placing short-term needs ahead of long-term needs. A recent article in *Scientific American* (25) recommended converting wasteland to agricultural use to solve China's food crisis. While not explicitly stated in the article, the impression is conveyed that wasteland is land not intensely used by human society, but clearly used by other species. Wasteland so defined is land going to waste in terms of human use, but it is not wasteland if other species and ecosystem services are valued. In short, the term wasteland would be inappropriate if this land were providing ecological services for society's life support system. For example, wetlands converted to agricultural purposes would no longer store flood waters and release them gradually into either surface waters or groundwater, thus changing both the amplitude and duration of flood peaks. This storage and release are definitely ecosystem services. However, this tyranny of small decisions—filling in a wetland here and there on a vast drainage basin—seems rational until the aggregate effect of a large number of small decisions is considered. California has eliminated approximately 91% of the wetlands that existed there in 1800 (21), thus having an effect on the amplitude of flood waters in that state. This reduction is, of course, not the only reason for floods since creating impervious surfaces such as roads, roofs, shopping malls with large parking lots, and the like also changes runoff patterns, as does decreasing the ability of natural systems to transpire and absorb rainwater by losing topsoil and clear-cutting forests. Small decisions considered in isolation from other decisions

may have effects too minor to measure and may seem inconsequential but, when taken in the aggregate, may have effects that can be measured and are accompanied by severe consequences.

Sub-condition 2. Society must not depend on yet undeveloped technologies to save it from the problems it has created.

This condition is also a part of balancing short- and long-term needs. Unquestionably, solutions to problems, particularly those involving development of new technologies, are often brought on by crises. The development of the atom bomb during the latter stages of World War II is a good example, or the U.S. space program, which was developed at a much faster rate after the former Soviet Union launched a spacecraft into orbit. Development of new technology does not inevitably follow a crisis; the AIDS crisis is one such example. Granted, some technological or medical solution to AIDS may be found through the use of advanced technology, but it will come too late to benefit many sufferers.

Goal 5. To ensure that most of Earth's population has the opportunity for a high quality life.

Condition. Human population over the long term must be stabilized at a point where adequate per capita resources are demonstrably available.

The U.S. Bureau of Land Management (BLM) has established limits to the density of cattle that may be grazed on BLM lands. These limits are, of course, not the same for every area because some areas have a higher carrying capacity than others. Nevertheless, in practice, carrying capacity is recognized for domesticated and semidomesticated animals, elevators, bridges, and wild animals such as deer and trout. However, society is not willing to admit that biophysical laws of nature apply to *Homo sapiens* in terms of resource utilization and carrying capacity. Quality of life is not high when the carrying capacity is at or above maximum. This problem can be observed in parking areas, where people must cruise the lot in search of empty space, or when a certain number of individuals are packed into an elevator, even if the number of people and their aggregate weight is within legal limits.

Sub-condition 1. When defining sustainable use of the planet, society can use quality of life as the primary criterion.

Alternatively, estimates can be made of how many people can be crammed on Earth at a subsistence level at any one period of time. Theoretically, sustainable use of the planet would be possible using either criterion, but the quality of life for an individual would be vastly different for each choice. Will quality or quantity be a primary condition for sustainable use of the planet?

Sub-condition 2. Human rights may not be met if the ecological life support system is endangered by doing so.

This condition is, again, part of the balancing act, that is, ignoring the needs of future generations by damaging their life support system in order to meet the needs of presently living persons. For example, destroying a unique ecological system to provide a power line right of way or yet another major highway will clearly be affirming that the need to reduce travel time for humans now living is more important than the need of future generations to have a robust ecological life support system and to enjoy its amenities and pleasures.

Sub-condition 3. The majority of people and countries on the planet must accept a single paradigm on sustainable use of the planet.

Getting most of the world, both countries and people, to accept a single paradigm seems an unachievable goal. However, this condition has already been met by the common acceptance of the economic growth paradigm. Arguably, the reluctance to relinquish the growth paradigm is the reason the term sustainable development has been used instead of the term sustainable use of the planet. At any rate, since a large portion of the planet, including all developed countries and most developing countries, at one time accepted the growth paradigm, and most still do, it is at least conceivable that an alternative paradigm could have comparable acceptance. Since the free market paradigm is still painfully under way in Russia and a number of other countries, this situation is an illustrative example of an occurring paradigm shift. Diamond (26) provides a plausible hypothesis [i.e., under certain conditions, a wide variety of cultural entities (in China) merged to a remarkable degree as a result of a shared paradigm] for achieving a shared paradigm from a sizable array of culturally different groups. As always, this change was achieved at a cost to a number of generations and cultures.

Sustainable use of the planet probably cannot be achieved with a mixture of traditional economic or ecological paradigms. The coexistence of a limits-to-growth paradigm and an unlimited growth paradigm does not seem viable. Further, environmental refugees are likely to increase as resources are overutilized or severely damaged (or both) in particular countries. Stemming the flow of environmental refugees (not to mention political and economic refugees) is likely to consume so much time and energy and be such a long-term management concern that the energy necessary for transition to sustainable use simply will not be available in time. It is disturbing that so much energy

and resources are devoted to placing the blame rather than solving the environmental problem (27). Instead of repairing environmental damage that occurred many years ago, society is engaged in endless legal battles to see if present property owners can be held accountable.

Goal 6. To avoid a human-induced episodic environmental catastrophe that would cause much human suffering.

Condition. When employing environmental management strategies about which the precise consequences are still somewhat uncertain, large protective safety margins (i.e., either slowing development or carrying it out extremely cautiously) are essential until the outcome has been better defined and the consequences have been determined to be acceptable and not of long-term sustainability significance.

The sun has a finite life span, even though it is probably in excess of a billion years, and the universe will not last forever (8). Consequently, no sustainability initiative should be designed for an infinite period of time. In fact, glacial and interglacial cycles of approximately 100 thousand years are well documented, and management strategies for sustainable use of the planet would definitely have to be altered as a consequence of these events. A possibility also exists that the Earth could be struck by objects from outer space that would cause dust clouds to change the Earth's climate and a variety of other events will occur over which human society has no control. However, society can control many events. For example, greater protection can be given to the other species with which humans share the planet. At the very least, the rate of biotic impoverishment (i.e., extinction of species) could be substantially reduced. Development of sustainable management strategies is also complicated by not knowing when the rapid rate of extinction of species will stop. Some species may have enormous value to human society, but these values may not yet be known, or the species themselves may be unknown because inventories of much of the Earth's biota are still inadequate. The problem is, of course, that short-term benefits accrue to those now living, who take risks with the planetary life support system, but the consequences of unwise decisions are likely to be endured mostly by future generations. Therefore, the type of development based on a frontier land use ethic, which is still all too present in human society globally, should be replaced by a maintenance ethic that would benefit both present and future generations.

Goal 7. To diminish the conflict between generations caused by U.S. Social Security and Medicare and elsewhere

caused by the perception that future generations will lead impoverished lives because of present greed. (This goal is not identical to Goal 4 because long- and short-term goals may shift significantly as one ages.)

Condition. Older people must become deeply involved in sustainable use of the planet to demonstrate by deeds, not words, the older generation's concern for generations to follow.

As the number of workers decreases and retirees increase and Social Security and Medicare costs rise, the perception is that older people are maintaining their lifestyle at the expense of younger people. Developing a sustainable use policy is the best way to demonstrate with deeds, not words, a commitment to the future or succeeding generations. This development is a shared undertaking from which younger people will be the primary beneficiaries, even though the older people should take pride in this joint effort.

Goal 8. To reincorporate all waste from human society into natural systems without damaging their integrity.

Everything used by human society comes from natural systems. Although, in one view, human society is a part of all natural systems, in some ways it is apart from them. Society cannot afford to extract materials such as metals from the Earth, use them, and then place them in long-term storage such as landfills and the like. Dangerous radioactive wastes and highly toxic chemicals cannot be accumulated in situations isolated from the web of life without further depriving both humans and other species of the use of this area of the planet.

Condition 1. Materials that cannot be safely reintroduced into natural systems should not be produced.

A substantial difference exists between artifacts created by human society, such as shopping malls, and radioactive wastes that require long-term storage. Difficulties in the United States in cleaning up hazardous waste sites highlight this dilemma. The uncertainties associated with effective long-term storage of hazardous wastes are daunting and not likely to be quickly resolved. The essence of sustainability is the benign, even beneficial, reincorporation of materials extracted from natural systems back into them. If this cannot be done with present methodology, such activities are incompatible with long-term sustainable use of the planet. This issue is not an unimportant detail in the quest for sustainability.

Condition 2. Assimilative capacity of natural systems shall not be exceeded.

Cairns (28) has defined assimilative capacity as the ability of an ecosystem to assimilate a substance without degrading the ecosystem or damaging its ecological

integrity. Cairns (29) has defined ecological integrity as the maintenance of the structure and function characteristic of a locale. Meeting this condition requires that assimilative capacity be quantified and that human society adjust its waste disposal into natural systems so that they remain healthy and suitable for sustained use.

Condition 3. To develop robust predictive models regarding assimilative capacity, validate these models, and continually monitor them to ensure that previously established quality control conditions based on these two prior activities are being met at all times.

Natural systems are made up of both living and nonliving material, and it is a *sine qua non* that all living material varies. Therefore, assimilative capacity will vary within limits, and using it effectively requires attention to this characteristic. All living systems respond to the aggregate of the potentially stressing materials to which they are exposed, not to individual components in isolation from the others, although this can, at times, happen. Therefore, the monitoring and other activities must be at the system level in order to be congruent with decisions made at the system level.

Goal 9. To develop equity and fairness in resource distribution within human society and with other species with which it shares the planet.

Condition 1. A sufficient majority of humans must acknowledge the reality of equity and fairness so that there is an incentive to preserve the ecological life support system for sustainability.

This equity and fairness are best achieved at the grass roots level rather than by government coercion. Government may sometimes prevent gross damage, but fine tuning ecosystem health must be the mission of all society. As Pericles said, "All honor to him who does more than the law requires."

Condition 2. Ethnic and racial strife, holy wars, wars over resources, and other extremely diverse political issues must be eliminated or restrained so that destructive energy can be rechanneled into constructive activities.

As Diamond (30) notes, humans genes are more than 98% identical to those of chimpanzees. The genetic differences between ethnic groups are less. Sustainable use of the planet will be best achieved if humans stop warring on their own and other species.

Goal 10. To develop a holistic sustainability initiative.

Condition. Each specific or targeted sustainability initiative (e.g., agriculture, transportation, energy, cities, fisheries, etc.) must not act as if it is the only "flower facing the

sun." It will be difficult to orchestrate these special interests but, otherwise, holistic sustainability will fail.

Ethics in Action or Inaction?

A substantial environmental ethic must be involved in any sustainability initiative. For example, Anglican Archbishop John Taylor (31) asked, "Is it immoral that the United States has to import over one half of its energy supply?" Similarly, he asks, "Is it reasonable that a child born in the United States or immigrating to it at an early age will probably consume 30 to 40 times the energy and natural resources per capita compared to the rest of the world, and possibly 200 times as much as some of the poorest underdeveloped countries?" One common belief among those few members of the general public who have given some casual thought to sustainable use of the planet is that, by minor changes in present practices, sustainability can be achieved without substantive behavioral change. However, much of the early literature on sustainable use of the planet indicates that a major paradigm shift and fundamental changes in human behavior, ethics, and lifestyles will be necessary. Stivers (32) espoused a new world that involved a radical change of attitudes and values. Birch and Rasmussen (33) argued that the most far-reaching change comes only with the combination of strong pressures and a compelling alternative vision.

Making no decisions that would compromise options for the next seven generations seems a sensible approach to formulating conditions for sustainable use of the planet. However, if a generation is 35 years, this span would cover 245 years, which is a long time for most human political groups. However, if each new generation were planning for the next seven, then it could adjust to climate changes, altered rainfall patterns, and other events not foreseen in the original plan. This plan might work equally effectively for a shorter number of generations, but seven seems an ideal number because it means that old growth forests, slow recharge rate groundwater aquifers, and other slowly renewing resources would get the protection they badly need for true sustainable use. The United Nations World Commission on Environment and Development (2) puts it more tactfully by stating that "sustainable development requires a change in the content of growth, to make it less material and energy-intensive and more equitable in its impact." Possibly this reasonable and moderate view was necessary so that the Commission would not be thought of as a group of environmental extremists. The *World Scientists Warning to*

Humanity, signed by over 1,600 of the world's leading scientists, was much more blunt, as the title indicates (34). Since this document was also signed by a number of the world's living Nobel laureates, one would have thought that this message would have received major front page attention in the world's newspapers, but it received very little attention and discussion in the news media as a whole. A similar statement by the officers of the Royal Society of London and the U.S. National Academy of Sciences (35) went virtually unnoticed. Orr and Ehrenfeld (36) feel that willful blindness has reached epidemic proportions and that nowhere is it more evident than in the U.S. Congress, which is denying outright the still-growing mass of scientific evidence about the deterioration of the Earth's vital signs while simultaneously attempting, often successfully, to dismantle environmental laws and regulations. However, there is a failure to distinguish denial from honest disagreement about matters of fact, logic, data, and evidence that is a routine and customary part of the scientific process. Orr and Ehrenfeld (36) feel that denial is the willful dismissal or distortion of fact, logic, and data in the service of ideology and self-interest. Although Ehrlich and Ehrlich (37) do not use the word denial, they do use the word betrayal and, unlike the comparatively short Orr and Ehrenfeld article (36), have substantive illustrative examples to document their position.

These issues become extremely important because if denial and betrayal are the problems then more scientific evidence will not help. Kuhn (38) recognizes these issues when he states that "a paradigm is a belief so strongly held that when contrary evidence appears the evidence is rejected." Even earlier, Dobzhansky (39) stated,

We like to believe that if we secure adequate data bearing on any scientific problem, then anybody with normal intelligence who takes the trouble to become acquainted with these data will necessarily arrive at the same conclusion regarding the problem in question. We like to speak of conclusions demonstrated, settled, proved and established. It appears, however, that no evidence is powerful enough to force acceptance of a conclusion that is emotionally distasteful.

One wonders what catastrophes human society must suffer before the major paradigm shift necessary to achieve sustainable use of the planet occurs. If the reasoned approach found in the publications of Robert and colleagues (3,40) is used, human society may be able to accomplish the transition gracefully.

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Global Coevolution of Natural Systems and Human Society*

Coevolución global de los sistemas naturales y la sociedad humana

John Cairns, Jr.**

ABSTRACT

Human society has been accustomed to thinking of natural systems as entities requiring protection or exploitation. There has been much hyperbole in the presentation of both views. Although people have spoken of the death of nature, it is unlikely that humanity could entirely eliminate all non-domesticated species. Each time human society does something, natural systems adjust, not always in ways intended. And, this, in turn, requires human society to adjust. This mutual modification is analogous to coevolution seen in pairs of species.

Coevolution between one species and another is often accomplished through harsh penalties for a component that does not respond rapidly to changes in the other component. A coevolution of human society and natural systems will be less unpleasant to humans if rapid information systems are developed to alert society to needed changes, coupled with a sufficiently high environmental literacy to make the changes before the selective pressures of natural systems are too harsh.

Instead of polarizing views of human society's relationship with natural systems, to the degree possible, this relationship should be viewed as one system coevolving with another. Wild systems must always be valued and maintained, but the point at which human society and complex ecological systems modified by humans co-exist is where society must spend more time working on a mutually beneficial relationship.

Keywords: coevolution, population growth, environmental literacy, environmental ethos.

RESUMEN

La sociedad humana se ha acostumbrado a pensar en los sistemas naturales como entidades que requieren protección y explotación. De ahí se deriva mucho de lo hipérbolo en la presentación de ambas observaciones. Aunque la gente habla de la muerte de la naturaleza esto es improbable ya que la humanidad debería eliminar por completo todas las especies silvestres. Cada vez la sociedad se ajusta un poco al sistema natural, no siempre de manera predeterminada. Esta mutua modificación es análoga a la coevolución vista en un par de especies.

* It is a great pleasure to be among those privileged to honor Dr. Eucario López-Ochoterena in this special issue of *Revista de la Sociedad Mexicana de Historia Natural*! I have warm memories of my association with Dr. López-Ochoterena, his colleagues, and his students. Intellectual stimulation was skillfully combined with gracious hospitality! This dedicatory manuscript was prepared as if I were giving another seminar at the invitation of Dr. López-Ochoterena.

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La coevolución entre una especie y otra es a menudo competitiva por haber dificultades en un componente que no responde rápido a los cambios en los demás componentes. Una coevolución de la sociedad humana y el sistema natural puede ser menos desagradable para el hombre, si la información del sistema se desarrolla tan rápido para alertar a la sociedad de la necesidad de cambio, al par de contar con una educación ambiental lo suficientemente fuerte para hacer los cambios necesarios ante la presión selectiva del sistema natural.

En cambio desde el punto de vista de las sociedades humanas las relaciones de polarización con el sistema natural, en el grado que sea posible, estas relaciones podran ser vistas como un sistema que coevoluciona con otros. Los sistemas silvestres siempre deberan ser valorados y sostenidos, pero hasta el nivel en que la sociedad humana y la complejidad ecológica en la modificación del sistema por el hombre coexista hasta el grado que la sociedad pueda devolver mayor tiempo de trabajo para llegar a una relación de mutuo beneficio.

Palabras Clave: Coevolución, desarrollo poblacional, educación ambiental, ética ambiental.

The World Community may not be sufficiently motivated to undertake those steps necessary to protect the global environment until it fully appreciates that a failure to do so will endanger the health of its children, and that of generations to come.

Noel Brown, Ph.D., Director,
North American Office, United
Nations Environment Programme

Selecting an Analogy

The particular analogies chosen to frame the discussion of global change seem to be a key part in communicating the scientific view of these issues to the wider public. Without access to the applicable science from many fields, the general public cannot fully participate in the debate. Of course, most ecologists feel that even the most basic ecological concepts are instrumental in enlightening the debate on global change. However, this can be true only if these concepts are communicated in a relevant context. In addition, ecological concepts must be integrated with key concepts from other disciplines: economics, demography, political science, cultural anthropology, public policy, etc.

One such ecological concept that may help shape the debate on global change is coevolution. A basic definition of coevolution is given by Raven and Johnson (1986): "The simultaneous development of adaptations in two or more populations, species, or other categories that interact so closely that each is a strong selective force on the other." In ecology,

coevolution has been used to describe paired changes in butterflies and the flowers they feed on (Ehrlich and Raven, 1964), hosts and parasites (Pimentel *et al.*, 1978), and predator and prey (Thompson, 1986). The concept has been extended to describe changes in more than species pairs, e.g., the reciprocal changes in agricultural practices and weeds (Ghersa *et al.*, 1994). Further, in cultural anthropology, the concept of coevolution has been appropriated to describe paired changes in the human culture and human genetics (Durham, 1991). Others (e.g., Odum, 1992) use it to describe the relationship between human society and natural systems.

The key parts of the coevolution definition are that the interacting entities must serve as selective forces on each other and that changes enhance the survival of each partner; otherwise, these change would not be adaptive. The idea I wish to explore here is that human societies and the global environment interact and shape each other, that these mutual changes can enhance the survival of both, and that understanding the mechanisms underlying coevolution may enhance the debate on global environmental issues.

This use of the term **coevolution** to describe the relationship between human society and natural systems has some similarities to the Gaia hypothesis (Lovelock, 1988). Living things, including humans, not only adapt to physical conditions but also modify them in ways sometimes beneficial to life. However, there are significant differences between the proposed coevolution analogy and Gaia's hypothesis (Van Valen, 1982). Gaia maintains that the earth is a superorganism in which nonliving and living components self-regulate to maintain a constant state (Kerr, 1988). In the superorganism analogy, the key concept is the physiological one of homeostasis. For example, a steady state in global climate would be maintained through feedback mechanisms in the same way mammals regulate body temperature. However, as Odum (1992) and others (Kerr, 1988) have pointed out, feedback in ecosystems is different from physiology because it has no fixed goals.

By selecting an analogy from farther up in the hierarchy of biological organization (e.g., cells, organs, individuals, populations, communities, ecosystems, landscapes, biosphere, etc.), the language of the physiologist is exchanged for that of the ecologist. Instead of the term **homeostasis**, the term **mutual change** is used. And, instead of any change of state being bad for the emergent whole, coevolution allows for the possibility of mutually beneficial changes. Coevolution occurs through the mechanism of selection. In the case of coevolution between human society and natural systems, the selection would be among alternate cultural practices (structures and functions of families, schools, communities of religious belief, governments at many levels, economies, and industries) and alternate landscapes. This shift in analogy accommodates current thought in the area of sustainable development because mutually beneficial change is possible if selective pressures elicit responses in both partners. Another description of the interaction between human society and natural systems invokes the chaos theory (Kauffman, 1993). In this view, the mechanism of selection is augmented by that of self-organization.

Do the basic requirements for coevolution exist in the relationship between human society and natural systems, i.e., do they shape each other? Certainly, humans have shown a remarkable ability to adapt to environments from one pole to the other. Human adaptations to these widely varying

environments have been largely behavioral rather than physiological. This sort of behavioral change falls within some definitions of an adaptation (e.g., Raven and Johnson, 1986) but outside others (Ricklefs, 1990). Clothing, shelter, fire, and agriculture have allowed people to change their physical environments to suit themselves. This physical restructuring of the environment that is a central part of human response to adverse environmental conditions has progressed and intensified, making changes increasingly pervasive, long-lasting, and removed from the intended modification. Human society has altered natural systems in significant ways. Now, in turn, is human society likely to be shaped by environmental changes that it has brought about? Of the many selective forces at play, some may be more effective than others in shaping their partner in coevolution.

Human Society as a Selective Force

Ways in which human society has presented a strong selective force to the global environment have been listed by many authors (e.g., Ehrlich and Holdren, 1971; Myers, 1979; Wilson, 1988; Ehrlich and Ehrlich, 1991; National Research Council [NRC], 1992a; Brown *et al.*, 1992). A few authors challenge the cause-effect link in some of these changes in the environment and human actions or dispute their importance (e.g., Ray, 1992; Bailey, 1993). Certainly, gross changes on a local level are easier to experience directly and to assess scientifically than are changes at the global level. Even Ray (1992) does not dispute the importance of local environmental problems such as pollution. However, some observed global trends are occurring at rates unprecedented in historical record, are correlated to simultaneous activities of human societies, and cause adverse effects in small scale, controlled experiments. Without replicate planets to manipulate, science will never get closer to a determination of causation at the global level than this. It is the projection of observed changes to larger scales, longer periods, interactions with other mitigating or potentiating factors, and future social consequences that is a much greater source of uncertainty. Even with room for responsible scientific debate about causation, magnitude, and importance, there are a number of areas in which human society demonstrates a strong selective force on the environment.

Habitat Fragmentation and Loss

Human society has been altering the physical structure of natural systems dramatically for thousands of years. Since the beginning of the agricultural revolution, agricultural systems created by human society have displaced natural ecological systems over much of the arable area of the planet. Even today, the loss of forests in certain countries, such as Brazil, is more likely to be due to clearing for agricultural purposes than from harvesting of timber (NRC, 1992a). Rates of deforestation in the most diverse systems, wet tropical forests, are estimated at 0.4 to 2.7% annually and are not readily reversible (Brown *et al.*, 1992).

Another example of precipitate losses in an entire category of habitat is wetland loss. More than half of the wetlands that existed in the coterminous United States has been lost since colonial times (NRC, 1992b). These wetlands once provided a means for containing floodwaters, cleaning water, and providing one of the most productive of habitats for fish and wildlife.

Loss of Species

With loss of habitat comes loss of species. Only a rough estimate can be made of how many species exist on the planet. Erwin (1988) suggests at least 30 million insect species and possibly 50 million in the canopy of tropical forests. Simberloff (1986) estimates that, if deforestation continues at present rates until the year 2000 and then halts completely, an eventual loss of about 15% of the plant species in Amazonia is likely. If the forest cover were further reduced to those areas now set aside as parks and biological reserves, 66% of plant species would eventually disappear as well as almost 69% of bird species and similar proportions of other types of animal species. The National Biological Inventory in the United States is now underway to improve knowledge of the species that inhabit this country and also improve the accuracy of the estimates of where they are and how many now exist (NRC, 1993). Carried out over a multi-year period, the inventory will facilitate more robust estimates of rates of species extinction.

There is no precedent within the period of human history to use in judging the potential effects of

the elevated rates of biotic impoverishment currently estimated. However, some experimental evidence shows that losses in species richness can affect key ecosystem services, especially the ability to capture sunlight and turn it into biomass, the ability to store carbon, and the ability to recover from unfavorable conditions. Naeem *et al.* (1994) manipulated trophically complex terrestrial mesocosms and found that more species-rich assemblages produced more biomass and stored more carbon dioxide than species-poor assemblages. Further, the relationship between richness and productivity appeared linear, yet there was no similar relationship between species richness and other important ecosystem services such as nutrient retention, decomposition, or water retention. In addition, a summary of work presented at the SCOPE Global Biodiversity Assessment Synthesis Conference in February 1994 reports the work of David Tilman and John Downing on prairie grasslands -- more species rich plots were better able to recover from drought (Baskins, 1994).

At this point, the database is too sparse to identify any crucial threshold in species richness or any general pattern between species loss and ecosystem functioning. Perhaps each species contributes incrementally to the functioning of the system or perhaps some species are redundant, i.e., duplications whose loss would not be critical. However, without knowing which of these relationships apply or how many species are being lost, a threshold in species loss could be passed without the scientific community even being aware of the event. This possibility concerns a number of people in species-rich Amazonia itself, as well as elsewhere in the world. Nevertheless, it would be misleading to characterize this situation as a matter of deep general concern. It is difficult for the average person to see how loss of species in a distant part of the world will affect his/her own future in any direct or important way. Much of human society thinks of the many individual contributors to biodiversity as pests, weeds, disease carriers, or things that bite, scratch, or are in other ways annoying. Most of human society either does not appreciate the functional roles of various species as part of a complex operating system and must be persuaded that many species are necessary to work efficiently.

New Habitats

Human societies have created new habitats quite different from those in surrounding areas and often different from anything that has existed before. For example, masses of heat-holding concrete and asphalt, a dearth of plants, and the lack of open waters in cities have been found to result in 10-20 F differences in temperature between cities and surrounding rural areas in summer (e.g., Akbari *et al.*, 1992). Some studies have linked local climate change from urban heat islands to local extinction of animals (Baur and Baur, 1993). Urban heat islands have also been blamed for skewing temperature measurements, thus leading to unwarranted conclusions about global temperature trends. Because urban environments present so many formidable obstacles to the survival of most species (e.g., little water, wide temperature swings, little plant life, concentrated pollution, etc.), the species that survive will be those opportunistic and communal species simultaneously tolerant of all these anthropogenic alterations. Obviously, the more individual stresses to be dealt with, the fewer species will be tolerant to all. Erwin (1991) has suggested that little more than weeds, flies, cockroaches, and starlings may be left in these extremely modified habitats.

Modifying Biogeochemical Cycles

While the inevitability, magnitude, and consequences of global warming are debated, there is much consensus over anthropogenic increases in atmospheric carbon dioxide and methane levels and the presence of novel chemicals in the atmosphere. Both natural and anthropogenic activities contribute to the movement of carbon dioxide, methane, and nitrous oxides back and forth from fuel and air and soil and water and plant and animal. Obviously, a great change in one rate can affect the others, with poorly anticipated secondary effects.

Hydrologic cycles have been modified extensively by human intervention, not only in rivers (i.e., dams, levees, storage basins, canals, etc.) but by deforestation, wetland destruction, and creation of impervious surfaces such as roads, parking lots, and roofs on houses. These structures and activities result in pulses of water in rivers following rainfall that are quite dissimilar from broader natural

pulses both in amplitude and duration. Even with human intervention, floods occur. Smith (1994) notes that forecasting and water management problems demand an interdisciplinary approach. However, he also notes in the same article that one of the causes of the flooding of the Mississippi River in 1993 was global anomalies in atmospheric circulation. This observation is important in a number of ways, but, for the purposes of this discussion, there are two: (1) global changes can affect human society's relationship with an ecosystem, such as the Mississippi River, in a major way, and (2) however robust the models developed, there will always be some uncertainties that could produce misery for those taking the risk of putting dwellings, etc. on the floodplain itself.

Environment as a Selective Force

In what ways has the environment presented a strong selective force to human society? In the most basic sense, life on the planet has evolved to function at certain gravity, pressure, atmospheric gas compositions, etc. Gross and immediate changes in these factors certainly have adverse effects on organisms, as shown from experimentation in space. On the local level, the environment still presents strong selective forces and pressures in the form of famine, disease, or habitat destruction from natural causes such as flood, fire, tornado, earthquake, and volcanic activity. Human society uses all the technology it can muster to mitigate these factors.

Limits to Population Growth?

The human population continues to grow at an unprecedented rate. Most growth is in developing countries south of or near the equator, and the rate of population increase in developed countries is, by present day standards, relatively slight. However, Myers (1994) notes that there is now a much broader consensus in science that population is a problem.

The relevant term from basic ecology in the discussion of local population growth is **carrying capacity**: "The size at which a population stabilizes in a particular place is defined as the carrying

capacity of that place for that species" (Raven and Johnson, 1986). Carrying capacity depends both on the number of users and the intensity of per capita use (Odum, 1992). While there is no evidence that the basic concept does not apply globally to humans, its relevance locally is obvious and unpleasant. Density-dependent limits on growth, such as the availability of food and potable water and disease transmission, provide strong selective pressures, but these limits have been extensively modified by human engineering. There are also density-independent limits to carrying capacity, such as earthquakes, tidal waves, and volcanic eruptions. While climate change has historically been a density-independent limit, per capita contributions to global warming may change it to a density-dependent limit. Contrarians have challenged the applicability of the carrying capacity concept for global human populations by pointing out its changeable nature locally through trade and other technology (Bailey, 1993). However, carrying capacity is never a static line in the sand; it changes as limits change. The green revolution, basic sanitation, and modern medicine all changed carrying capacity by modifying density-dependent limits. Global warming, salinization, soil loss, and pollution may modify both kinds of limits.

Still, instances in which carrying capacity is locally exceeded are an unpleasant and too common occurrence; one response is to flee. Myers (1993a,b), Trolldalen *et al.* (1992), and Westing (1992) have described the problem of environmental refugees. Myers estimates that there were at least 10 million environmental refugees compared with 17 million other refugees caused by political, religious, and ethnic conflict. It is worth noting that the United Nations and individual countries have been notably unsuccessful in stabilizing any of these situations, although, in Somalia, starvation was temporarily alleviated at enormous economic and military costs. This loss of stability in human society and the brutality so commonly associated with it has, in Africa, caused deterioration of already scarce habitat for gorillas and other species that resulted from mass movements of people into areas ill equipped to accommodate them. In areas of Africa that are comparatively stable politically, poachers have caused serious reductions in populations of large animals already in serious decline. Myers (1993a) mentions that the gravest effects of climate change

may well be those on human migration as millions of persons are displaced by shoreline erosion, coastal flooding, and agricultural disruption.

The United States and many other developed countries have another type of environmental refugee -- those affluent individuals choosing to live in areas comparatively unaltered by human society. These affluent environmental refugees may be doing considerable cumulative damage to the integrity of natural systems by picking relatively wild areas and altering them by building roads, power lines, sewer lines, and water lines.

When the carrying capacity question is asked in a global rather than a local context, it is transformed into a new question about limits to human ingenuity given a fixed ultimate energy source: solar input. Many people believe that technological progress can ameliorate limits for an extended time, and, indeed, there are foreseeable technological fixes that could conceivably expand the carrying capacity of the earth. For example, the next agricultural revolution might be facilitated by genetic engineering of more efficient food crops. However, the raw material for genetic engineering is biodiversity. Scientists can move genes, but they cannot make them. If current rates of species loss are unabated, most of the raw material for genetically improved foods, fuels, and pharmaceuticals are lost with them. Thus, disparate parts of the global change picture interact in unpredictable ways. •

The ultimate existence of limits seems hard to dispute given the fixity of solar inputs, but the timing for reaching those limits can be predicted only with uncertainty.

Ecosystem Services

Natural systems provide many services to human society either free of charge or with minimum management effort. These have been touched upon throughout this discussion but deserve more explicit attention. Examples of such ecosystem services (e.g., Westman, 1978; Wilson, 1988) are:

1. the capture of solar energy and conversion into biomass which is used for food, building materials, and fuel.
2. the decomposition of wastes such as sewage.
3. the regeneration of nutrients in forms essential to plant growth (e.g., nitrogen fixation).

4. the storage, purification, and distribution of water (e.g., flood control, drinking water purification, transportation, etc).

5. the generation and maintenance of soils.

6. the control of pests by insectivorous birds, bats, insects, etc.

7. the provision of a genetic library for development of new foods and drugs through both Mendelian genetics and bioengineering.

8. the maintenance of breathable air.

9. the control of both microclimate and macroclimate.

10. the provision of buffering capacity to adapt to changes and recover from natural stresses such as flood, fire, pestilence.

11. the pollination of plants, including agricultural crops, by insects, bats, etc.

12. aesthetic enrichment from vistas, recreation, inspiration.

These ecosystem services are essential to the human quality of life. If natural systems are no longer able to provide these services, they will have to be replaced through human engineering. Currently, society is unprepared to do so. In Biosphere 2, the cost of providing these ecosystem services through human engineering was a staggering \$9 million per person per year (Avisé, 1994).

These ecosystem services have been characterized as environmental interest — they are the payoff for maintaining environmental capital (i.e., the structures of natural systems). The economic analogy continues — if one dips into capital by destroying wild habitats, a loss of interest can be anticipated. Present knowledge of the ecosystems delivering these services is not sufficiently robust to enable a reasonably reliable prediction of what the consequences will be in delivery of services if 10%, 15%, 35%, or 50% of the earth's present habitats or species are lost. Neither does society know the degree to which managed systems supply ecosystem services comparable to natural systems. In addition, at the same time that environmental capital is being replaced with very different structures, human population is growing. The consequence is that the amount of ecosystem services per capita is plummeting.

The term **sustainable use** is common these days, and the conditions for attaining this state have been defined in broad strategic terms (Huntley *et al.*, 1991; Lubchenco *et al.*, 1991; Risser *et al.*, 1991). For example, Huntley *et al.* (1991) include, under sustainability, equity and coexistence with other species and components of mankind's heritage in a biologically and culturally diverse world. The ecological research agenda to support this has been summarized in Lubchenco *et al.* (1991) and Risser *et al.* (1991) and prioritizes research to understand changes in climate and its effects on ecological processes, patterns and interactions with biological diversity, and breaking points at which ecological systems are no longer sustainable. An example of the various degrees of sustainable use is provided by Stickney (1994), who discusses the varying degrees of dependence upon hatcheries for replenishing natural stocks of fishes. He notes that this can vary from near total dependence to elimination of hatchery programs.

Of course, equating sustainable use to a set of steady-state, ecological conditions is naive. Holling (1986), Odum (1989), and many others have pointed out the dynamic nature of ecosystems and the low probability of long-term, steady state conditions. Constant adjustments must be made by human society to accommodate episodic stresses on natural systems. For example, during extremely low flow conditions, withdrawal of water cannot simply be set at the same levels as during normal and high flow periods. Sustainable use almost certainly means paying close attention to the condition and health of the system being used and not over-stressing it even if this means ceasing or reducing use for substantial periods of time. Sustainable use will also mean adjusting the $I = P \times A \times T$ equation (environmental impact = population X affluence X technology) so that the multiplicative impact of these three attributes of human society remain at a level that will not harm the integrity of ecological systems.

Coevolution in the Absence of Strong Selective Forces

Coevolution in natural systems between one species and another is often the result of harsh penalties exacted in those individuals or components that

do not respond adequately or with sufficient rapidity to alteration in the other components. In the absence of strong selective forces like famine and disease, what forces are likely to change human behavior? The coevolution of human society and natural systems will be less stressful if rapid information systems are developed to alert society to needed changes that are coupled with a sufficiently high environmental literacy to accept the necessity to make the changes before the price of not doing so has gotten too high.

People are most affected by failures in ecosystem services that are intense, local, and immediate. However, as an environmental problem increases in intensity, spatial extent, and temporal extent, it is more difficult to experience directly or personally. In addition, cause-and-effect relationships become less obvious, more uncertain, and, therefore, less likely to motivate action. These are typical features of global environmental issues. Skinner (1983) suggests that people are unlikely to change their behavior on the basis of information or advice alone. Behavioral change is even more unlikely if the information is about a distant, future, or remote event; change is more likely if information from the particular source has led to beneficial consequences in the past. As such, operant learning is unlikely to change behavior relevant to global issues (e.g., Ornstein and Ehrlich, 1989), and it may be quite difficult to change behaviors without some strong, unpleasant, concurrent pressures. Tools to change behavior using only weak selective forces include economic incentives, environmental education, and systems of ethical or religious belief.

Environmental Economics

Economic forces are a proven system for providing rapid feedback necessary to change collective human behavior in absence of strong, selective pressures on human biology directly. However, in order to promote the coevolution of human society with the natural world, the true environmental costs of human activities have to be expressly included in all economic analyses. This has not been the case to date. Instead, environmental costs have been relegated to the category of externalities; futures are discounted, natural resources (i.e., ecological capital) are not depreciated, and the economic costs of waste products are not assessed. Recent work has greatly improved the ability to include

legitimate environmental considerations in economic analyses (e.g., Costanza, 1989).

Even so, economic selective pressures cannot function if they are circumvented by governmental policies or other "social traps" (Costanza, 1987). One of the most dramatic illustrations of a failure in human cultural adaptation to a biogeochemical cycle is the continued insistence on floodplain construction in societies where alternative options are open. Without enormous government subsidies, people would not be so eager to live on floodplains. Similarly, irrigation water in some of the western states would not be so cheap if government did not subsidize both the building of dams to collect the water and the construction of pipelines and canals to transport it to places where it would not normally occur. Government has also encouraged deforestation and mining of government lands, which might not have occurred in the way it did had these lands been in private ownership. The C38 Canal dug along the Kissimmee River probably would not have been built had private funds been necessary in its construction.

On the other hand, there is some evidence that current economic systems recognize the value of some ecosystem services. Cost considerations have promoted the use of tools from natural systems rather than relying on entirely technological solutions to modify environmental selective pressures. More intensively managed ecosystem services provide an alternative, and often cheaper, method of providing for human needs. Examples include the replacement of chemical technologies by artificial wetlands to treat many kinds of wastes, such as sewage, acid mine drainage, urban runoff, etc. (Hammer, 1989). Strategic planting of trees may save 200 billion kilowatt hours annually in the United States through modifying microclimate (Akbari *et al.*, 1992). There is also some movement toward the restoration of damaged ecosystems to provide for ecosystem services lost and missed by human society. The restoration of the Kissimmee River in Florida is perhaps the best known example (NRC, 1992b). This Restoration Demonstration Project, begun in the late 1980s, looked at techniques and the feasibility of restoring some of the ecosystem services lost when the Kissimmee was channelized, such as restoring hydroperiod, water quality, and habitat for fish and birds in the Kissimmee and the Everglades. The NRC report (1992b) that summarizes this and a number of other

illustrations of restoration of aquatic ecosystems provides both guidance and inspiration for such efforts. I had the privilege to serve on the NRC committee that prepared this report and was struck by the enthusiasm and justifiable pride of all those involved with the restoration projects that the committee visited. This trend toward returning to managed, natural systems as the technological fix of choice can be seen as a form of benign coevolution between the environment and human society. Both are modified to increase chances of survival.

Environmental Literacy

Increasing environmental literacy may also affect human behavior in the absence of strong selective forces. Some questions inherent in the debates on global change are scientific: Is there a global temperature increase? Is this increase outside the normal operating range? How will this affect biotic interactions? Other questions are quintessentially political: How sure should society be before it expends scarce resources to mitigate a problem? Should society work or pay to protect other peoples, other species, future times? Who benefits? Who pays? Some of these questions are discussed in more detail below. However, clearly, in order to be able to participate in the public debate about the proper course of action, the general public needs access to relevant scientific data as well as political points of view. The shareholders in the system especially need to understand the scientific process and how it differs from other human endeavors. Yet, the environmental literacy of even the college student population seems woefully inadequate (Wallace *et al.*, 1993).

Science does not prove things, but instead fails to disprove them at some predetermined low level of uncertainty. This is in contrast to legal concepts of reasonable doubt. The quality of scientific studies is variable, and some are poor; however, when many studies from different researchers provide independent lines of evidence leading to the same conclusion, this constitutes strong evidence. When the weight of scientific evidence supports a hypothesis, every alternative does not deserve equal time or media attention. This contrasts with the equal time provision for political parties on television. When scientific information must be applied to an environmental problem that occurs

at a larger temporal or spatial scale than humans can practically investigate, models to extrapolate across scales must be constructed. These models will always involve uncertainty. For every chosen course of action, there are trade-offs: if managers are intolerant of modeling uncertainty and postpone mitigation, it implies a tolerance of risk that may be exaggerated. The appropriate levels of tolerance for both uncertainty and risk are properly part of the public debate. In addition, the uncertainties of the scientific extrapolations are often presented explicitly, while the uncertainties of economic extrapolations are hidden.

Environmental Ethos

Clearly, moral or ethical components must be included in the debate on global change, but I suspect the number of issues in this category will decrease as clear scientific data demonstrate human dependence on natural systems and the simple self-interest at play in preserving them. Ethical questions fall into several categories: Do wild systems have intrinsic value? Does society owe anything to future generations? How much should individual freedoms or properties rights be sacrificed for preservation of the common good? How much geographic and temporal equity should there be in the distribution of environmental costs and benefits? VanDeVeer and Pierce (1994) provide a discussion of some of these issues. Certainly, it is difficult to deny humans, who are living on less than \$1 per day, the opportunity to clear tropical rain forests for agricultural purposes or to deny housing for the homeless in order to prevent the loss of a single wetland.

There is evidence that communities of religious beliefs have served as the cultural transmittor of important local ecological information and have protected and distributed ecological services. Stevens (1994) provides examples of this concept. In Bali, rice temples had for centuries scheduled irrigation water rotations and planting cycles for competing farmers. These schedules were abandoned during the early introduction of green revolution techniques. However, in the presence of intervening problems with pests and insufficient water supplies, the original schedules have been found to be optimal, even with new high yielding varieties of rice. In Benin, West Africa, seasonal religious restrictions on fishing techniques

preserved the health of aquatic systems. Enlisting both the intimate knowledge of the local ecosystem and the influence of local religious institutions has proven to be an essential tool.

What Next?

Where does the coevolution analogy for the relationship between human society and natural systems lead society? In one possible pattern of coevolution, human society continues to present strong selective forces to natural systems and natural systems may eventually respond with strong selective forces. This may lead to a sharing of the planet only with domesticated species and a few other extremely tolerant and persistent species (i.e., pests) that have defied human management efforts. Because there will be little redundancy in species function left, any new pest or disease could cause severe fluctuations in food crop yields or pest control. This pattern is analogous to the recognized pattern of coevolution in host and parasite referred to as the arms race (Thompson, 1986) — the host develops some defense against infection and the parasite counters it and becomes more virulent, etc. Odum (1992) has also suggested the parasite-host model for the interaction between man and the biosphere. However, he points out that the most successful parasites reduce their virulence and establish some rewarding feedback that benefits their host to survive over the long term. Otherwise, the demise of the host means the demise of the parasite as well. In addition, as resources become strained (and humans already appropriated nearly 40% of the products of photosynthesis a decade ago; Vitousek *et al.*, 1986), mutualism, in which both partners benefit, becomes a more effective strategy for survival. Mutualism would require tempering the strength of the selective pressures and responding rapidly to changes. Human society could temper their virulence and respond quickly to changes in natural systems by establishing feedback loops. The current attention to a biomonitoring system for ecosystem health in one approach to developing this feedback loop (Costanza *et al.*, 1992).

While human culture will continue to respond to strong selective forces such as famine and disease, the pattern of coevolution cannot be shaped by weaker selective forces if they are obscured by

imperfect cultural devices. Many of the changes currently proposed in the environmental economics and green engineering address these shortcomings. John Cairns, Jr. and R. M. Harrison summed up some of the changes that will foster mutualism between natural systems and human society in their revised foreword to the Chapman and Hall Environmental Management Series, for which they are co-series editors (statement reproduced with permission of Chapman and Hall):

Focus is now shifting from the toxicological aspects of waste disposal to the larger issue espousing a transition to new resource use policies that: conserve natural resources and energy for long-term sustainable use; minimize ecological damage during the extraction of raw materials; minimize wastes during production and recycle as much as possible of the wastes produced; facilitate the re-incorporation of the product into natural systems at the end of its life cycle; use wastes from one production process as inputs (i.e., raw materials) in some other production process (e.g., municipal sludge to agricultural production). There is a concomitant shift from merely preventing observable deleterious effects from potentially toxic materials to enhancing ecosystem health and condition.

While wild systems must always be valued and maintained, it is where human society and complex ecological systems modified by humans co-exist that we need to spend more time working on a mutually beneficial relationship.

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CONSERVATION, The Answer To - MEETING SOCIETAL RESOURCE AND ENVIRONMENTAL REQUIREMENTS FOR THE 21ST CENTURY

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If the answer is "Conservation," then what is the question? One possible Question, "What is the best utilization of our resources - resources of all kinds?" Or perhaps it is a question of priorities - "How do we choose among comfort, economic, and environmental conditions. Or perhaps conservation is not an answer but a description of actions that require wise use of resources. The question then becomes not "What" but rather "How."

We must first understand and quantify, to the extent possible, our resource systems. Surveys and census data are abundant. Programs to gather ground-truth data have provided vast data sets as to soil, near-surface materials, and topographic characteristics. Modern remote sensing techniques are being developed that classify characteristic patterns of vegetation and current land-use. However, these efforts are largely two-dimensional and lack the depth of characterization provided by earth scientists. These data need to be assimilated into broader geoscience formats that will form the basis for conservation of our integrated resource systems.

A priority will be to establish the status of the resource base (natural, people, economic, and environmental). This will include a geoscientific evaluation of the natural resource system:

- ◆ its sensitivity to utilization,
- ◆ current and potential environmental impacts,
- ◆ potential type and level of development, and,
- ◆ the type and level of stress that might be placed on the system.

This compilation of data can then be integrated into the broader aspects of societal wants, needs, requirements, and cultural priorities.

One of our most valuable resources is space - space on the surface and near-surface of our planet. And it is the characteristics of this space that will control our societal actions. Thus, control of this space through land-use policy will be the mechanism for establishing conservation of our resources. The scientists responsibility is to participate in both the compilation and interpretation of data and the implications of imposing the various options of land-use regulation and policy. Conservation of our resources can only be achieved by effective and acceptable land-use practices, acceptable to the scientist, to government, and to society in general. It is only within this framework that we can meet societal resource and environmental requirements for the 21st century.

AN EMERGING SOCIETAL ROLE FOR GEOSCIENTISTS

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Societal needs for resources in the 21st century will be based initially on comfort, economics, and environment. Fundamental to these objectives is an understanding of the resource base and how it should be conserved, conserved in the sense of wise utilization. To carry out a program of "resource conservation" by effective and acceptable actions and policies will require a number of accomplishments by geoscientists. 1) We must learn to at least coordinate, if cooperation is difficult, with many different audiences with highly varied agendas. 2) Geoscientists need to reclaim the image of "environmentalists" from those who actually espouse the theme of "preservationists". 3) We must seek "Common Ground" for our programs.

1) Many issues of resource utilization quickly move to confrontational and litigious arenas. Economics may be a factor but more often it is contrasting philosophies that create divisiveness. As geoscientists we should occupy the high ground whenever possible and represent the natural resource systems. Competing users and savers must be bound in their commitments by the capability of the resources over time. Conservation, wise use of the resource including non-use, may form the basis for conciliation. Geoscientists can delineate this framework of mineral, animal, vegetable, and particularly space.

2) Few people are more intimately familiar with our natural environment than geoscientists, particularly a field scientist. By training we are comfortable with perceiving an issue in at least three and probably four dimensions. We are capable of conceptualizing not just the short-term societal gain but also the long-term impact on the resource base. Concepts of multiple use, reserve establishment, and wilderness areas need to be considered as evolving policies not just immediate decisions. Every decision will have an impact on the natural resource system. As geoscientists, we should provide the factual base that delineates these impacts.

3) We must strive for common ground - common in both the sense of consensus and in an acceptance that much of our resource system will be common ground rather than privately controlled. More and more of the land-use decisions are controlled by regulation and legislation. And it is by control of land use that control of resource utilization is achieved. Geoscientists must be a part of this "decision for the common good" process.

What geoscientists can do

Participate, particularly in arenas where attitudes differ from your own.

Prepare, know the issues, both the real and perceived.

Collect, the background data that more fully delineate the issues.

Cooperate, utilize your expertise to contribute and perhaps improve the current attitudes and opinions - It is much more effective to modify than to confront.

Anticipate, what are the pending issues, policies, conflicts that will impact the utilization of our resources.

Educate, take every opportunity to communicate the characteristics of our natural resource systems and their possible reaction to development.

Negotiate, so that the real winners are the resources.

Innovate, find solutions that others, less familiar with the resource systems, might have overlooked as acceptable actions.

Stimulate, your fellow geoscientists both individually and through the professional organizations to enlist as participants in the policy area of their choice.

All areas of society must take responsible action to determine the appropriate programs for societal resource and environmental requirements in the 21st century. The geoscientist must effectively represent the natural resource system in this process.

Natural Resource and Environmental Management Issues and Geologic Decision-Support Tools

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Natural resource and environmental management issues require translation of complex scientific and technical information so that public policy officials and the public may understand and use earth science information. Documents that translate such information are geologic decision support tools. For example identification of conflicts between natural resource and environmental management issues and the need for aggregates in an expanding metropolitan area may be assisted with a map showing lands for potential mineral resource development. Such a derivative map can be rapidly produced using a geologic map. Watershed management and planning issues related to stream protection and restoration, flood forecasting, water supply and water quality require data collection networks such as stream gaging networks, a tool used to collect water flow and water volume data. Nutrient loads in streams, a key environmental issue, may be more accurately predicted using two tools, a physiographic map to define hydrologic response units, and SPARROW, a newly developed modeling technique. Geologic decision support tools such as these, and the systems that develop them, are critical in addressing many natural resource and environmental management issues.

THE RESOURCE INDUSTRY AND SCIENCE: THE INTERFACE

A POSITION PAPER

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One of the critical ways that we will meet societal resource and environmental needs will be through ensuring a continuing supply of good graduates able to do outstanding R&D.

As an industry at the leading edge of science, technology and engineering, the resource sector, more than most, needs ready access to world class research and technology. In recent years there have been a number of profound changes in the way that R&D is delivered.

In the past decade or so, there have been profound changes in the way that research is undertaken by the petroleum industry. For many years, science and technology was delivered through the medium of the in-house research and development facility. There were several reasons for this, including tradition, but probably the prime reason was that research and development was seen to provide the competitive edge to the company. As such, it was considered essential to retain control of the proprietary scientific information that provided that edge for as long as possible.

That model no longer applies to the same extent for a range of reasons, including pressure on costs, outsourcing and globalization.

Along with the pressures of cost reduction there was also a round of takeovers and mergers, resulting in the combining of R&D groups and again the inevitable overall decrease of in-house research effort. I am not saying that this was necessarily a bad thing, and indeed, it may well have resulted in more cost-effective science. But it inevitably resulted in loss of in-house research capacity in the industry overall. In response to this net research loss and the need to stay price-competitive, there has of course been a trend to "buy-in" much of the research and technology innovation, whether through outsourcing or contracting out.

The benefits of this external approach to R&D delivery are two-fold. Firstly, it is less costly to the company, and secondly, and more importantly, it carries with it the opportunity to more readily access a much wider range of external ideas and expertise.

Is this major change of philosophy in the delivery of research and technology sustainable in the long term, or are there inherent problems in the outsourcing approach? Paradoxically, the answer to both of these questions is yes! Yes, it is sustainable, but yes, there are potential problems. It is only sustainable if we address these problems.

There can be no doubt that the present outsourcing strategy will work for the petroleum industry for a time. There are experienced and bright research-oriented scientists and technologists about, with a good knowledge of company priorities, for they have often been trained as employees by the same companies which now use them as external research consultants and contractors. Also, there are many new technologies in existence or in the pipeline as a result of previous proprietary research and development. But unless positive action is taken, "outsourced" scientists and technologists can become progressively de-skilled and outdated in a relatively short time if they are cut off from a research environment in a company, university or research organization. If this happens, then they cease to be useful to the industry and society.

The solution to this potential problem is commonly seen to lie in informal "networking" between researchers or through attending professional meetings and courses, and there can be no question that these may well provide part of the answer. But serendipity and informal networking will not meet the science and technology needs of the resources industry and society for more than a few years. It certainly will not produce a future quantum leap in our knowledge, or the development of a new paradigm of the type that has played such a major part in innovation and industrial development in the past 20-30 years.

But if outsourcing of research and development is here to stay, and I suspect it is, how then do we maximize the undoubted benefits of more open access to research and technology innovation and minimize the problem of short-termism, instability and a lack of in-house research capability? Indeed, how does the petroleum industry retain the capacity to know what scientific questions to ask if it no longer has a research capacity and is driven by the immediate and urgent needs of exploration or production? The answer has to lie in providing a comprehensive, well-defined and stable structure to a scientific and technological network involving government, the universities and the petroleum industry that will allow a strategic approach to be maintained.

The long-term nature of oil and gas exploration and production, and mineral exploration, with perhaps a 20-year payback period on the science that paved the way to the major commercial discovery, does not lend itself to a "hired hand" sort of approach to research. Excellence in research and technology must be carefully nurtured over a long period. But this does not mean that the nurturing has to be done

in an ivory tower separated from the industry. In fact, quite the reverse. It is best done within a science network in which the industry is fully engaged. But the network has to have the right structure plus a financial base that provides stability, so that in addition to the more tactical medium-to short-term projects, we can also pursue necessary long-term research free from fluctuations in the price of a barrel of oil, or other short term commercial issues. But at the same time researchers must recognize that they will not be given a blank check by the industry. Their research must not only be of a high level and relevant, it must also be cost effective. It has to also be said that neither research, nor its exploitation, can be based on the assumption that there will be a real and sustained increase in the price of oil.

The other trend that has also profoundly affected the conduct of research and technology innovation, is the phenomenon of globalization. The global resource company can decide to have all of its research undertaken by the research group back in the home country of the company. This approach may be effective for some global and generic issues or for developing a new technique that has the potential to be universally applicable. But there are many times when this approach is not successful. Reasons for this may include lack of local knowledge, an insular approach to the problem, or a tendency to try to apply a generic approach when it is not appropriate. Understandably, there can also be resentment within a country providing the resource which is excluded from the research or technology development on which the future of the industry in that country may depend. In fact, as a result of outsourcing and downsizing, this is probably not a major issue as few companies now have major in-house R&D capacity.

A global approach to science and technology brings with it the potential for a company to source the best research advice, wherever it exists in the world. This provides an enormous incentive for the industry to ensure that networks of research providers are truly global and wholly inclusive, so that the entire range of experience, expertise and ideas can be accessed by the industry. There is a further benefit from this to the researchers themselves: Yes, on occasions, they may be subjected to the harsh world of competing against researchers in other countries to obtain funding, but this also means that they are benchmarked against other groups, thus providing a clear measure of whether their science is internationally competitive in terms of quality or effectiveness.

Therefore the changes that have occurred in the delivery of science and technology to the industry have resulted in a number of benefits for the industry. But there is no guarantee that these benefits will be maintained or meet the long-term needs of industry if we adopt a totally laissez-faire attitude. What it needs is much closer R&D cooperation between industry, government and the universities. We need to consider how best to achieve this?

THE PETROLEUM INDUSTRY AND CO2

A POSITION PAPER

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There is by no means universal agreement on the role of CO2 and other "greenhouse" gases in global warming. Despite these and other uncertainties, there is increasingly a view within the petroleum industry that it must play a more proactive role in the issue. Symptomatic of this is the opinion expressed by John Browne, Group Chief Executive of BP, who commented in a speech to Stanford University in May 1997 that "The time to consider the policy dimensions of climate change is not when the link between greenhouses and climate change is conclusively proven but when the possibility cannot be discounted and is taken seriously by the society of which we are a part. We in BP have reached the point." In other words, BP (and other companies) are considering what precautionary action should be taken right now. The other recent event which will have a profound impact on the oil and gas industry is the Kyoto conference on climate change, and the international agreements reached at that meeting on limiting CO2 emissions to the atmosphere.

Drastically cutting the use of fossil fuels is not a solution to the CO2 problem in the short term, given the profound and unacceptable impact that this would have on the global economy. But the industry, in the partnership with government and the research community, must together consider the issues and look for potential solutions, so that rather than being seen as one of the villains in the piece, the petroleum industry and particularly the gas sector could be seen as a leader in cutting CO2 emissions.

Compared to other industries, the petroleum industry generates much of its CO2 at point sources, whether at the wellhead, the LNG plant or further downstream, at the power station. Therefore, in some ways collection of CO2 is less of a difficulty to the sector than it is to others. What is, of course, a problem, is how to dispose of that CO2 once it is collected. We must now start to think more creatively about how to dispose of CO2 and other greenhouse gases. Options include "geological disposal" by injection into aquifers, ocean disposal, re-use in power generation and the chemical industry and various forms of "offset". Emissions trading and no doubt many other "schemes" will require geological input. Are we as earth scientists turning our minds to these issues and are we being sufficiently active in the debate? Whilst there are some notable exceptions I suspect that overall we are not.

THE ROLE OF THE EARTH SCIENCES IN SUSTAINING OUR LIFE-SUPPORT SYSTEM

A POSITION PAPER

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The complex interplay between physical, chemical and biological processes, whether at the micro, macro or global scale, requires that we take a holistic approach and examine total systems rather than just one or other element of the system. Human activities are for the most part just normal physical, chemical and/or biological processes yet, at the same time, they can have some distinctive features compared to natural processes, in particular the speed or the scale at which they may occur. Additionally, there are some materials, for example certain chemicals, and increasingly certain genetically modified biological materials, which are entirely or largely the consequence of human intervention. Therefore it is not unreasonable to see human activity as a distinctive process which has some unique features and consequences. Together it is the interactions of these four processes, physical, chemical, biological and human, which not only define the form of processes but also the long-term viability or sustainability of processes and their consequences. The earth sciences are pivotal to understanding the interaction between these processes because earth materials are themselves a consequence of those same interactions and processes. In some cases the intervention of human activity is of no consequence either because that activity is compatible with the natural world or because it is miniscule in scale compared to natural processes. However, in some cases the impact of human activity is so profound that it may call into question the sustainability of a natural process, an ecosystem or life itself.

The concept of sustainability is perhaps flawed to some extent by the fact that there is no attempt to build a time scale into the concept other than the mention of future generations. If we consider renewability we could argue that, given enough time, all resources will be renewed and therefore, in theory at least, their exploitation is sustainable. But to try to set sustainability within geological time is disingenuous and we must surely see sustainability within a human time frame which could be as little as tens of years or as much as thousands of years. Set against this time frame the present generation becomes much more accountable for its actions.

As an example of the difficulties in doing this let me illustrate the problem of adopting a long-term holistic approach to energy issues.

The impact of the use of fossil fuels on the atmosphere (increasing CO₂, acidification, particulates) is well known. But it is also a critical element in enabling us to produce the food to feed the world's population (through intense farming: transportation of farm products, powering of water pumps, land reclamation and clearance), and providing domestic water. It has also decreased the dependence of parts of the world on wood thus not only decreasing the over-exploitation of forests but also the soil and coastal erosion consequent on that over-exploitation. But it can be argued that the energy does not have to be derived from fossil fuels with solar power providing the ultimate sustainable power. But if this were a practical option (and it is not at the present time), it could have a profound impact on mineral exploitation and usage, which would lead to significant environmental impact through dumping of used materials unless they could be fully recyclable. The issue of recycling is an important one, particularly for minerals, it would in effect add an extra sliver of "reserves" to the total picture. But for this to be effective, all manufactured products, whether concretes, alloys or car components, need to be designed with their recycling capability in mind, if recycling is to be done with minimal loss of the commodity and minimal use of energy. Also where there is waste it should be as benign as possible. This philosophy is starting to be accepted and the earth scientist must be ready to play a role from the point of view of the "design" of the full life cycle of the commodity, because there is likely to be a need for earth materials with new specifications.

At the broader (global) scale the earth sciences are needed to determine global physical and chemical fluxes, reservoirs, pathways and sinks; to consider these on time scales ranging from decades to millennia and on scales of magnitude ranging from the micro to the macro and global, and to separate out anthropogenic from "natural" or pre-anthropogenic rates and processes. But more than this, the earth sciences can also provide some of the answers to many of the sustainability issues now facing us. Whilst there are many serious issues impacting upon the sustainable use of the Earth's resources, there is every reason to believe that solutions will be found, not least by the earth scientists. Some of the issues we must keep in mind in seeking those solutions are as follows:

We must plan on global growth but work to minimize its impact.

The sustainability of our life support system depends on an extraordinarily complex interplay of factors affecting the availability and use of water, air, soils, land, energy and minerals. Geoscience is a key to this understanding and this will require better documenting, surveying, monitoring, modelling and understanding of the system as a whole.

For most people the important sustainability issues are not availability of metals or oil but access to clean water, good soils, adequate building materials and a secure place to live. Geological education and values must reflect this and educators must be prepared to move well outside the traditional approach to geological education, in particular placing much greater stress on surficial geology, urban geology and hydrogeology.

Interdisciplinarity and effective networking are essential to the future of the earth sciences, particularly as some of the major resource companies “downsize” and “outsource” their science, thus placing greater reliance on external expertise.

A narrow short-term market-driven approach underlies many sustainability problems; a broad-scale long-term market-driven approach may provide answers, but this must take into account principles such as intra/inter generational equity, polluter-pays, proper natural resources accounting, appropriate returns to the public and the rights of indigenous people. Earth scientists must be prepared to proselytize, communicate and speak out on such issues.

Politics is short-term, whereas resource and environment issues are long-term. Consequently we must ensure that robust institutions exist, notably national geological surveys that are able to undertake long-term strategic geoscience mapping, surveying, monitoring, databasing and underpinning research and development in association with academia and industry.

The important geoscience challenges of the future are likely to be found in inner city areas, waste dumps, low-cost bulk-commodity quarries, over-exploited farmlands, polluted rivers and coastal swamps rather than in the beautiful mountain settings that lured many of us into geology in the first place.

**CRUDE OIL AND ALTERNATE ENERGY PRODUCTION FORECASTS
TWENTY-FIRST CENTURY
UNITED STATES AND WORLD
THE END OF THE HYDROCARBON ERA**

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ABSTRACT

Predictions of production rates and ultimate recovery of crude oil are needed for intelligent planning and timely action to ensure the continuous flow of energy required by the world's increasing population and expanding economies. Crude oil production will supply increasing demand until peak world production is reached. The energy gap caused by declining conventional oil production must then be filled by expanding production of coal, natural gas, unconventional oil from tar sands, heavy oil resources, oil shales, nuclear and hydroelectric power and renewable energy sources (solar, wind, and geothermal).

Declining oil production forecasts are based on current estimated ultimate recoverable conventional crude oil resources which are 329 billion barrels for the United States and close to 3 trillion barrels for the world. Peak world crude oil production is forecast to occur in 2020 at 90 million barrels per day. Conventional crude oil production in the United States is forecast to terminate by about 2090. World conventional crude oil production will be close to exhaustion by 2100.

Sustainable world energy consumption will then have to depend on solar, coal, nuclear, and other renewable energy sources. Stabilization of world energy use is forecast to begin during the second half of the next century a world population begins to stabilize, efficiency of energy use continues to increase and conservation becomes a new paradigm. Policy changes can induce behavior and steer the economy away from ultimately inferior paths to directions that are in the best interest of society at large (Solow, 1974). Increased investments in new technologies for the development of renewable energy sources are needed now to ease the path to a sustainable global energy supply.

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As a person who has degrees in earth science and geology and then went on to a Ph.D. in ecology, I am very interested to attend this conference and learn how these sciences are interacting at a national level of science and policy. As an educator, I am also interested in exploring with other participants how to more effectively communicate ideas of finite resources to student audiences that have never experienced a resource crunch. Half of the students I teach now are born in the 1980s and have no first hand knowledge of war-time scarcity or the energy crisis. They are trained to be voracious consumers from an early age, and by the time they are in college, hard to convince that there are resource challenges they should care about. Finally, I teach a summer travel course concerned with the interface between science and public lands policy in Utah, currently on the hotseat in regards to wilderness designations, oil exploration in the new Grand Staircase-Escalante National Monument, and large scale mining and grazing operations that appear unsustainable. I look forward to new insights from our conference that I can share with my students.

The dilemma of the geologist: Earth resources and environmental policy

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ABSTRACT

American environmental policy has developed over the last 25 years under a preservation ethic, which is a dilemma for geologists who must explore for and develop earth resources for society. Geologists have a professional responsibility to provide the earth resources, upon which society absolutely depends, in a society that values unspoiled scenic vistas more than the earth resources they contain. Recent federal elections have amplified public debate over the appropriateness of current environmental laws and policy. Impacts of environmental preservation policies are seen in a decline in standard of living, in lack of consensus on priorities, and lack of science in risk management. In order to sustain society's needs for earth resources, we must reexamine our stance about environmental standards, and develop a holistic approach to balancing societal needs for resources with societal desires for a pleasant physical environment. Human health and safety should be our most important goals; recreation and esthetics are of lesser importance to most of the world's population.

THE PROBLEM

Environmental policy and law in the United States have been driven by a preservation ethic for more than 20 years but have come under increasing criticism in the last few years for perceived excesses detrimental to personal property, individual rights, and economic progress. Many of these issues are being fought out in the Congress and in court as this is written. Rhetoric on both sides is strong, but the media, which had favored environmental preservation, are now more equitably examining issues and effects (Ward, 1993).

In recent years grassroots organizations favoring individual rights, private property rights, and resource conservation have risen to challenge environmental preservation organizations in the legislative process. Legal challenges to environmental groups and assessment of litigation costs for frivolous complaints are now being instituted (The Anchorage Times, 1993). Questions about cost/benefit ratios and special interests now are routine, and there are frequent challenges to soft or poor science underlying popular issues. Zealots and their excesses have pulled the entire environmental movement and its hard-fought gains under scrutiny. Some of these gains have been unquestionably good for

the nation and all its people, but there is a backlash as fringe groups strive to press their agendas upon an increasingly perceptive and unwilling public. Congressional review of major environmental laws at any time may either improve the effectiveness of the legislation or simply change direction and focus of environmental law.

In consequence, it is absolutely necessary to reestablish the basic tenets of a national environmental policy that preserves an acceptable quality of life for all of American society in its equations of cost and benefit. National environmental policy must satisfy generally accepted norms for it to be successful, norms that include opportunities for citizens to be economically upwardly mobile, that create jobs for those who wish to work, that provide a realistically healthy life environment for all, and that provide a breadth of recreational opportunities accessible to all. Our national policies now conflict with these norms.

Further, our environmental policies must be science driven rather than agenda driven. Misleading science has no place in public policy. Science that is the basis of regulatory action must be separated from the regulatory actions themselves. Law that is contrary to science can not be tolerated if we are to keep public faith and support for sustaining the physical environment to

which we aspire. We must confront inaccurate science, half-truths, and mistruths.

Geologists are the forefront of these issues because we are largely responsible for providing the earth resources upon which society is sustained, yet we find ourselves ever increasingly limited in where we can explore for and develop the energy and minerals the nation needs.

Five major areas of weakness are present in national environmental policy: (1) there is a lack of recognition of societal needs for earth resources to preserve the standard of living; (2) there are no established environmental priorities; (3) there is no consensus on environmental standards; (4) environmental policy is fractured by spurious issues, suffers from inflation of issue significance, and accepts direction by special interests; and (5) effective environmental action requires higher quality and more holistic science than now attained.

Let us examine some issues the American public must understand if we are to develop a rational and useful national policy. While I anticipate much debate about what is included in this conceptual base, it forms a nucleus about which to crystallize our debate.

LACK OF RECOGNITION OF SOCIETAL NEEDS FOR EARTH RESOURCES

The very fabric of society is rooted in earth resources, but there is no widespread public understanding of the relationship of standard of living, earth resource wealth, and costs of environmental policy. Earth resources are not accorded the significance in policy that they play in sustaining the economy and our social fabric. One reason for this lies in the divorcement of the American people from their earth resources: land, water, minerals, energy, agriculture, and forestry. Increasing urbanization has created a separation between resource use and understanding of resource origins. Little connection is made by "Aunt Sophie" between turning on her television set and mining coal; dressing in new man-made fiber clothing and drilling oil wells; or eating a bounteous meal and making fertilizers, products of those same oil wells. Many years ago we farm kids laughed at city kids who thought milk came from bottles in grocery stores. We did not correct then the problem of source and product divorcement, so now we reap conflict over resource access.

Why worry? I worry because the basis of American wealth that provides our standard of living is the monetary value of extracted American earth resources, plus the value added to these resources through manufacturing. The relationship can be expressed as:

$$S_{ol} = W/P$$

where S_{ol} = standard of living, W = national wealth, and P = population (Gerhard and Puderbaugh, 1993).

Limitation of national access to earth resources—be they water, timber, farmland, minerals or energy resources—assumes that the limitations will mean that fewer of the

resources are used (Gerhard and Weeks, 1996). In fact, limitation of access and increased costs of value-adding simply substitute foreign earth resources for our own, and transfer American wealth elsewhere to pay for the substitution. Thus, the term "W" does not increase as much as it would if the access were unlimited. Population continues to grow, that of the United States growing from 125,000,000 to over 257,000,000 in my lifetime, from the mid-1930s to the present. The United States has managed to increase its wealth in proportion to its population growth until recently. The ratio is declining, and this reflects in a lessened rate of increase in standard of living. When coupled to the trade balance figures of the same years, there is an absolute decrease in standard of living indicated for the United States (Figs. 1, 2).

The obvious consequence of this change in standard of living growth is a reduced standard of living for the already financially disadvantaged of America. The effects of increased costs of resource access, environmental regulation, and importation fall most heavily on those least able to afford it; in effect, the environmental movement has become regressive. "Environmental racism" is a term frequently used in nonscientific literature to refer to siting of potentially environmentally hazardous or unsightly facilities in minority neighborhoods. Brimelow and Spencer (1992) argue that the early 1990s cost of environmental regulation by the Environmental Protection Agency (EPA), using EPA's own estimates of cost, was about \$450 per person per year, with dramatic increases into this decade.

Our social fabric depends on continuation of our standard of living, despite arguments that the standard is too high. Too high for whom? Perhaps the financially advantaged will wish to voluntarily give up some of their toys, but an ever-increasing financially disadvantaged class who cannot find new jobs when displaced by the depressed economy, who have never found a stable job, and who live on taxpayer largesse have nothing left to give. I cannot address the unequal distribution of wealth in this paper, but it must be part of our environmental equation.

At this writing the national debate about balancing our federal budget rages. We cannot balance a budget without cutting social programs or increasing revenues. Current environmental regulations stifle economic progress and depress revenues, perhaps rightfully, but they are now viewed by many as part of a national problem.

ESTABLISHING ENVIRONMENTAL PRIORITIES

There is no prioritization of environmental issues in national policy today. Each group, each interest, devotes its energy, time, and resources to narrow and often counterproductive issues, without understanding the overall impact of the issue of the proposed solutions on the global setting. People think narrowly. Often the costs of mitigation are not proportionate to the problem, or larger problems are ignored in favor of popular sentiment for small-scale issues.

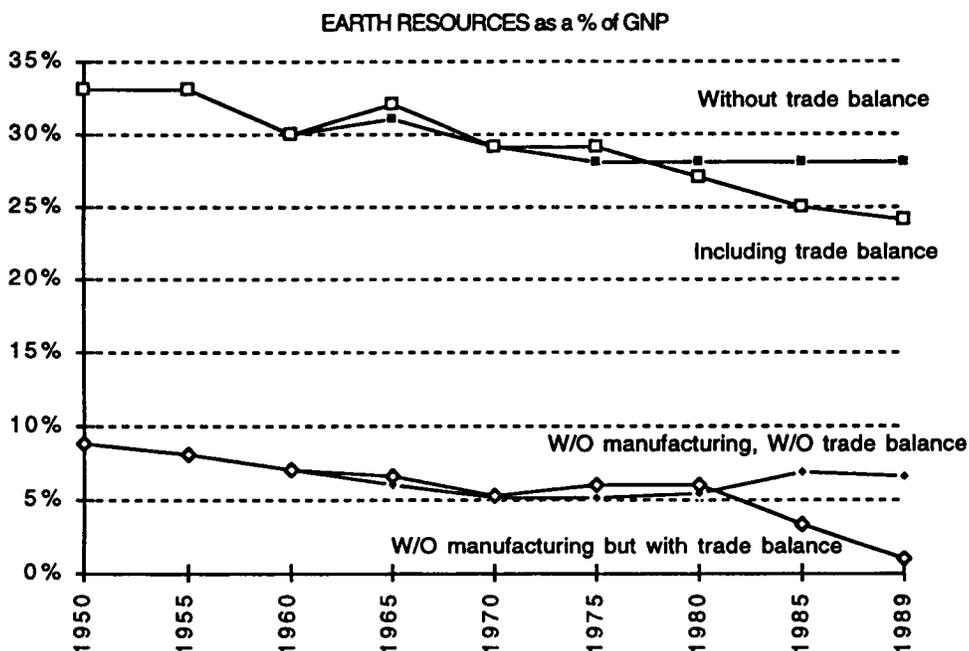


Figure 1. Percentage (%) of earth resources value in the gross national product (GNP). Upper curves of graph include "value-adding" manufacturing. Trade balance summed with curve as noted. Note that the percentage of earth resources in the GNP declined from 1950 to 1975, then stabilized, if trade balance is not included. However, when the balance of trade, largely controlled by the price of imported oil, is included, the percentage continues to drop. The lower curves reflect just the value of earth resources (agriculture, forestry, construction, fishing, and mining, including oil and gas extraction), without (w/o) the manufacturing value, divided by the GNP, without the trade balance, the curve shows a decline in percentage from 1950 to 1970, but increases slightly from 1980 to 1989. When the trade balance is included, the value drops precipitously from 1980 to 1989. All values are based on 1992 dollars. Data from post-1989 not available. Data from U.S. Bureau of Census (from Gerhard, 1996).

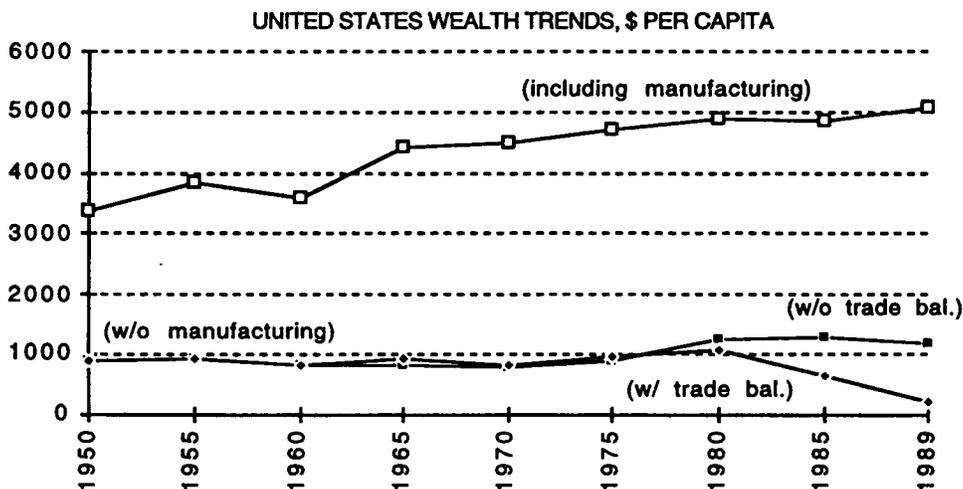


Figure 2. United States wealth per capita, expressed as dollars (\$) per person, in 1992 dollars. Uppermost curve represents value of earth resources, including "value-added" manufacturing, which rises steadily in value per capita from 1950 to 1980. From 1980 to 1989 the rate of increase is very small. The lower curves present the earth resource wealth values per capita without (w/o) the "value-added" manufacturing. The upper curve does not include the trade balance (bal.), the lower curve does include the trade balance (w/ = with). Note the steep drop in wealth per capita from 1980 to 1989 as the increasing value of imported resources is summed into the total. Unequal distribution of wealth accounts for an apparent increasing standard of living of the wealthier portion of population, and the worsening plight of the financially disadvantaged. Data from U.S. Bureau of the Census (from Gerhard, 1996).

Scalar issues

In a previous paper (Gerhard, 1994), I outlined a base scaling of issues, ranging from microenvironmental issues to mega-issues, which I reiterate and amplify here.

Microenvironmental issues. Issues that are short term or in home are microenvironmental, such as disposal of household chemicals, lawn mulching, objections to sand and gravel extraction in the neighborhood, recycling of household wastes, and similar small-scale individual decisions. These are personal decisions, and although they impact the lives of others, their impact tends to be very local, and action agendas can be very personal.

Macroenvironmental issues. These issues are of larger temporal scale and cut across geographic boundaries. They include air pollution in large cities, single major aquifer contamination or dewatering, factory smokestack output, or single tributary stream basin issues. Frequently, like the preceding class, these are issues of NIMBY, "not in my backyard," but actions of no one person can realistically materially affect an issue.

Tackling these issues requires organizational action rather than personal action, but care must be exercised not to let parochial views override negative effects of actions on the community.

Mesoenvironmental issues. Regional in nature, these issues may have impact on very large numbers of people. The Mount Saint Helens volcanic eruption and the eruption of Mount Pinatubo in the Philippines are examples of natural phenomenon that fall into this category. Acid rain, when perceived as an issue, would have fallen into this category. Automobile efficiency and offshore drilling prohibitions are of similar scale in their potential long-term effects on standard of living. Population growth is at least this important. Pesticide regulation, predator control, insect control, and crop fertilization are all issues of this magnitude and have great impact on nearly all of society.

Great care must be exercised in the application of governmental power to insure that the issues solved are not symptoms, and that the solutions devised are real, necessary, and do not cause negative large scale-downstream effects. National government is responsible for exercising this concern and care, but must do so in an open and informed arena. The examination and treatment of environmental problems must be holistic.

Megaenvironmental issues. Global climate change, ozone concentrations, and biodiversity are the three most popular issues today in America, although the furor over ozone depletion seems to have waned. However, overpopulation, mass famine, soil erosion, desertification, and massive plague are much more pressing to the majority of the world. Mega-issues are of global scale.

Impacts on society

Once issues have been scaled in scope and size, they then can be scaled as to impact on society.

Human health and safety. There should be no argument that the highest priority for environmental action is about issues adversely affecting human health and safety, but the importance

of an issue should reflect the geographic scale or number of individuals in need. For instance, global climate change, when it occurs, whether it is cooling or warming, would affect the entire global population. A spread of the *Ebola*-type virus could be a mega-issue of human health. Megaenvironmental issues affecting human health and safety are the most important issues of all.

Perturbations of natural systems. Earth systems suffer human interference poorly. Whether groins are installed to preserve one beach that in turn cause erosion farther along shore, or whether there is unwise construction on flood plains or in earthquake zones; much human suffering and death occurs when geologic systems are ignored. Thirty thousand deaths in a recent earthquake in India underscores the need to consider earth systems as one of the most significant environmental parameters affecting humans. The 1993 Midwestern United States floods also emphasize the problems of human interference in natural systems: artificial river control measures on rivers in the Midwest added significantly to flooding, and the unrestrained development of flood plains in these areas was responsible for preventable damage.

Societal interest issues. These issues are primarily conflicts between perceived environmental issues and property valuation. Facilities siting problems are at the root of most of these problems, although occurrence of pests, moderate air pollution, and other inconveniences resulting from human activity fall into this category. Frequently these issues are expressed as "NIMBY," (not in my backyard) issues. Many of these issues also reflect changing values and concepts of personal risk in society, such as using environmental laws and zoning to preclude mixing of incomes and social classes, establishment of social support facilities (such as halfway houses), and thoroughfares and bus routes in neighborhoods.

Esthetic issues. Many loudly contested environmental issues involving earth resources are simply esthetic issues: some people regard an oil well drilling location in the Rocky Mountains as an engineering marvel; others regard it as an invasion of pristinity. Mines and mining districts are variously regarded as environmental eyesores or as major historical artifacts of our heritage. For many of these issues perspective is individual and not based upon real long-term physical environmental effects. Haze in the national parks may be objectionable, but it has never been documented as a hazard. Many times arguments over esthetic issues pit region against region, or community against community, for some of the nastiest confrontations of all. Recreational interests have precipitated many confrontations, since many recreation issues benefit only the financially advantaged.

Graphic evaluation and prioritization. The scalar values for the environmental priorities versus the societal values can be cross-plotted to arrive at a generalized "significance factor" for each issue discussed, where ranking 1 = greatest long-term significance and 16 = least (Table 1).

This table provides a measurement for the importance of any issue. At a minimum, use of the table requires that each participant critically examine his or her stance, identify the perturbation

TABLE 1. SCALE OF VALUES FOR EVALUATION OF ENVIRONMENTAL ISSUES

Scale Value	Societal Value			
	(1) Health, Safety, of People	(2) Nat. Systems Perturbations	(3) Societal Interest	(4) Esthetics, Recreation
(1) Mega-	1	2	3	4
(2) Meso-	2	4	6	8
(3) Macro-	3	6	9	12
(4) Micro-	4	8	12	16

ment aspects of his or her issue, and then argue for inclusion in a priority block.

By means of Table 1, earth scientists can focus on real resource and environment issues, while demonstrating to lay citizens the relative merit of other issues.

SUGGESTED OTHER ACTIONS

Building consensus on environmental standards

There are no consensus environmental standards. There is no national consensus about what our ultimate goals are. There can be no "pristine," since it never existed. The biota and the earth have been changing for billions of years and will continue to change. Humans are part of the biota, their works and deeds are part of the equation with which we work, and wishful thinking and social engineering will not change that constraint. Therefore, we must agree on a set of standards to be attained. That agreement will not be by simple congressional vote or agency rule—it will have to be a consensus of the people. Why is this necessary? Simply, we are now enforcing environmental policy by ex post facto regulations and by constantly changing attainment standards. Our employers are never sure of their attainment goals, and the costs of constant change serve only to depress the economy and suppress capital development.

In order to build a national consensus on standards it is necessary to recognize that regional differences exist and adjust standards to these differences. For instance, the national 55 mile-per-hour speed limit instituted during the oil crisis of the 1970s was never truly enforceable in many states and resulted in the most massive civil disobedience since Prohibition. Laws that make little sense are rarely obeyed, and in Nevada and Montana, as examples, the speed limit law simply made lawbreakers out of average, law-abiding citizens. Yet, in the eastern states, the law made sense—there are many more passenger-miles driven in the populated east, distances are shorter, and traffic accidents more frequent. What was good for Massachusetts, however, was not useful for Nevada, where the opposite conditions exist. As one example of the current change in federal attitude, that law was repealed.

Similarly, methods of trash and garbage disposal in New

York City are not an individual option, and care must be exercised to insure that the mass of garbage and toxic chemicals disposed of in that teeming metropolis do not pollute the region; however, it is most difficult to argue reasonably that the trash and garbage of one remote Wyoming ranch should be subject to the same regulations as New York City. The costs of rural trash disposal under new federal law almost insures widespread passive disobedience. The town of Pretty Prairie, Kansas, faces the imposition of EPA fines and penalties for not having constructed a water purification plant to treat its town water, which the EPA contends violates the EPA nitrate standard. The cost of the plant would be about \$600,000. The town has a property tax base of about \$16,000 per year. There will be no locally funded water plant, no matter what EPA insists. Civil disobedience is the result of poor legislation and regulation.

Clearly, population density is a major controlling factor in environmental mitigation. The EPA has not established baselines including naturally occurring chemistry of water, air, and land. Acquisition of baseline information should be a first priority of the EPA. Then population density criteria should be developed to implement standards of "pristine" that are truly appropriate to the various population densities.

Special interests and agendas

The environmental debate has been fraught with spurious issues, misinformation, and special interests. There is need to ask questions about issues, about motivation and group benefits (Heidelberg Appeal, 1992). There is need to weigh costs against accomplishment. There is need to analyze issues clearly and in language that all understand.

Our global environment is constrained first by its geology, second by its chemistry, and third by its biology. The role of natural earth systems in constraining the environment and controlling human effects is poorly understood except by geologists. Thirty thousand deaths in remote India from preventable earthquake damage is not a concern to most people, whereas the possibility of a few or perhaps tens of early deaths from natural radon is considered a major national issue. Floods annually kill and bankrupt people, but little is done to mitigate these controllable effects of natural events. We do not nationally recognize what level of natural risks we face.

Lack of geologic perspective arises frequently. One of the great quasi-scientific mistruths is that we are "running out" of a resource (read oil, iron, copper, etc.). The geologic truth is that our resources are unlimited for all practical purposes. Most people do not understand that richness of resources controls price and value, and we simply run out of resources that we are willing or able to afford. During the oil embargo and consequent price rise, we conserved. Now, during the lowest prices in recent history, we use oil freely. Technology also provides resource alternatives when the marketplace demands them.

Possible global climate warming is another case in point. There is near hysteria about the catastrophic changes humankind is

wreaking on global climate. Yet, we ignore that the only evidence for climate warming is increased CO₂ in the atmosphere. The climate has not yet changed. Greenland ice cores have provided striking information that makes our present CO₂ issue pale. The amplitude of earth climate variation documented in the Greenland ice core is great, but more important, the core documents two major human-interest issues. First, the last 8,000 years have been remarkably stable in climate, compared to all previous time. Human civilization has evolved in the last 8,000 years without regard to the natural climatic cycles of the past, but will almost certainly have to engineer society to survive the swings that will occur. The swings tend to occur with changes in atmospheric CO₂ concentrations, which also took place before civilization. Second, climate changes may not take centuries to evolve, they may take place in decades (Dansgaard et al., 1993; Mayewski, 1993).

John S. Perry recently wrote for the National Academy's Board on Global Change, "Yet each year will bring a new environmental crisis clamoring for redress in political councils—ozone depletion last year; climate this year; invasion of exotic species, ground water quality, chemical time bombs, tropospheric ozone, and so on in years to come" (Perry, 1992, p. 13, 14).

It is possible to advocate issues for personal or professional gain. There is much research money to be gained if your issue is perceived to be the "catastrophe of the year." Issues of "rangeland reform" and changes in the 1872 Mining Law are not about fees the federal government collects, but about recreation and esthetics; mines are not pretty when operating, and cattle are not native animals. Therefore all issues and any proposed solutions should be questioned, specifically targeting the beneficiaries of proposed policy. Some questions that need to be asked are:

1. Why is the policy, law, or action necessary? What are the costs, and what are the benefits?
2. Is "who benefits" identified, along with "who loses?" Do all citizens receive benefit from the action and is any group unfairly bearing the costs? Are the special interests identified?
3. Is the scale of action appropriate to the scale of effects?
4. Are the proposed changes scientifically sound or else scientifically innocuous? Will the action precipitate a worse problem? Is the risk being mitigated worth the risk being introduced?
5. Are anthropogenic effects carefully separated from natural effects?

Environmental action requires high quality and holistic science

Perhaps most important to us who work as scientists is the need for scientific integrity in the law and rule-making process. Legal language must be scientifically valid and arguments based more upon scientific fidelity of issues. The earth is a planet, a relatively solid body of minerals that happens to be enclosed in a thin envelope of fluids (oceans and atmosphere) in which we have evolved. That is our final constraint. It is incumbent upon us, geologists, to confront inadequate, dishonest, and poor environmental and resource science.

Science is not well-integrated in federal environmental law and regulations. Environmental law should be a statement of legislative principles and objectives. The implementing regulations are where objective science should play a very strong role, but where objective science is commonly sacrificed. For instance, the legal language of The Endangered Species Act contains a scientifically fraudulent definition of species that provides for the protection of subspecies, and does not provide standards for designation of therein defined species (subspecies) (The Endangered Species Act, P.L. 93-205 et seq.).

The Environmental Protection Agency sets standards for contamination that have become measurement-technology-based rather than based upon actual knowledge of human effects or human evolutionary tolerance. Where numeric standards are specified, they may lead to requirements that are not technically feasible. Where technology is specified rather than goals, market disruptions can occur. There is a clear need for objective science to support regulations and advise Congress about implications of proposed laws. There are two actions that the federal government can take to mitigate these problems.

The federal government should reorganize natural resources and environmental research to remove such research from the regulating agencies and into an independent agency focused on providing objective science. The National Aeronautics and Space Administration (NASA) is a suitable organizational structure model. Geologists should advise the federal government on needs and organization for natural resources and environmental research. A recent Hedberg Research Conference sponsored by the American Association of Petroleum Geologists Division of Environmental Geosciences recommended that the federal government should ensure that assessment of natural resources and environmental research is conducted by scientific, not regulatory agencies. Regulatory agencies should develop policy and regulations based on the objective research provided by a "natural resource and environmental science agency" (Gerhard et al., 1996).

Second, risk-based assessment and risk management must be the cornerstone of all public environmental policy. Much environmental regulation is based upon perceived risk and esthetic values. Human health and safety are of paramount concern, but risks are not well understood. Consequently, law and regulations may address issues of little consequence while omitting consideration of real issues. Much has been written about risk assessment in the human environment, and informal risk numbers are frequently used in television broadcasts and other media. The ultimate goal of science-based risk assessment is to prioritize the issues upon which public dollars and economic activity are expended. Choices include economic, human health, and intangible values, such as esthetics. Weighing risks among the options available and placing resources where we can save the greatest number of lives are obvious goals.

Geological responsibility. Finally, there is concern that the earth sciences are not playing an appropriate role in the public debate about natural resource access and production. Geologists and their professional societies have not met their public respon-

sibilities to provide objective science to the legislative and regulatory process. Geology must be better represented in Washington to provide objective science to lawmakers and regulators. It is clear that those who propose new endangered species and other land withdrawals succeed unless objections are raised and appropriate science is presented to counter withdrawal arguments. Thus, agencies generally err on the conservative, correctable, side, and succumb to the "squeaky wheel" syndrome. The responsibility of the profession of geology is to provide the earth resources to society that society needs, even when society does not generally recognize its needs or the conflicts between its needs and desires.

SUMMARY

As a broadly educated geologist and natural scientist, I am most concerned with the issues revolving around the access to and extraction of earth resources, while cognizant of the broad chemical and biologic questions being raised. I am confused by rhetoric, rhetoric that decries the mere presence of humankind on earth while ignoring the explosive growth of global population and that is unwilling to address the population issue. I am confused by those who purport to investigate the scientific issues of environment, while choosing, against advice, to ignore the fundamental geological controls on global environment and biodiversity. I resent the regressive nature of current environmental policy that places a disproportionate share of environmental costs upon those least able to afford to pay.

The nation needs environmental leadership that can make positive advances, that can encompass all of its citizens, and be open to public scrutiny. We must strive to improve the process that develops our environmental policy. Our economy must be able to support the environmental costs, and provide for standard of living in addition to the environmental quality of life. We must develop policy that reflects a consensus of the people, and that encourages enthusiastic support and compliance. Setting standards, insisting upon high standards of ethics and truth, allowing for regional differences, and providing frameworks for evaluation

of issues and results are crucial to long-term success. We have not yet reached these goals.

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Rational Science for Rational Policy: A Conference Summary

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ABSTRACT ●

"Rational Science for Rational Policy" was the theme of the American Association of Petroleum Geologists, Division of Environmental Geosciences, Hedberg Research Conference held in Estes Park, Colorado, on September 24 to 27, 1995. Thirty-two participants representing a broad cross-section of government, private sector, and public interest groups and academic institutions dissected and discussed the origin, effects, and potential solutions to resource supply and consumption issues engendered by environmental law, regulation, and public perception.

The following five questions were addressed by panel discussions and presentations:

1. What are American environmental goals and resource needs?
2. What earth resources does the United States need now and in the immediate future?
3. What are the major environmental policies of the United States and how do they impact earth resource supplies?
4. What is the scientific basis of each of these policies and are these bases valid?
5. What changes in environmental or earth resources policies does the United States need to make in order to provide adequate resources to sustain society, and what will be the environmental consequences of those policies?

The sessions were wrapped up with a discussion of the question "What is the global view of the future?"

Some conclusions of the conference encompassed recognition of the need for much better risk analysis and risk management in governmental policy and for independent scientific analysis and supporting data for environmental policy issues.

RESOURCE ACCESS PROBLEMS

Increasing global and U.S. population demands an increasingly abundant supply of earth resources to maintain a global, frequently poverty-level, standard of living. Production of earth resources and value-adding by labor creates new wealth, a measure of societal standard of living. The U.S. standard of living has dropped continuously since 1980

as measured by earth resource production and value-adding (Gerhard, 1994). A grossly negative balance of payments during 1980 to 1995 helped drive the standard of living down. One illustration of the problem is that petroleum imports are historically ~60 to 70% of import costs (exported capital) and thus are the largest single factor in the current balance of payments deficit. The United States has changed from a net exporter to the world's greatest debtor in relatively few years. How has this come to pass? How has an apparently rich nation become the world's greatest debtor and caused the less fortunate citizens to endure a lower standard of living?

Earth resources include soils, water, timber, crops, fisheries, minerals, and energy resources. Wealth is produced by extraction and use of these resources plus the value added by labor to make useful products. Reduced per capita production of earth resource-based wealth has resulted generally from reduced access to the resource base. This reduced access is in part physical and in part financial (cost).

Physical access to resources on federally controlled lands is increasingly difficult due to a myriad of park and wilderness land withdrawals, restrictions by presence of endangered species, and clean air and water regulations. At the present time, ~65% (377,000,000 ac/152,569,810 ha) of the federal lands in the United States is at least somewhat restricted to resource access. Cost-restricted access arises from regulations that impose restrictions on methods of access, such as mining process, requirement for helicopter-borne seismic acquisition for petroleum exploration, litigation over access to federal lands near already restricted lands, litigation over impacts on scenic vistas, endangered species restrictions on access to timber, or animal loss to predators through restrictions on control measures. These statements are not judgments about the efficacy of regulations and law but merely statements that each regulation bears a cost. Generally, resource regulations focus on either human health and safety or aesthetics and recreation.

How serious is the global and U.S. resource supply problem? For those knowledgeable about the relationship between petroleum exploration discoveries, reserves, and production rates, the lack of exploration activity in the United States over the last 10 years cannot be hidden. Although

The formal report has appended the keynote address by Hon. Harrison H. Schmitt, the Annapolis Accords on Risk Assessment and Risk Management, and the Hedberg Conference earth resources data set (Gerhard and Weeks, 1996). Copies of the full report can be obtained from the Kansas Geological Survey.

large reserves remain, and very large resources are undiscovered and unrecoverable with today's economics, productivity rates (i.e., the rates at which consumption can be sustained) are dropping like a proverbial rock.

Increased costs and legal entanglements have contributed to an exodus of the petroleum exploration industry to foreign targets, the loss of >400,000 petroleum exploration and production jobs in the United States, reduced domestic production, and consequently increased petroleum imports. Prior to the oil embargo of 1973, U.S. petroleum imports were ~35%. Imports are now >50% of consumption. At current consumption rates and prices, by the year 2000, the United States will be importing 10,000,000 bbl/day, at a cost of \$170,000,000 of American capital wealth per day (over \$62 billion/yr).

Alternative domestic energy sources are limited in today's technology. Widespread solar energy production has not yet materialized, although solar energy has become useful for remote applications, such as replacement of windmills for stock watering and operation of highway signs. Convenience and economy of coal-fired electrical generation override any widespread applications of wind and solar energy. Increased nuclear electrical generation seems unlikely for the near future because of public perceptions about health effects and legitimate concerns over long-term waste disposal. Long-term global energy needs are even more dramatic. A way to meet the increased demand of the developing world population estimated at 6 billion people by 2000 and 10 billion people by 2050 may not exist. The rest of the world will compete with the United States for energy resources.

Future metals consumption can be reasonably forecast, particularly in the United States, where per capita consumption has leveled after significant post-World War II growth. For example, by 2000, the United States will consume 7,560,000 metric tons (8,316,000 short tons) of aluminum per year, not including recycled aluminum. This metal must be produced from mined ores. Other metals will have similar increasing demands just to maintain the present, inadequate standard of living of much of the rest of the world. Vast amounts of metals must be mined and processed for the global economy to function and generate the wealth that permits clean environments.

Construction materials drive the cost of new homes and community infrastructure. Large volumes of very heavy materials are required which precludes long transportation distance; therefore, access to sand and gravel is nearly always contentious. Growth in sand, gravel, and crushed rock has stabilized in the United States per capita, but as population grows, so will demand for construction materials. Use of metals are expressed in units of thousands of metric tons per million population; construction materials must be expressed in tons per person. In the United States, sand,

gravel, and crushed rock are used at the rate of ~8 tons/person/yr. The aggregate alone to rehabilitate all of the highways that need repair would cost \$75 billion.

Construction minerals must be mined in close proximity to use because of the high cost of transportation which is currently ~\$0.20/ton-mile. These low unit value resources have a very high place value. In glaciated portions of the country, sand and gravel may be easy to acquire and are widely distributed, but in other parts of the U.S., such as the Midwest, bitter arguments arise between scenic values and construction needs.

Water quantity is not a problem in most of the United States. Water quality may be a significant issue in the future; however, existing federal regulations appear to adequately avert many potential water quality problems. Elsewhere, population pressures in Asia and Africa have already strained available desert supplies, and spreading desertification in the Sahara and sub-Saharan suggest that these problems will get worse. The fastest growing populations are those of Africa, followed by Central America and Asia.

Why be concerned about future resource supplies? Because society depends on minerals and energy to function, and the standard of living of fellow citizens depends on providing those resources. As capital shifts overseas, the standard of living decreases. The United States may not have to continue to export huge amounts of capital and accept foreign ownership of national assets, but the nation has shown little proclivity to change public policy to encourage resource extraction and processing. Capital is exported because the United States has no substitute export product.

OVERCOMING REGULATORY BARRIERS TO RESOURCE AVAILABILITY

How can geologists provide the ever-larger amount of resources that society demands for survival while encountering increasing difficulty of access and costly regulatory barriers to the same resources? This question was considered at the American Association of Petroleum Geologists, Division of Environmental Geosciences, Hedberg Research Conference "Rational Science for Rational Policy" held in Estes Park, Colorado, on September 24 to 27, 1995. Thirty-two participants represented a broad cross-section of government, private sector, and public interest groups and academic institutions. They dissected and discussed the origin, effects, and potential solutions to resource supply and consumption issues engendered by environmental law, regulation, and public perception.

CONFERENCE CONCLUSIONS

Several conclusions arose from deliberations of the conference. All comments and discussion at Hedberg Conferences are considered unattributable, but the following state-

ments are consensus views of the participants. The conclusions are categorized generally into those addressing the geological participation in public affairs and the need for objective science, specific major current issues, and identification of issues to be addressed.

Other issues that are not discussed herein but were defined by Conference participants included the following:

- Consequences of regulations are not clinically evaluated;
 - Conservation rather than preservation should be the basis of policy;
 - Regulatory policy should stress problem solving rather than adversarial confrontation;
 - Environmental policy and law would benefit from better integration of agency goals and among agencies; and
 - Better integration of environmental policy goals in law-making is desirable.
- I. Science is not well-integrated in federal environmental law and regulation. Environmental law should be a statement of legislative principles and objectives. Objective science should play a very strong role in regulations that implement law, but science is commonly sacrificed. Specified numeric standards may lead to requirements that are not technically feasible. Where technology is specified rather than goals, market disruptions can occur. In the U.S. Endangered Species Act, the definition of species as subspecies is erroneous and has led to excesses in application of the law. There is clear need for objective science to support regulations and for scientists to advise Congress about implications of proposed laws.

The federal government should reorganize natural resources and environmental research to move research responsibilities from the regulating agencies into an independent agency focused on providing objective science. The National Aeronautics and Space Administration is a suitable organizational structure model. Geologists should advise the federal government on needs and organization for natural resources and environmental research.

- The Estes Park Conference attendees agree that the federal government should ensure that assessment of natural resources and environmental research are conducted by scientific, not regulatory, agencies. Regulatory agencies should develop policy and regulations based on objective research provided by a "natural resource and environmental science agency."
- II. Geologists and geological societies have not met their public responsibilities to provide objective science to the legislative and regulatory process. Geology must be better represented in Washington, D.C. to provide objective

science to lawmakers and regulators. Proposers of new endangered species and other land withdrawals succeed unless objections are raised and appropriate science is presented to counter withdrawal arguments. Thus, agencies generally err on the conservative, correctable side and succumb to the "squeaky wheel" syndrome. Geologists have disdained advising government for fear that these activities may be mistaken for "lobbying." Geologists must participate in the public debate.

The American Institute of Professional Geologists and the current governmental affairs program of the American Geological Institute are trying to meet these needs but have inadequate staff and resources. If the American Association of Petroleum Geologists executive committee fails to take action, many support the Division of Environmental Geosciences taking leadership.

- The Estes Park Conference attendees strongly recommend that the American Association of Petroleum Geologists, the largest professional group in the science, establishes a separately chartered group, with paid staff, to alert the profession to issues and to advance objective geological perspectives on natural resource and environmental law and regulation.

Academic geologists should provide to students the guidance and enthusiasm needed to become active scientist-citizens. One participant correctly observed that few scientists are members of Congress.

- The Estes Park Conference attendees believe that the geological profession should advise the government about minerals, land, and environmental policy as a professional responsibility, provide a national source of objective science for evaluating federal policy and regulations, and communicate with and educate citizens and decision-makers about the roles of earth resources in society.

III. Much environmental regulation is based on perceived risk and aesthetic values. Human health and safety are of paramount concern, but risks are not well understood. Consequently, law and regulations may address issues of little consequence while omitting consideration of real issues. Much has been written about risk assessment in the human environment, and informal numbers are frequently used in television broadcasts and other media. The ultimate goal of science-based risk assessment is to prioritize the issues on which public dollars and economic activity are expended. Choices include economic, human health, and intangible values, such as aesthetics. Weighing risks among the options available and prioritizing resources to save the greatest number of lives is an obvious goal (Annapolis Center, n.d.).

- The Conference attendees unanimously support the "Annapolis Accords" of the Annapolis Center regarding the need for science-based risk assessment and management.

IV. Environmental law and regulatory practice frequently conflict with supplying resources to society. This is a major issue. A cumulative ballot of sub-issues construed to be of greatest significance are as follows:

A. Utilize science-based risk assessment in environmental law and regulation.

"There are heavy costs involved if society fails to set environmental priorities based on risk. If finite resources are expended on lower-priority problems at the expense of higher-priority risks, then society will face needlessly high risks. If priorities are established based on the greatest opportunities to reduce risk, total risk will be reduced in a more efficient way, lessening threats to both public health and local and global ecosystems" (Annapolis Center, n.d.).

- Conference attendees recognize the difficulty of educating the public about risk assessment and suggest one place to start is to adapt the principles of petroleum industry risk analysis to environmental risk assessment.

B. Natural geologic processes, ambient natural background levels of elements and minerals, and natural processing systems do much to control the human environment but are insufficiently considered in developing cleanup standards. Part of this problem is due to the inability of federal rule making to consider local settings. Consequently, standards may be unrealistic, inadequate, or unattainable.

Natural geological processes, including erosion, stream transportation, volcanoes, earthquakes, and hurricanes, fundamentally control the human environment, and humans can only engineer survival around them. Geological processes proceed according to physical and chemical laws, without respect to political boundaries. Eliminating arsenic from the environment in eastern North Dakota or selenium near Pueblo, Colorado is not possible: they are contained in the soils and bedrock by virtue of sustained volcanic eruptions that occurred 70 million years ago.

Effective environmental quality decisions carefully consider local natural settings and do not violate natural laws. Distinguishing anthropogenic change from natural change is critical to effective regulation.

- Geologists have a special responsibility to inform decision-makers about local geochemical and geodynamic conditions during rule making. Working with nature is much more cost-effective than trying to work against nature, which always fails.

- Governments should develop attainable environmental standards. Not all standards are realistically attainable, and some are attainable only in limited geographic areas.
- Geologists must advise government on attainability of trace chemical and geodynamic standards.

C. Governmental decisions should always incorporate cost-benefit analysis. The United States cannot afford to ignore the costs and benefits derived from its actions. Policy decision may provide a low-cost/high-benefit result, but decisions should demonstrate knowledge of cost and benefit. It is important that the geological profession develop the methodology to ascertain costs and the physical and chemical results (benefits) of proposed actions. Sometimes these must be qualitative. What is the cost of channelizing a river? Cost can be expressed in dollars for the actual construction, in relative value for changed wildlife habitats, and in both dollars and relative values for reduced groundwater recharge.

- Geologists should advise government about the geologic costs and benefits of proposed actions.

D. Government should stress prevention versus cleanup. Prevention of environmental problems is clearly the preferred choice over mitigation or cleanup: the costs of legislated cleanup are extremely high, owing to litigation costs, imposed standards of practice, and malpractice. The Superfund Act has had a very high cost for limited benefits.

- Policy should be driven towards incentive-based prevention measures, recognizing the temporal nature of technology and practice.

V. Estes Park Conference attendees recognize "geology as the science of change." Geology differs from other sciences in two fundamental aspects: constant change and time. Many environmental and natural resource issues become contentious because participants do not understand that the earth is dynamic, constantly changing, and changing over time periods not easily comprehended by nongeologists. Geologists have a perspective on change and time not shared by the average American.

Many people argue that society is changing the earth and that these changes are detrimental to "the earth." Yet, most human impacts on the surface of the earth have been minor perturbations of the natural changes that configure the environment, history, and the future. The geologic profession is learning to separate anthropogenic from natural effects even though many of these changes are not fully understood. As

an example, global climate change, although a valid research area, must be placed in the context of the long-term changes observed in recent ice-core analyses in Greenland and Antarctica (Fitzpatrick, 1995).

Geologic records show that climate has been stable for an anomalously long time, long enough for agricultural society to evolve. Natural climate change will occur and dramatically affect society. Perhaps anthropogenic effects will either add to or subtract from natural changes. Geology can help society to better prepare for and adapt to change, whether global warming or cooling. This is not to say that preparation for climate change should not happen—it should.

- Change is a geological constant. Geologists must do a better job of educating decision-makers and the general public about constant global and evolutionary change.

Why are people concerned about future earth resource supplies? Because society depends on minerals and energy to function. The standard of living of fellow citizens depends on the ability to provide those resources. No other profession can supply society's material needs.

- Geologists have a responsibility to provide the earth resources necessary for all people to have a healthy standard of living.

VI. Future Division of Environmental Geosciences interest groups may develop with the purpose of providing science-based commentary on specific topics. Future conferences may be planned around individual issues suggested by the Estes Park Conference, such as global climate change, endangered species, risk management and assessment, or others. Interest groups may wish to comment on proposed new environmental laws/regulations or to review existing ones.

- Conference attendees recommend that the Division of Environmental Geosciences plan and host a series of conferences and interest groups at least once a year.

ACKNOWLEDGMENTS ●

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Earth Resources Data: A Basis for Resource Analysis and Decision-Making

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ABSTRACT ●

Many discussions of earth resources and alternative land use focus on perceived resource needs rather than useful information.

Earth resources are not just minerals and fossil energy. They also include forestry, agriculture, fishing, and all other activities that extract value from the earth. These resources are the fundamental basis of wealth, and without their harvest, society would founder. Per capita consumption rates for earth resources in the United States are stabilizing, but population increases continue to place demands for more earth materials. Many people have requested wider distribution of information and knowledge of resource data sources. These data may be useful to other geologists for analysis of resource availability and future needs.

INTRODUCTION ●

Understanding societal earth resource needs and analysis of issues of supplying those resources depend on knowing present and past rates of use and trends toward future uses. The recent American Association of Petroleum Geologists, Division of Environmental Geosciences, Hedberg Conference, "Rational Science for Rational Policy," analyzed United States (U.S.) environmental policies with respect to geologist's professional imperative to supply society with earth resources.

As part of that conference, the convenors prepared data compilations and charts of past earth resource use as the basis for assessment of future demands. These charts received much favorable comment during and after the conference. They are reproduced here with caption comments for use by other earth scientists who may find them useful for discussion of policy impacts on resource supplies and the needs of global and American society for earth resources.

Earth resources are not just minerals and fossil energy. They also include forestry, agriculture, fishing, and all other activities that extract value from the earth. These resources are the fundamental basis of wealth, and without their harvest, society would founder. Judgements about resource development and extraction frequently are made without regard to future needs. Sand and gravel are overstepped by residential developments, prime farms are encroached upon

by expanding suburbs, and minerals and timber are locked beyond reach for recreational and aesthetic values. These are policy decisions. Agreement with the decision is not as important as whether the decisions are informed decisions.

PURPOSE

The purpose of this article is to provide other geologists with some of the means to assist others in making informed policy decisions.

The format for this text is tailored to the presentation of the graphical data. Captions encompass the writer's observations about the data but avoid extensive discussion or interpretation of the data. The references are the source of the data. The reader is encouraged to review the sources as well as the graphs.

EARTH RESOURCES

Population Growth

All earth resource issues are tied directly to global population growth. If there were no humans, there would only be a de facto "pristine" environment. However, in recent centuries, global human population has grown rapidly and is "exploding" at the present time (Figure 1 to 3).

Population growth rates are variable around the world. The current population of >2.5 billion people is projected to rise to over 10 billion by 2050 (Figure 1), a logarithmic increase. In contrast, the U.S. population has been rising at a rate of ~25 million people/10 yr., and projections suggest that the rate will slow by the middle of the next century (Figure 2). Population growth rate is greatest in Africa, followed by non-United States North and Central America. European growth rate is the smallest, followed by the former USSR and the United States (Figure 3).

With burgeoning population, earth resources production must proportionately increase to maintain the existing standard of living. If the standard of living in poor regions is to improve, even higher increases in production of resources will be necessary to encompass growing economies (e.g., southeast Asia). For geologists and other earth resource producers to understand the magnitude of the task ahead, tabulation of current consumption trends of various major mineral and energy commodities both globally and for the United States is necessary (Figures 4 to 29).

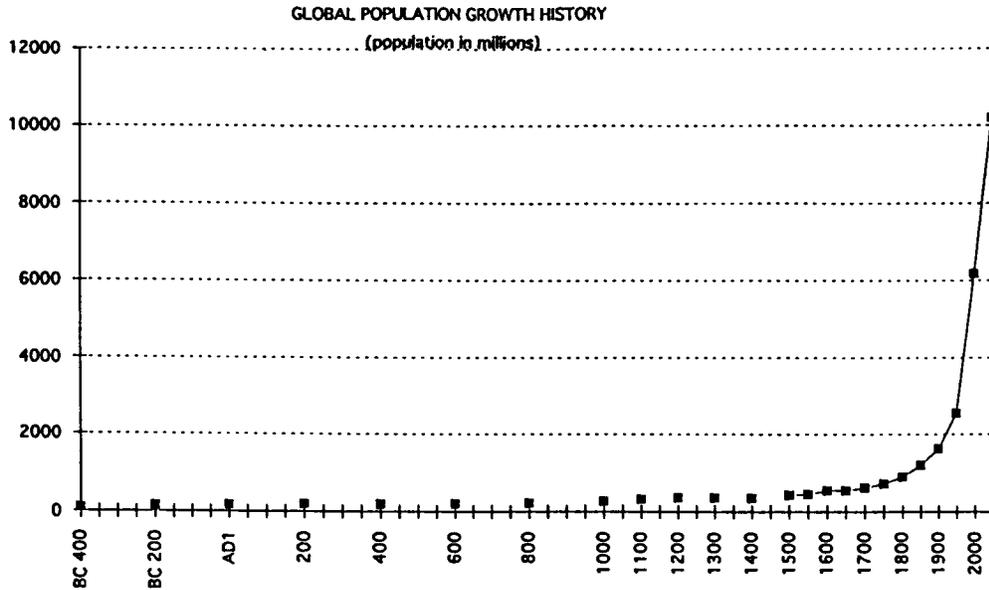


FIGURE 1: Global population growth, 400 b.c. to 2050 a.d. (from McEvedy et al., 1978).

Metals

Metals consumption is a major area of earth resource use, and mining of metals is a topic of environmental discord. Consumption of metals is a measure of economic progress, with greater consumption indicating an industrialized economy. Consumption of major metals grew globally from 1900 through ~1950, a trend mirrored in the United States. A major surge in consumption also took place immediately following World War II in the United States (Figure 4 to 17). Data for aluminum, copper, lead, nickel, tin, zinc, mercury, and silver are presented. Iron consumption has not been calculated because of the difficulty of separating the various categories of iron, steel, scrap, and basic ore production, the vast global trade in the commodity, and trends toward other metals use. Figures for these commodities are contained in the references cited.

Significant increases in global per capita consumption of aluminum, copper, and nickel may indicate an increasing global economy, rising standards of living, and conse-

quently, rising expectations for increased standards of living around the world. Planning for resource development must include considerable increased mining activities for these metals. For example, copper is being used now at a rate of 6,500 metric tons per million population. That consumption is projected to be 10,000 metric tons per million population by 2020, but the population will rise from ~2.5 billion people today to nearly 8 billion by 2020. Simple multiplication shows that 80,000,000 metric tons of copper will need to be produced in the year 2020 to satisfy projected demand. This is ~246% of current consumption. Demand increase may not be sustained for the next 25 years, or a substitute commodity may be developed. Nonetheless, this calculation indicates the immensity of the problem. A shift from producing 32,500,000 tons of new copper per year now to 80,000,000 tons in 2020 must transpire.

In the United States, the per capita use of copper leveled at ~8500 metric tons per capita (2,122,000 tons of copper and 250 million people; 1990). Projected U.S. population growth suggests that by 2020 325 million people will in-

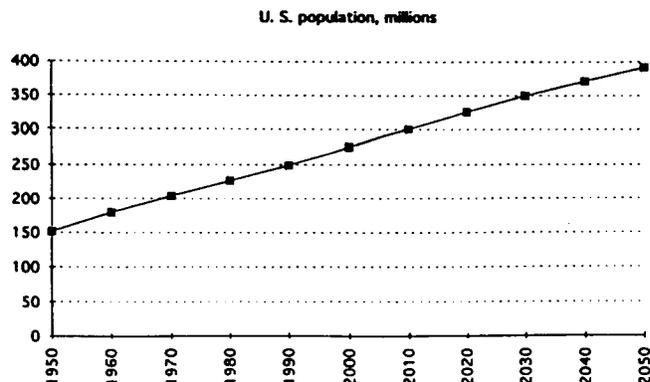


FIGURE 2: U.S. population growth, 1950 to 2050. Note nearly straight line growth (from U.S. Bureau of the Census, 1994).

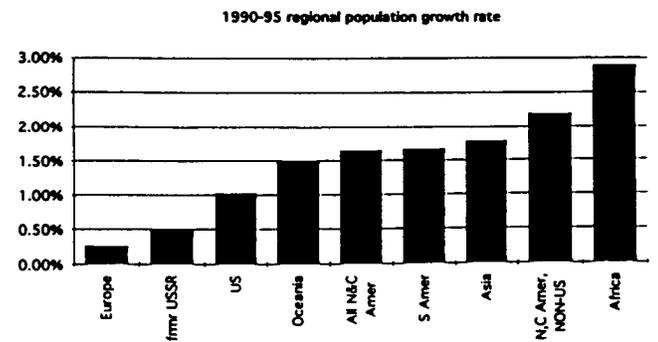


FIGURE 3: Global regional population growth rates, 1990 to 1995 (from Urban and Trueblood, 1995).

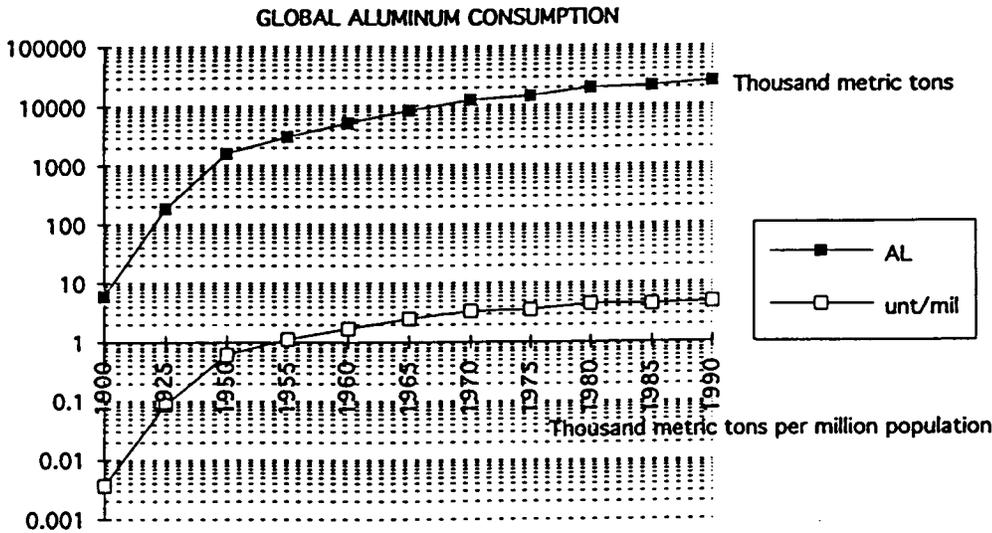


FIGURE 4: Global aluminum consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

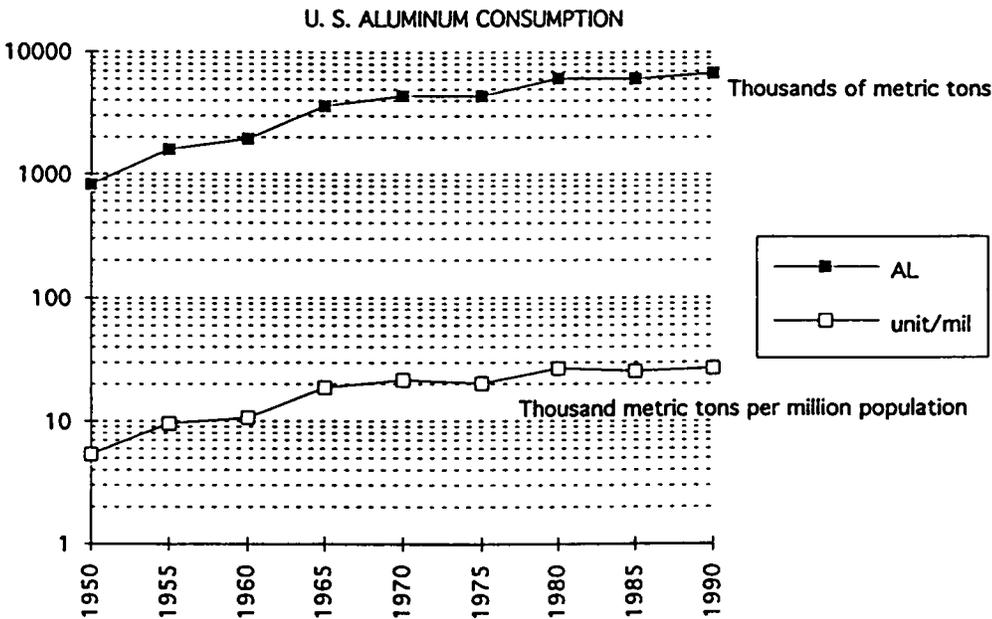


FIGURE 5: U.S. aluminum consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

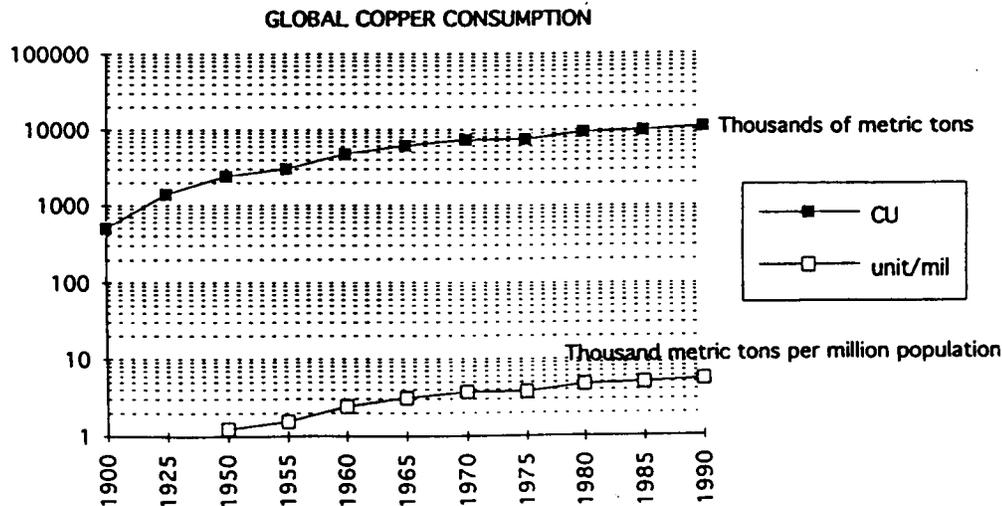


FIGURE 6: Global copper consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

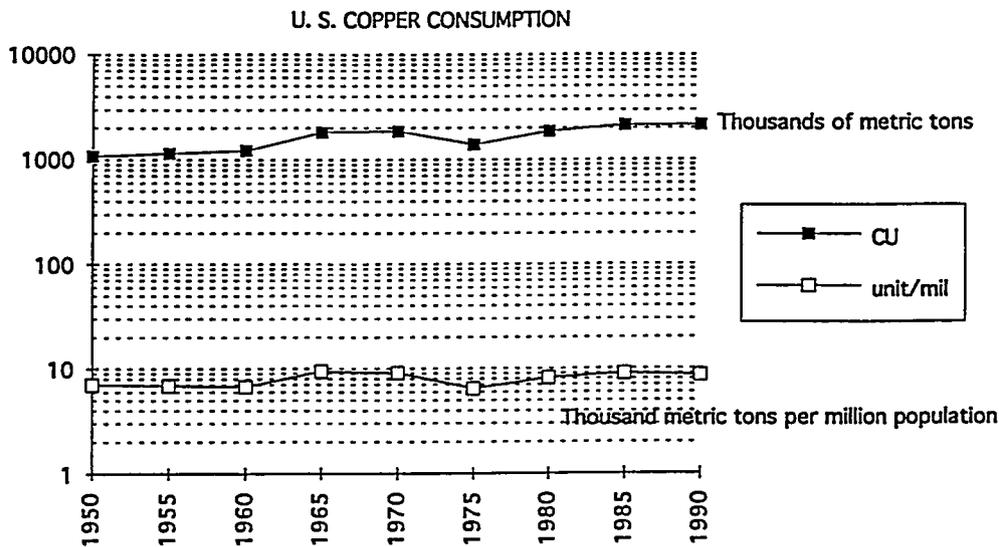


FIGURE 7: U.S. copper consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

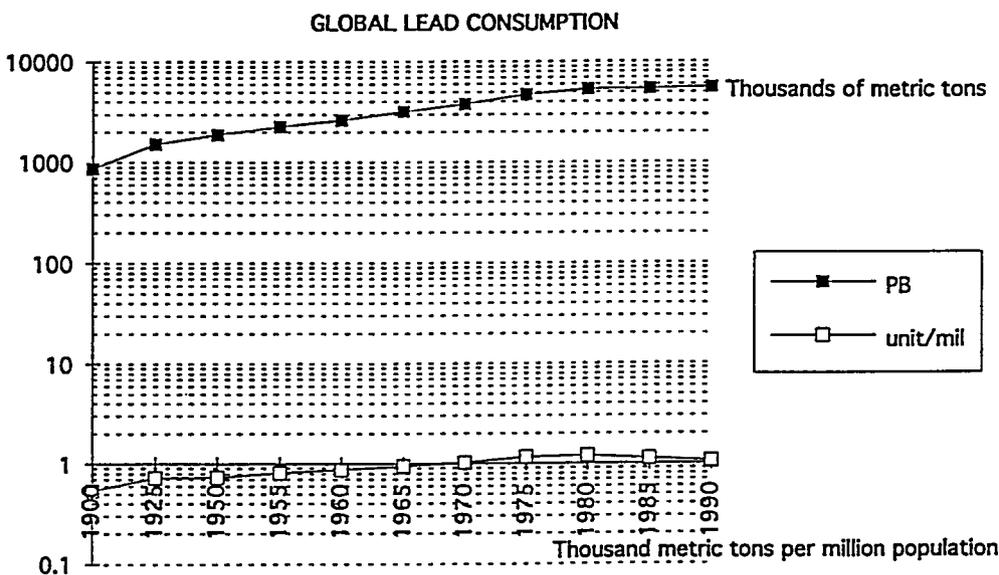


FIGURE 8: Global lead consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

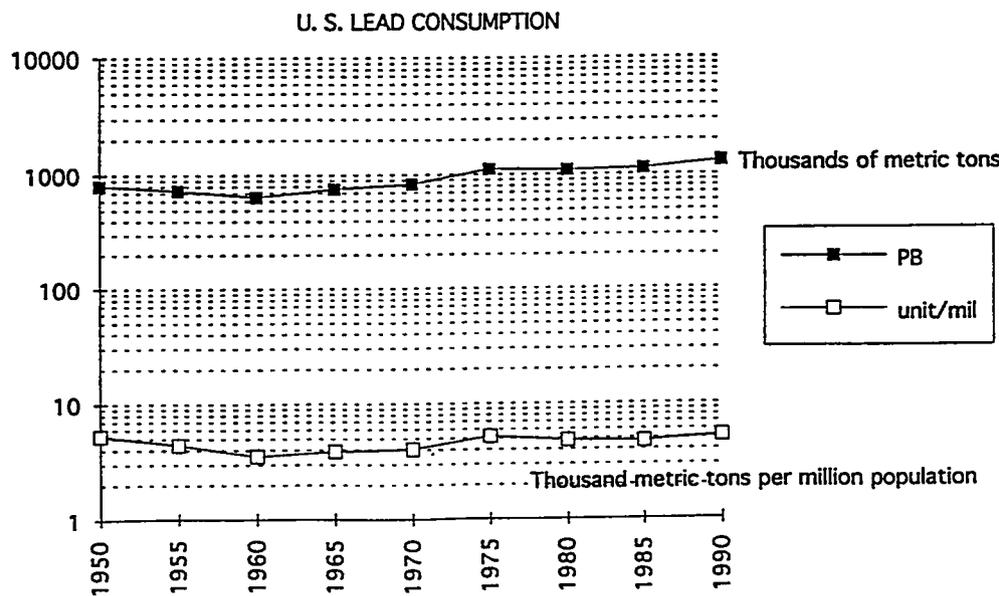


FIGURE 9: U.S. lead consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

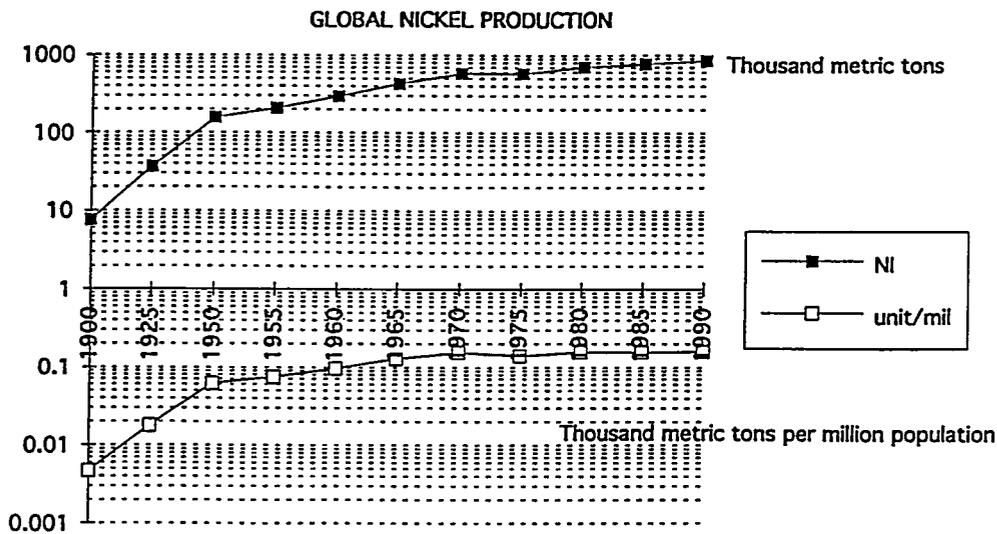


FIGURE 10: Global nickel production, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

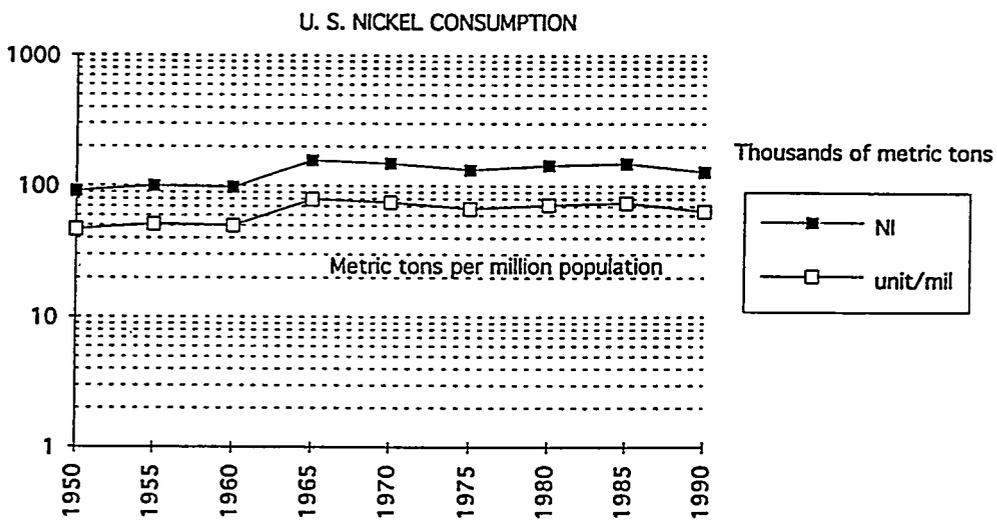


FIGURE 11: U.S. nickel consumption, expressed as thousand metric tons and as metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

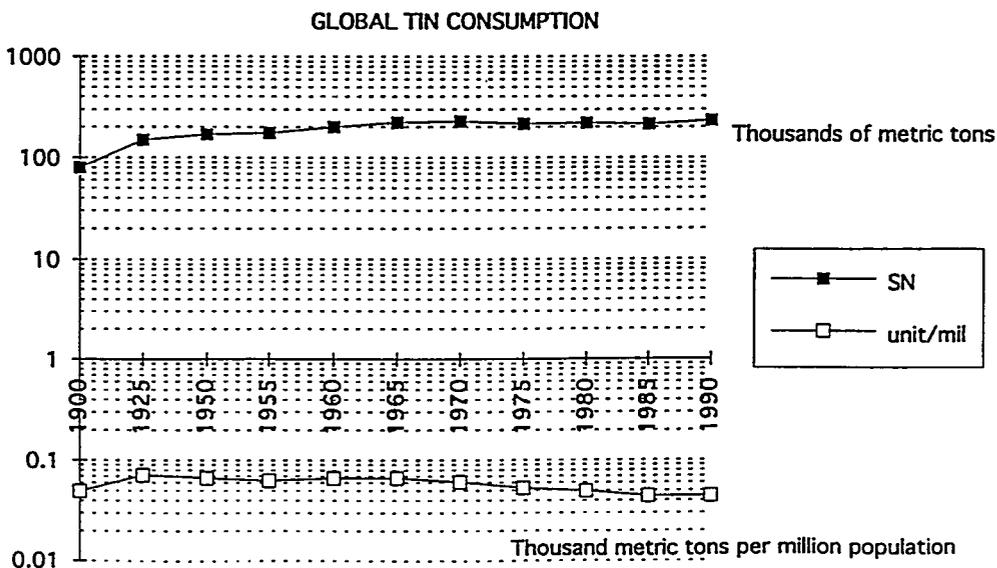


FIGURE 12: Global tin consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

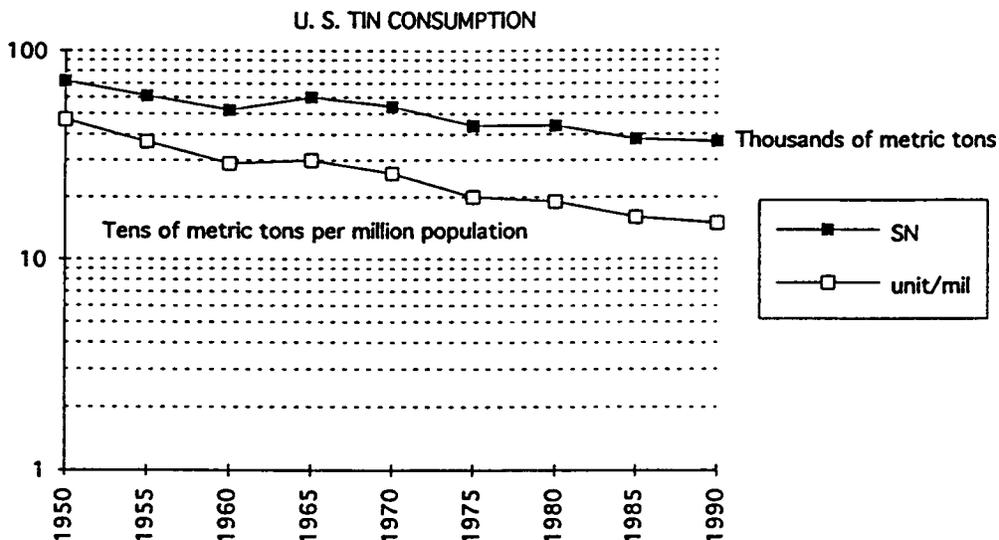


FIGURE 13: U.S. tin consumption, expressed as thousand metric tons and as tens of metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

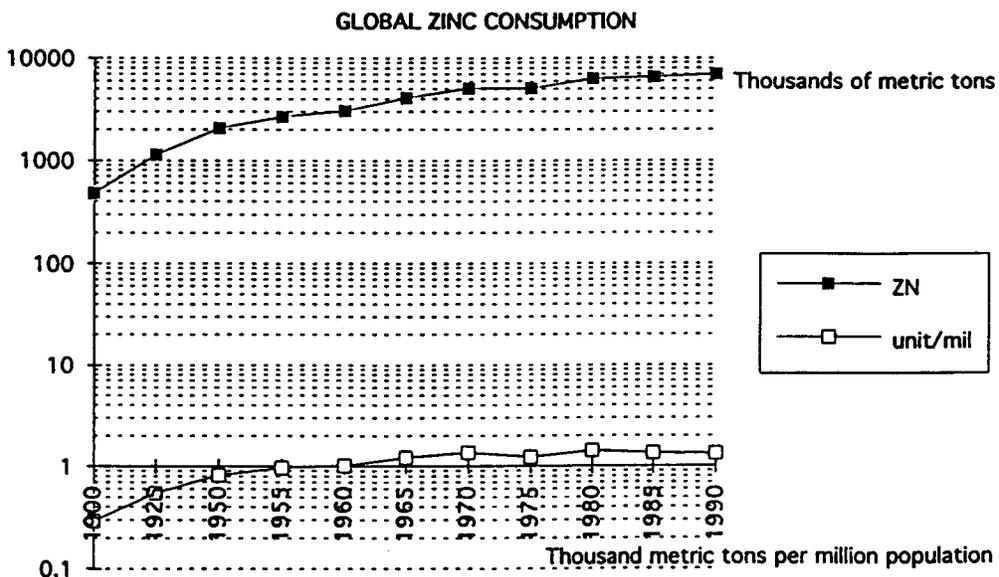


FIGURE 14: Global zinc consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

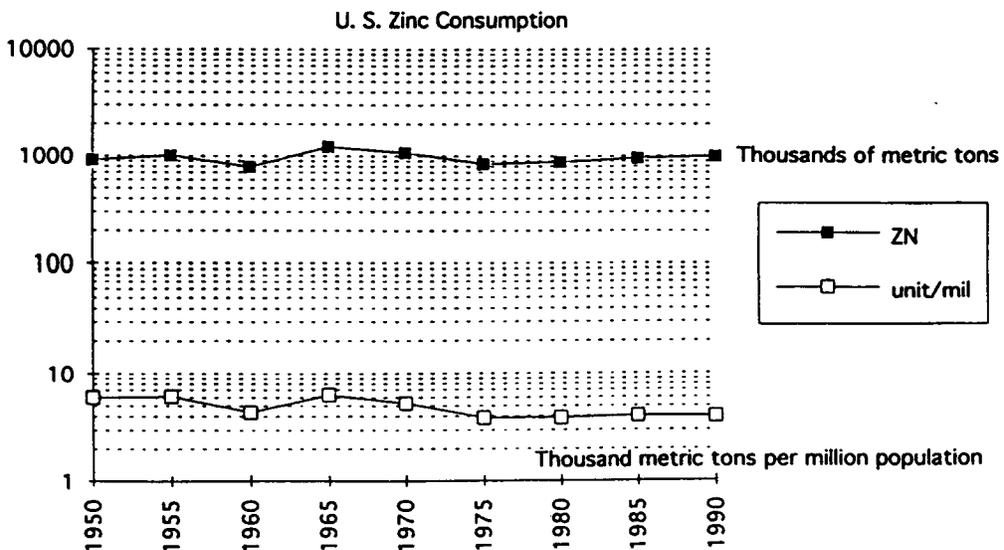


FIGURE 15: U.S. zinc consumption, expressed as thousand metric tons and as thousand metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

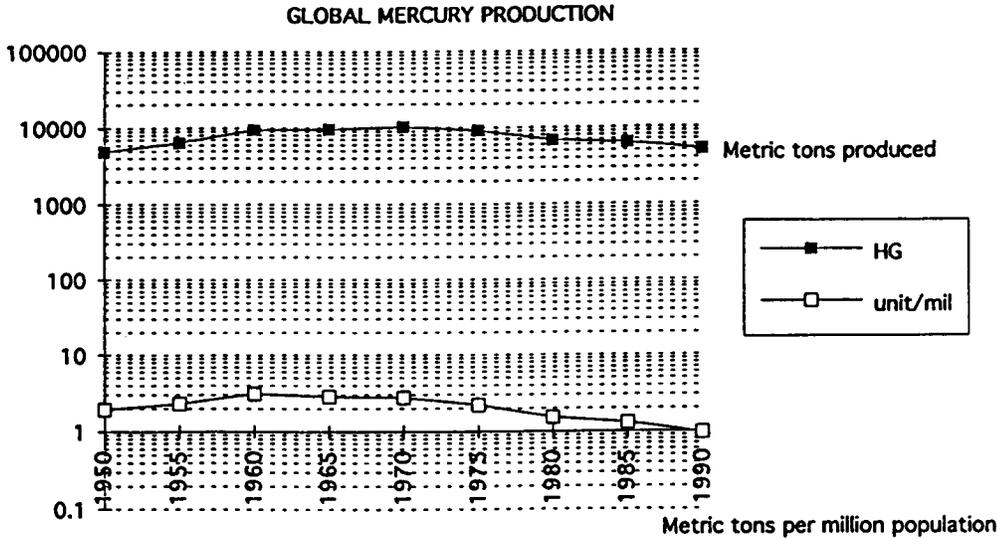


FIGURE 16: Global mercury production, expressed as metric tons and as metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

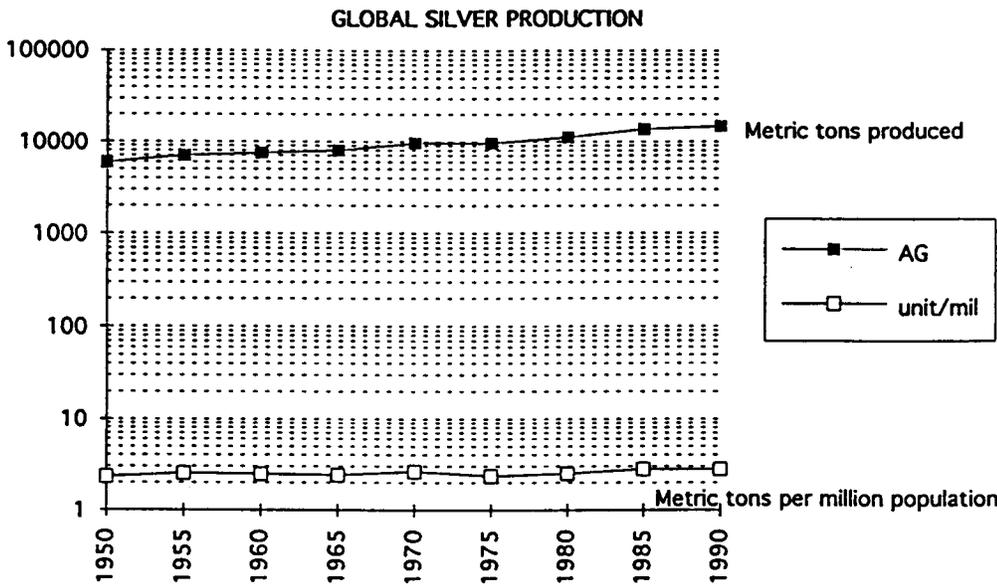


FIGURE 17: Global silver production, expressed as metric tons and as metric tons per million population (from Aktiengesellschaft, 1960, 1971, 1981, 1991).

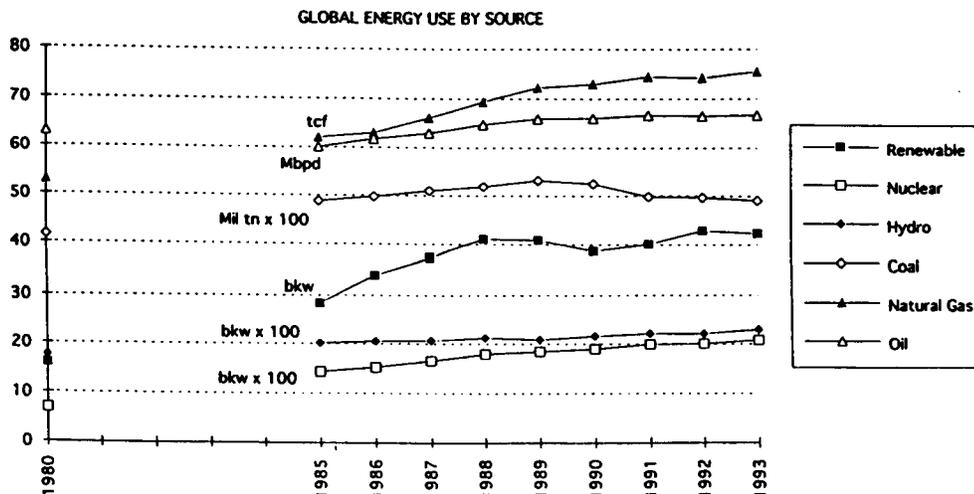


FIGURE 18: Global energy consumption by energy source. Note that the scale for each energy source differs. Renewable energy is scaled in billion kilowatts; other energy sources are scaled in much larger units, such as hundreds of billions of kilowatts (from U.S. Department of Energy, 1994).

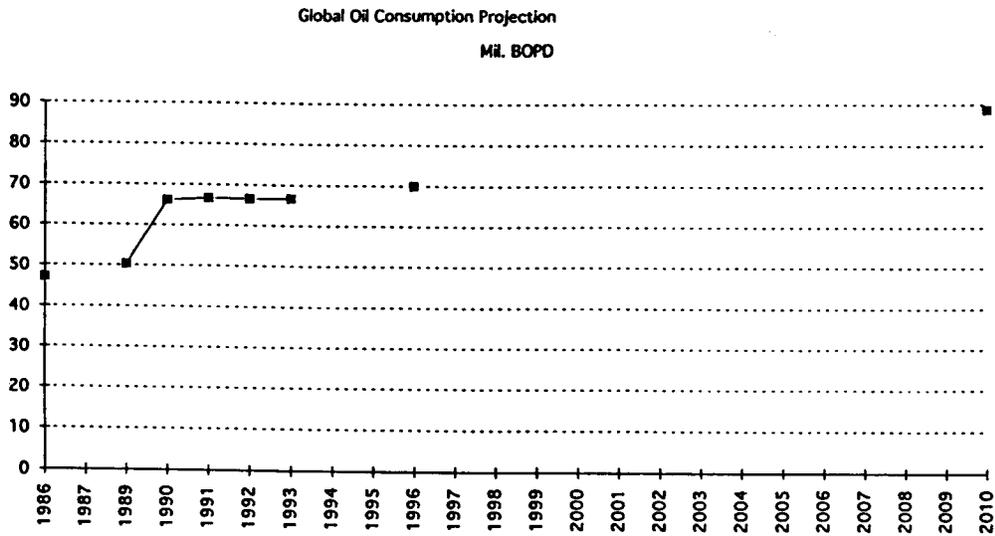


FIGURE 19: Global oil consumption projection in millions of barrels of oil per day (BOPD). By 2010, projections show global oil consumption to be >90 million BOPD (from U.S. Department of Energy, 1994).

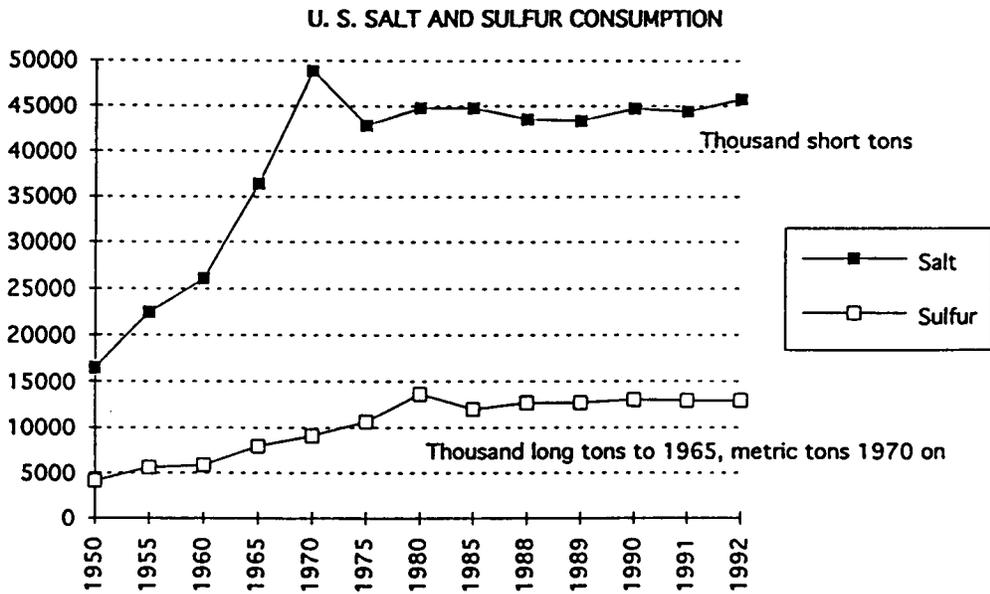


FIGURE 20: U.S. Salt and sulfur use (from U.S. Department of Interior, Bureau of Mines, 1950-1993).

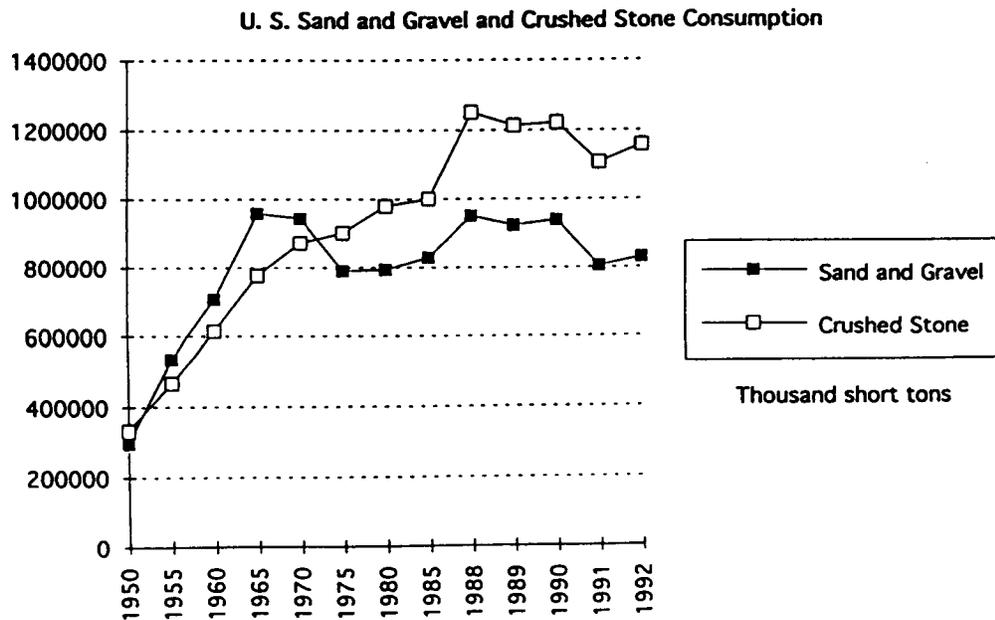


FIGURE 21: U.S. sand, gravel, and crushed stone consumption (from U.S. Department of Interior, Bureau of Mines, 1950-1993).

PERCENT PUBLIC LAND WITH RESTRICTED MINERAL ACCESS

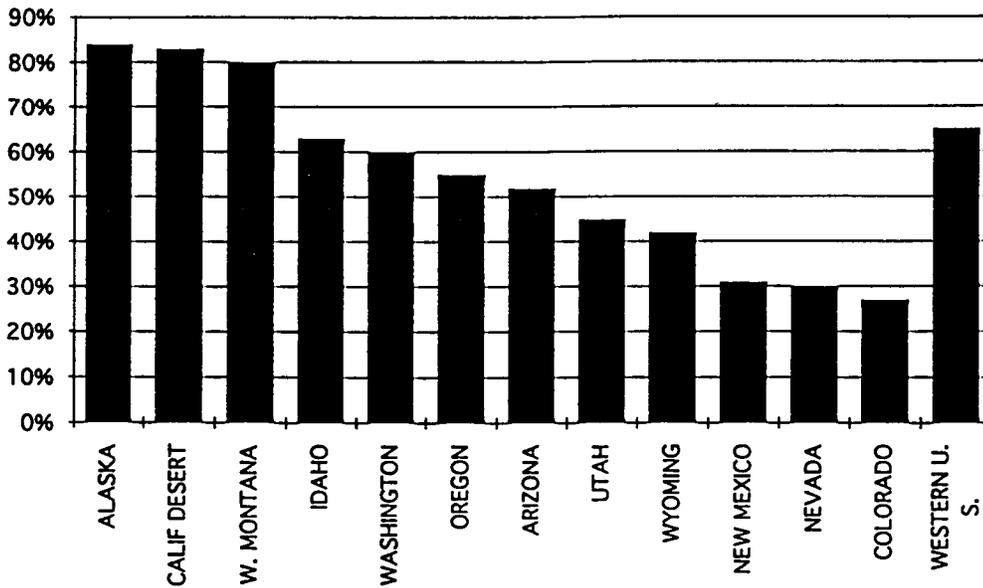


FIGURE 22: U.S. percent restricted public lands access for energy and mineral development (from Beach et al., 1985; Longwill, 1985; Crandell and Hamilton, 1986; Gray et al., 1988; Hyndman et al., 1989; Roberts et al., 1989; Anderson et al., 1991; Hyndman et al., 1994;).

crease copper demand by 637,500 tons/yr, for a total demand of 2,759,500 metric tons. This is a 30% increase in demand with no per capita increase. Similar calculations may be made for other resources. The impact of growing population on resource demand is very serious.

Tin and mercury have reduced impact in the global economy, with reductions in per capita use from 1900 to modern times, probably reflecting the reduction use of "tin" cans, the reduction of use of mercury in thermometers and gold amalgam processing, and recent recognition of the toxicity of mercury (Figures 12, 13, and 16). Several metals have reached consumption equilibrium in global and U.S. society. Zinc, silver, and lead demand is stable with respect to per capita demand but increases in production are required because of population growth.

Energy

Energy consumption is a relative measure of standard of living. Consumption of energy replaces human and animal work, relieving drudgery and bringing mechanical and electronic advantage to society. Global sources of energy are varied, and the consumption of nearly all types of energy is growing. Fossil energy continues to be the greatest source of energy by far (Figure 18). Petroleum (natural gas and oil) is the largest supplier of energy and the most easily transported. Global demand is projected to reach 90 million barrels of oil per day by 2010 (Figure 19). No problem in meeting that demand is indicated, although prices may stabilize if that scenario comes to fruition. Global production averaged 62,123,000 barrels/day in 1995. The projection for 2010 is for nearly 50% greater demand than at present.

U. S. TIMBER AND LUMBER PROD., IMPORTS, CONSUMPTION

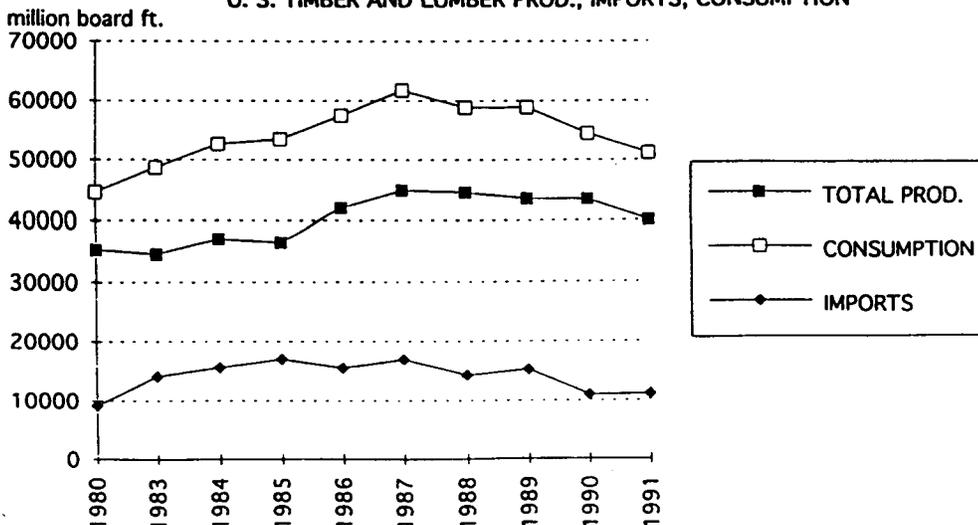


FIGURE 23: U.S. timber and lumber production, imports, and consumption in millions of board feet (from U.S. Bureau of the Census, 1994).

U. S. FISH CONSUMPTION PER PERSON

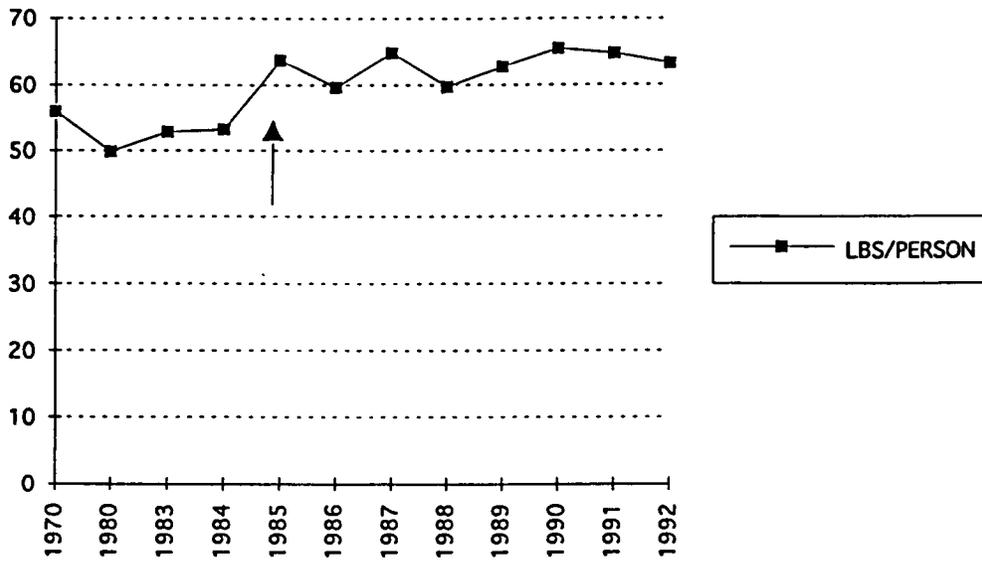


FIGURE 24: U.S. fish consumption per capita. Arrow is time of significant recognition of health benefits of eating fish (from U.S. Bureau of the Census, 1994).

U. S. FISH CONSUMPTION, CATCH, AND IMPORTS IN MILLION POUNDS, LIVE

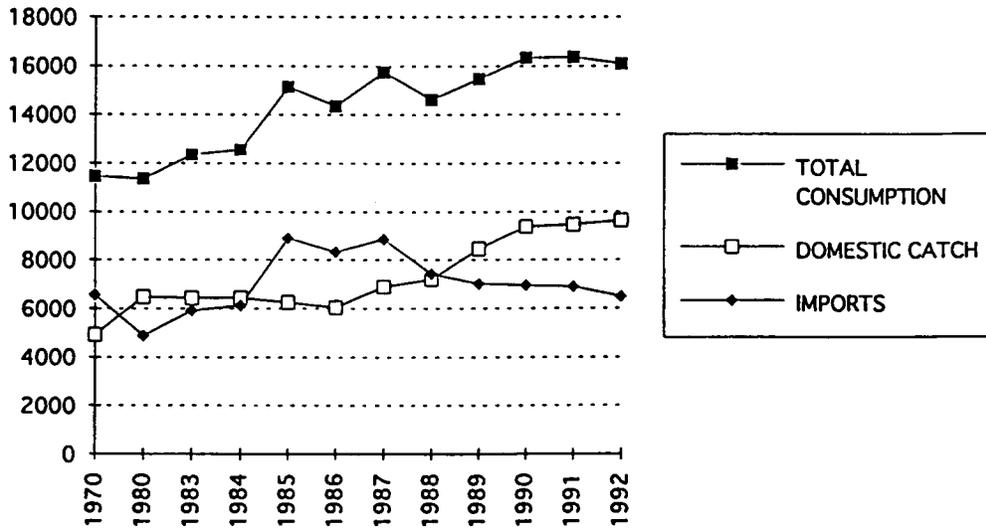


FIGURE 25: U.S. fisheries production, imports and consumption in millions of pounds live weight (from U.S. Bureau of the Census, 1994).

MILLIONS OF DOLLARS VALUE FARM PRODUCTS

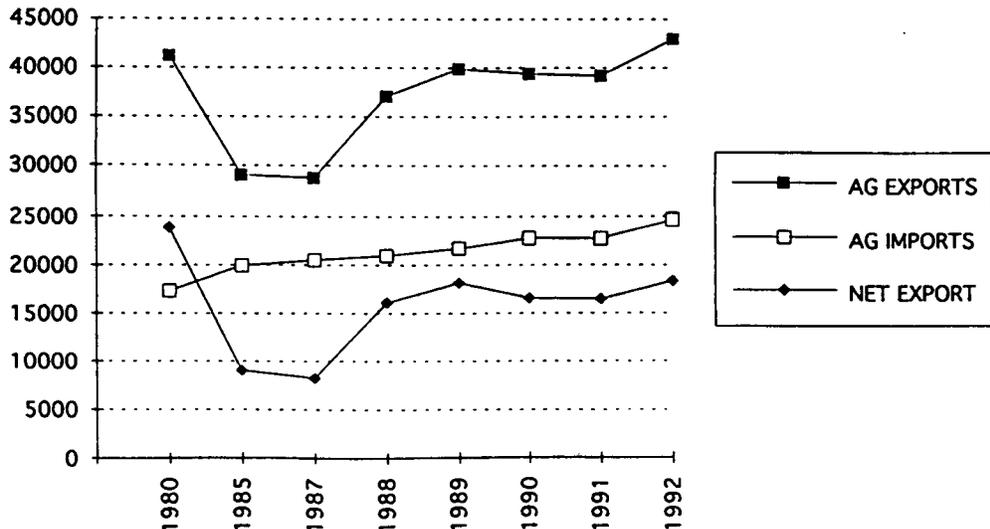


FIGURE 26: U.S. agricultural exports and imports in millions of dollars (from U.S. Bureau of the Census, 1994).

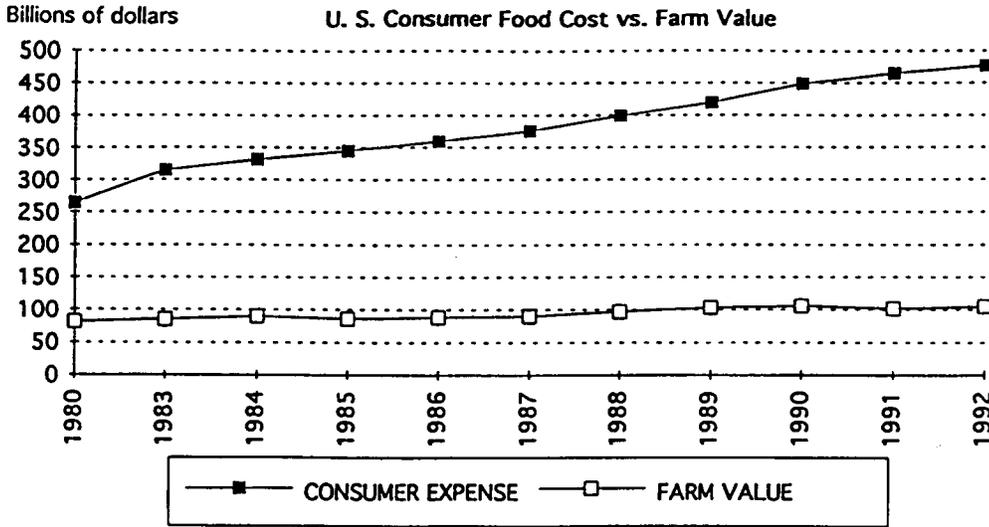


FIGURE 27: U.S. agricultural product value versus received farm value in billions of dollars. Farm income has not risen at the rate of rise of consumer prices (from U.S. Bureau of the Census, 1994).

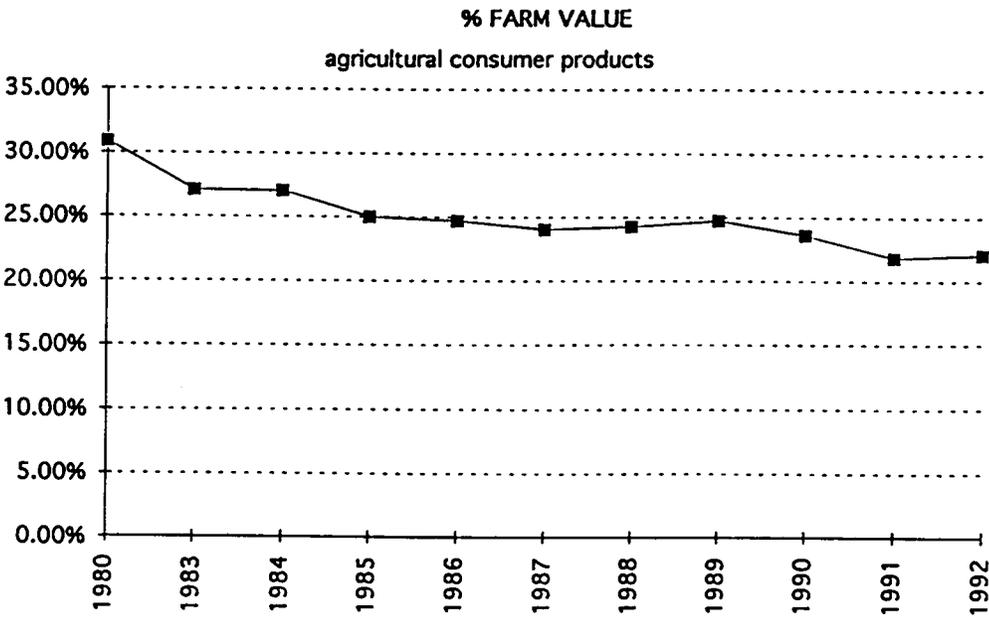


FIGURE 28: U.S. farm receipts as percentage of consumer prices (from U.S. Bureau of the Census, 1994).

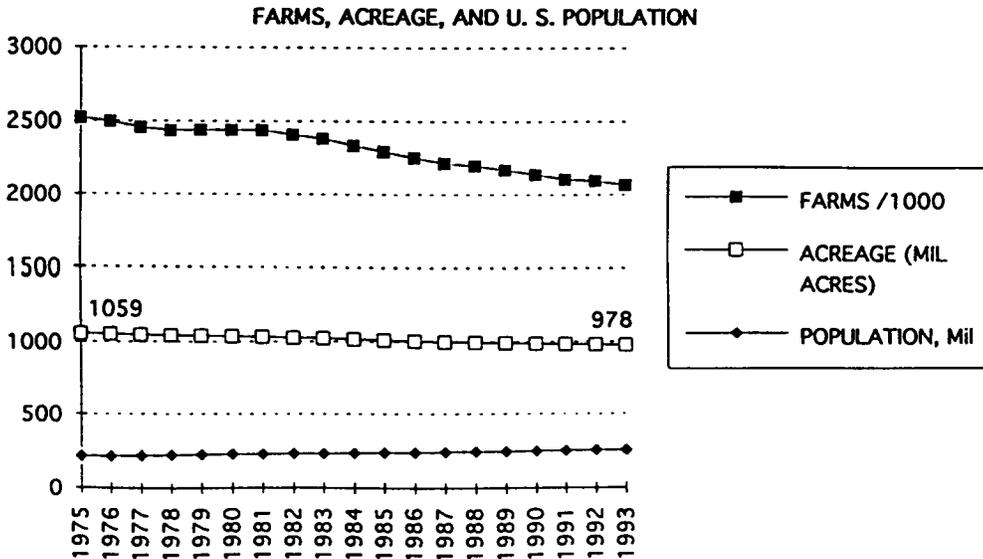


FIGURE 29: U.S. farm acres and number of farms versus population. The number of farms decreases rapidly starting in 1982. Total acreage farmed decreased but not as rapidly, indicating some growth in the size of average farms, as well as loss of land to suburban development and abandonment (from U.S. Bureau of the Census, 1994).

In the United States, ~18,000,000 barrels of oil per day are consumed. Domestic oil production has dropped from 8,870,000 barrels per day in 1984 to 6,640,000 in 1995, a 25% drop and consequent equivalent increase in imported oil.

Nonmetallic Minerals

Unglamorous but necessities of life, nonmetallic minerals have a high "place" value as compared to high "unit" values of metallics. Use of nonmetallic minerals is heaviest in the chemical industry, infrastructure development (roads and bridges), and building construction. Consumption levels of nonmetallics is surprising to many people (Figures 20 and 21). In the United States, salt and sulfur consumption grew rapidly from post-World War II to ~1980 and since then has leveled. Salt consumption has more than doubled while sulfur consumption approximately doubled. Per capita use is dropping.

Sand, gravel, and crushed stone use shows a similar rise from the end of World War II. Because these commodities reflect the general economy because of their use in construction, the consumption levels may not be easily interpreted (Figure 21). Contraction of the economy during the oil embargo of the mid-1970s is reflected in consumption levels, as is the expanding economy from them to the early 1990s. Tremendous quantities of these commodities are demanded each year, yet the location of mines, quarries, and pits for these materials must be located near the area of use. Transportation costs reach \$0.20/ton mile in the mid-continent region. Suburban overstepping of these resources can be a serious problem in metropolitan areas.

RESOURCE ACCESS

Future supplies of metallic and nonmetallic minerals frequently are located in western lands, where scenic and recreational land uses conflict heavily with mineral and energy extraction uses. Public lands (i.e., those lands managed by federal agencies) have been retained in federal ownership for various reasons since the days of open homesteading and now are managed for nonresource use, obviating much of the "multiple use" philosophy that prevailed during the post-World War II years until the mid-1970s. New laws and regulations have decreased mineral entry access to these lands to preserve them in their present state. This is to the detriment to the development of the national mineral estate but to the advantage of recreational and aesthetics interests. The trend in recent years has been to designate large wilderness areas and endangered species habitats, effectively reducing or eliminating mineral and energy development or other occupancy uses. The extent that these withdrawals impact the ability of the nation to meet its mineral needs can be measured by the amount of land withdrawn. Of 576,869,000 acres (233,455,686 hectares) of federal lands, ~62% or 359,152,000 acres (145,346,823 hectares) are restricted

from mineral access to some degree and 322,189,000 acres (130,388,102 hectares) (56% of all federal lands) are severely restricted from access (Figure 22). Further withdrawal efforts are continuing in Congress.

NONGEOLOGIC EARTH RESOURCES

Several other earth resources are crucial to the well-being of society. Fishing, timbering, and agriculture all play essential roles in society. In the United States, extensive home ownership and availability of housing is dependent on access to lumber. Paper is created from forest products. Seafood restaurants are popular in the current health craze. The nation provides citizens with a cornucopia of fibers, fruits, vegetables, and meats. All of these are earth resources upon which our social fabric is constructed.

Timber and lumber consumption exceeds production in the United States. Wood imports rose ~75% between 1980 and 1986 and then declined to 1980 levels by 1991, reflecting a construction boom and later "bust" in that decade (Figure 23). Production rose during the early 1980s and dropped only a few percentages in the latter part of the decade, although consumption declined considerably during the recession of 1991. Consumption remained at a >10% increase between 1980 and 1991, probably reflecting the population increase. Homebuilding and construction levels control much of the use of wood products.

Fisheries consumption has risen dramatically in the United States since 1970 (Figure 24). The emphasis on the health value of seafood and increased production of seafood resulted in a significant jump in per capita consumption in 1985 from ~52 to 63 lbs (23.6-28.6 kg)/person. New processing methods for bulk conversion of raw fish to derivative products (e.g., imitation crab from Alaskan pollock) helped fuel the rapid increase in U.S. consumption. The domestic catch increased dramatically from ~1988 through 1992 with corresponding lessened imports (Figure 25). Part of this may be due to new and tightened restrictions on the foreign fishing fleet within our 200-mile limits. Loss of the Pacific salmon fishery in 1995 may seriously impact the domestic catch and imports may rise. There is concern that the global oceans may be overfished.

Agriculture provides most of the food that graces the nation's tables. The U.S. agriculture policy has been based on inexpensive and abundant food and the nation's farmers have always responded. The United States has the cheapest food prices in the world and an abundance that many countries can only dream about.

Agriculture export/import balances are increasing in value each year (Figure 26). Exports dropped precipitously in 1985 and did not recover until ~1989; however, increasing import values kept the U.S. net export below 1980 levels through 1992, the last year of available data. Farmers receive an ever-lessening percentage of value of American

food (Figure 27). Whereas in 1980 the farmer received ~31% of the consumer market-basket cost in revenues, by 1992 the farmer received only 22%. When farm value is plotted against consumer expense (Figure 28), the disparity is easily seen; between 1980 and 1992 consumer food costs nearly doubled, but farm income increased only 10%.

A consequence of this disparity in income is the decline of the number of American farms and the number of hectares farmed (Figure 29). The number of farms dropped from ~2,500,000 in 1975 to a little over 2,000,000 in 1993. There was a net increase in the size of the average farm. The area farmed dropped from 1,059,000,000 to 978,000,000 acres. Some of this loss was to suburban development: some was to abandoned farms or conversion to hobby farms. Because population continues to increase, individual farms must become more efficient to feed society. Each farmer's production feeds more and more people each year. Each Kansas farmer's crop feeds the equivalent of ~100 people.

SUMMARY ●

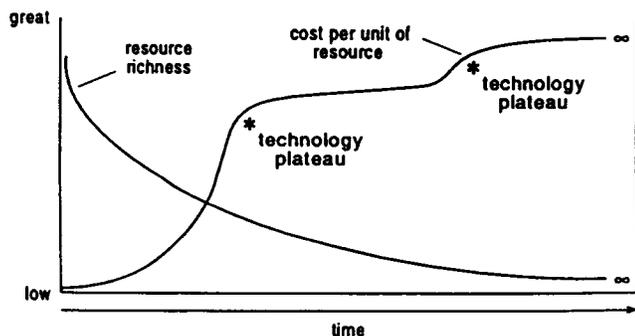
Per capita consumption rates for earth resources in the United States are stabilizing, but population increases continue to place demands for more and more earth materials. On a global scale, the demand for new earth resources of all kinds is staggering, as other countries struggle to survive and their societies aspire to U.S. and European material affluence. Supplying these resources is the task of the earth resource professions. Minerals and energy are the province of the geologist. Extraction of minerals and energy is currently conflicting with popular demand for preservation of scenery and recreational opportunities free of industrial development. In this setting, some speculate on when mankind will run out of the resources upon which society depends so heavily. The answer, of course, is that geologic resources will not run out (Figure 30). The ability or willingness to pay for certain resources are the limiting factors. Society will substitute other materials for those that become too expensive. Copper will never be "gone", but new, rich, easily

mined deposits may not be readily discovered. There will always be lower grade deposits until the costs of mining and smelting become too great to bother. Substitution of other materials then takes place. Sometimes, as in the case of plastics and aluminum, the technical superiority of new materials and technology simply overcome the market for formerly used materials, such as iron.

Geologists face a difficult task in meeting future U.S. and global resource needs. It would be helpful if society understood these needs.

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The nation will not run out of resources, it may lose the ability to pay for them.....as richness goes down, cost goes up.

FIGURE 30: Economic limits to resource extraction, showing the relationship between resource richness and cost per unit. As richness declines, the cost of each unit goes up. Technological developments can temporarily stem rising unit cost (modified from Gerhard and Weeks, 1996).

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DISCOURSES ON SUSTAINABILITY IN THE OIL INDUSTRY

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Discourses on sustainability differ widely in their philosophy and focus. Common to all is the understanding that human development cannot and does not take place without some interaction with, and influence on, the natural environment. Beyond this, the differences may be greater than the similarities. A broad classification contrasts the radical with the conservative, the imaginative with the prosaic. The key participants are, variously, the government and its institutions, bureaucrats and "experts," the scientific community, private corporations, special interest groups, the community at large and nature itself.

The response by the international oil industry to environmental concerns, in particular climate change, during the 1990s has been channeled through several distinct discourses, each emphasizing different aspects of the relationships between human potentials and needs on the one hand and the earth and its resources on the other. These are briefly characterized as follows:

Denial: typical of early responses to a perceived threat to a previously unchallenged activity, this discourse attempts to downplay the importance of sustainability issues and to deny their legitimacy in the absence of rigorous proof. The "denial" discourse runs parallel with an anti-romanticist argument which seeks to bury environmental idealism in its own myths.

"Promethean": an optimistic view of the essentially unlimited nature of oil and gas resources under appropriate economic and technological conditions, to be exploited to their full potential through a philosophy of "wise use" wherein environmental concerns are countered by human ingenuity. Within the same discursive domain there is a counter-argument that oil and gas resources are, indeed, rather limited and that their conservation makes good sense both economically and environmentally.

Market environmentalism: an economic rationalist approach that values environmental assets and liabilities in market terms. Carbon emissions trading and the Clean Development Mechanism feature in this discourse.

Balance: this discourse acknowledges the inevitability of tradeoffs between energy resource use and ecosystem preservation, and advocates a scientifically-based approach to "balancing" economic and environmental goals, with a focus on technological "fixes".

Ecological Modernization: in this approach, the tensions between government, industry, scientists and environmentalists are resolved through “corporatist” partnerships that reformulate the nature of energy-dependent infrastructures with the goal of decoupling economic growth from energy use.

The way one discourse views the world is not always easily comprehended by those who subscribe to other discourses. The analysis of each involves an understanding of the worldview of its proponents and a deconstruction of the metaphors and rhetorical devices employed. Each can then be fleshed out by looking at its historical origins and the politics around which it has evolved. Such analysis is of value in determining whether the discourses within the oil industry form an evolving and converging set of arguments from which to chart a course for a sustainable energy future, or whether there are contradictions between them which must be resolved through a deliberate policy process.

In the context of this conference, recognition of the range of extant discourses is a first step toward the initial goal of eliminating the rhetoric and avoiding “a scrambling for dominance of perspective.” Understanding where participants stand in this regard will facilitate meaningful dialogue between adherents to different viewpoints without having to return continually to first principles. Moreover, interchange can then occur across discourse boundaries and it is this process, which is dialectical in nature, that brings about change.

Position Paper for Conference on

Meeting Societal Resource and Environmental Requirements for the 21st Century

Effective Studies of Ecosystem Management/Resource Extraction Relationships Require Multi-disciplinary Science

Marguerite J. Kingston
U. S. Geological Survey

The rapid rise of the world's population, coupled with the universal drive toward higher living standards, places an increasing burden on the carrying capacity of the Earth. Continued population pressure could endanger the earth's habitability. Increased population also means a greater demand for natural resources, including clean water, topsoil, and industrial minerals as well as hard rock minerals, and fossil fuels. To improve our stewardship of this fragile planet, researchers need to address an earth system that integrates geology, hydrology and biology with biochemical elements. Effective environmental science not only spans the breadth of the natural sciences, but also engineering and social systems, and the socio-political arena.

Broadly trained scientists are needed by society to deal with and solve these twin challenges of environmental deterioration, and diminishing Earth resources. Although it is often repeated that the really interesting discoveries are to be found at the interfaces between scientific fields, many universities do not provide a supportive environment for scientific efforts that cross disciplinary (departmental) boundaries. In addition, there exists a scientific illiteracy among working scientists who are forced by our present educational system into extreme specializations at early stages of training. A physicist may know little about genetics. Biologists don't understand semi-conductors. The education system needs to provide graduate students with new opportunities for interdisciplinary study and research. A new generation of scientists and engineers need to be trained to address interdisciplinary problems related to biogeochemical processes in complex environments. In addition, science education for non-scientists should provide an integrated science curriculum that focuses on societal issues. A more integrated approach to science education will allow science to be taught in a broader societal context. If the difficult problems surrounding environment and resources issues are discussed in the classroom, science will become more relevant to the average student.

Interdisciplinary science already has made important advances in mineral-environmental research including bioremediation of environmental contaminants. Bioremediation, the degradation or stabilization of contaminants by microorganisms (e.g., bacteria, fungi, actinomycetes, and cyanobacteria) is a safe, effective, and economic alternative to traditional methods of remediation.

designed with the goal of providing information on single agency missions. They also tend to focus on a single resource or issue.

The National Science and Technology Council (NSTC), a cabinet-level council, is the principal means for coordinating science and technology across the federal government. Its Committee for Environment and Natural Resources (CENR) has recognized a high priority need to integrate and coordinate environmental monitoring and research networks and programs across the Federal government. This effort will allow a comprehensive evaluation of our Nation's environmental resources and its ecological systems. By integrating these monitoring and research activities, the Nation can begin to assess the status of resources and their multiple uses in the context of entire ecosystems. Integration will add value to existing programs by linking broad-based survey, inventory, and monitoring information to research on environmental mechanisms.

Science in the National Interest is a science policy document released by the President in 1994, that reflects the efforts and contributions of a diverse group of individuals drawn from academia, industry, professional societies and government. The actions described in this document are being implemented by the NSTC. I would like to close by connecting the five goals set in ***Science in the National Interest*** to the importance of multi-disciplinary research to effective studies of ecosystem management and resource extraction.

These are to:

- Maintain leadership across the frontiers of scientific knowledge
- Enhance connections between fundamental research and national goals
- Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human, and financial resources
- Produce the finest scientists and engineers for the twenty-first century
- Raise the scientific and technological literacy of all Americans

Background Information for:

Panel 1: Global standard of living, present and future

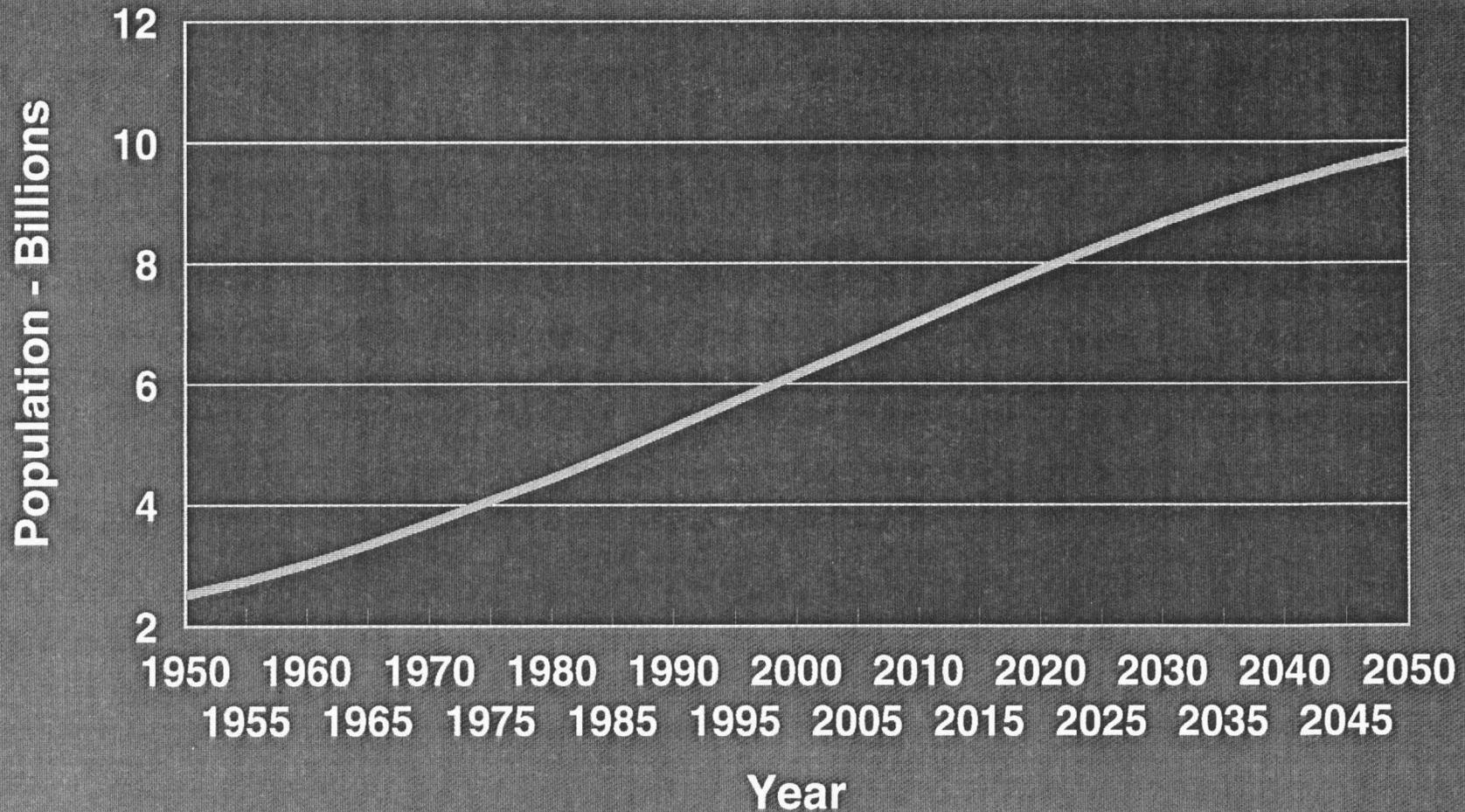
P. Patrick Leahy, Chair

- Impacts on resource supplies to U.S.
- Global population growth and demands
- Geologic process controls on earth and biologic systems

Meeting Societal Resource and Environmental Requirments for the 21st Century

Taos, New Mexico
October 11-14, 1998

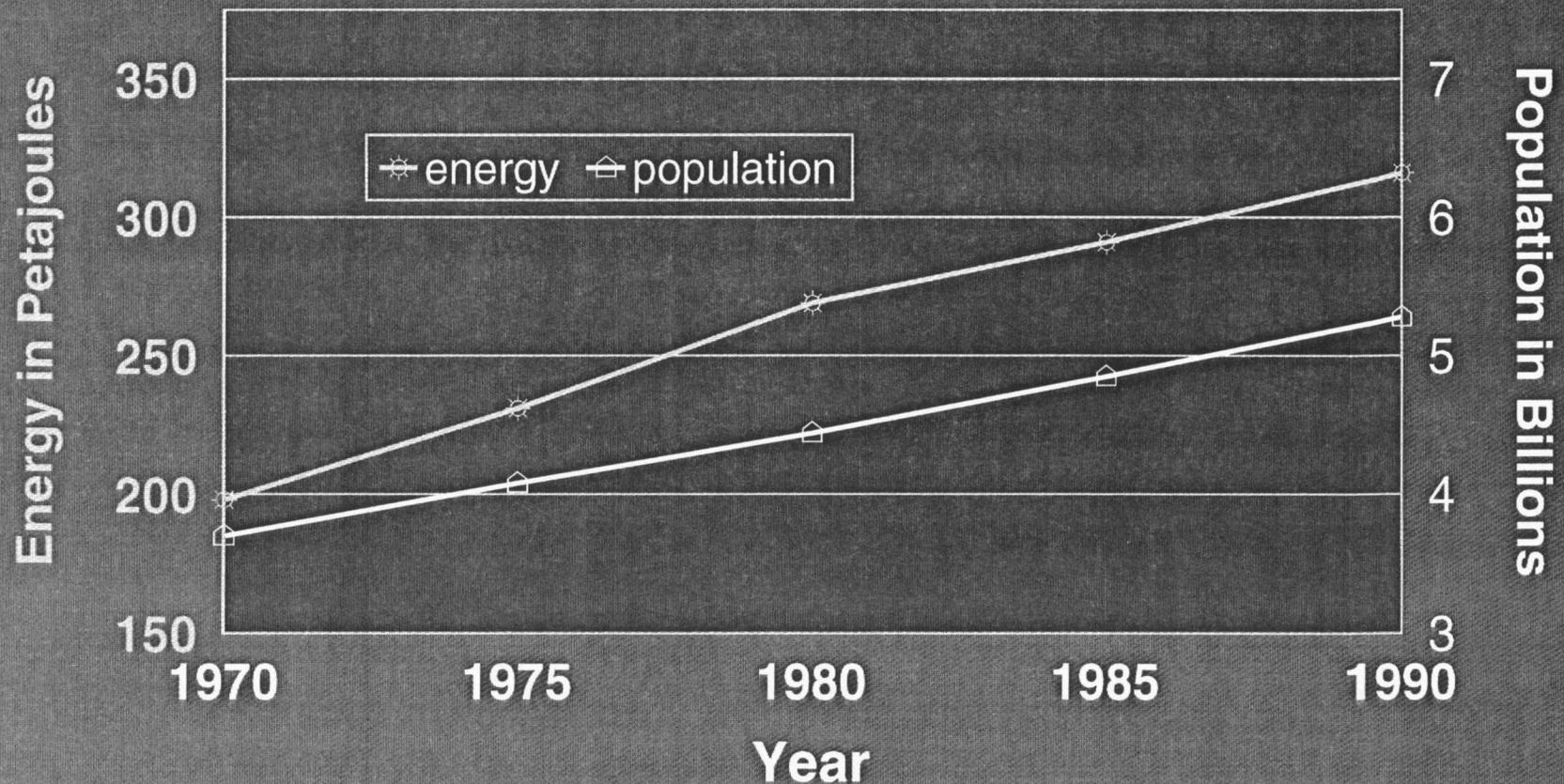
World Population 1950 - 2050



Source: World Resources 1996 -1997



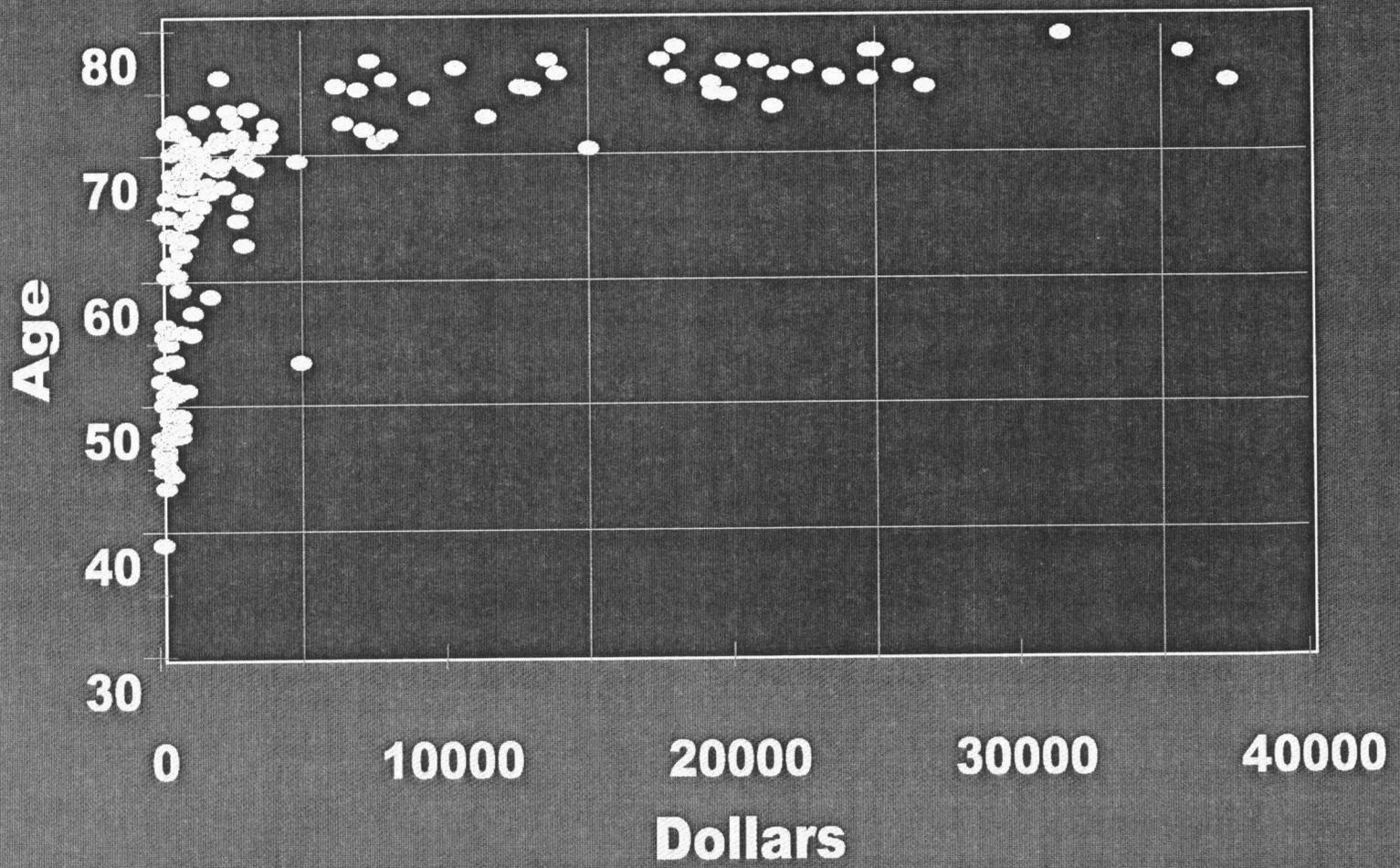
Growth in World Population and World Energy Consumption, 1970 - 1990



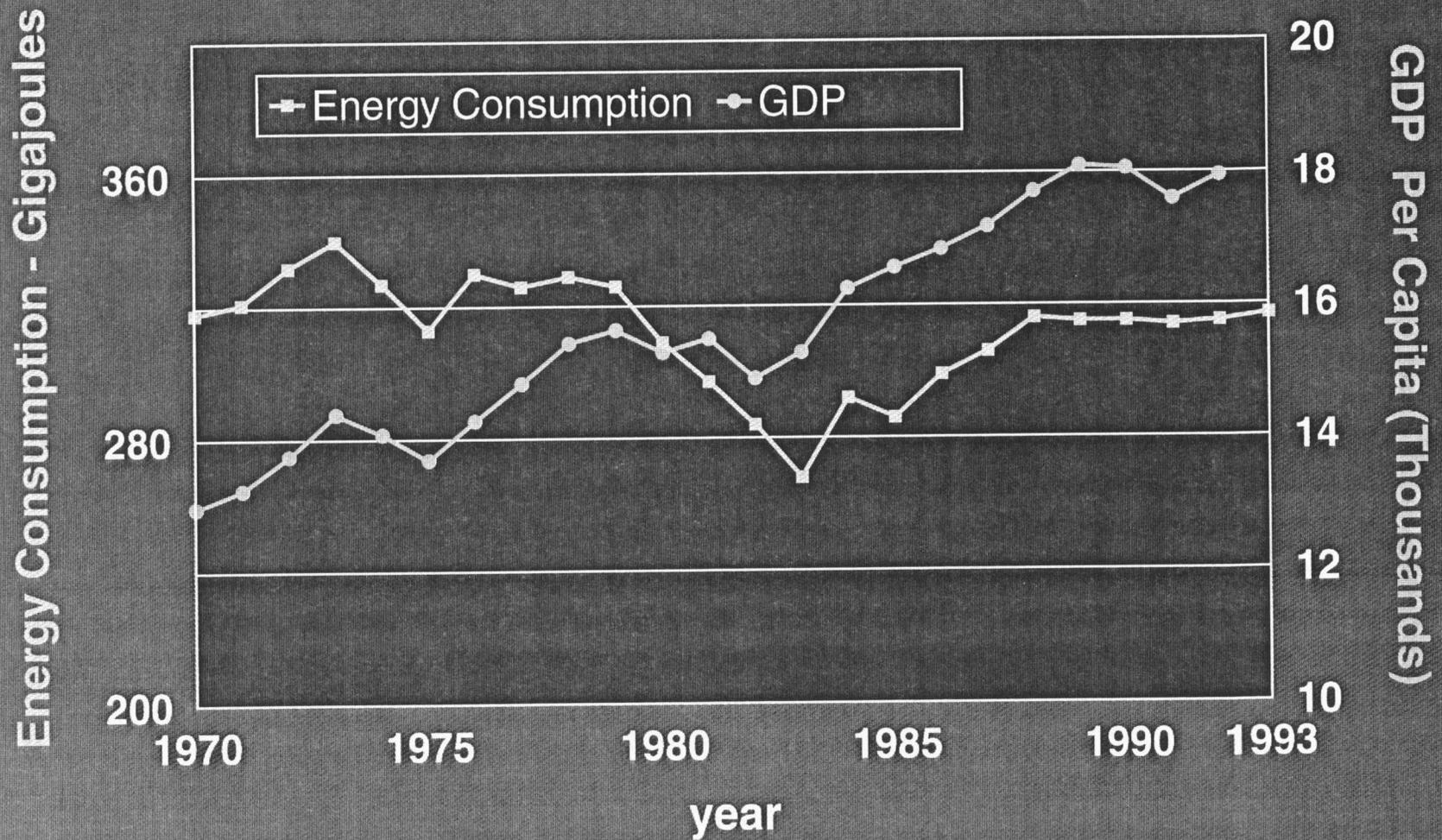
Source: World Resources 1996 -97

USGS

Life Expectancy VS GNP Per Capita



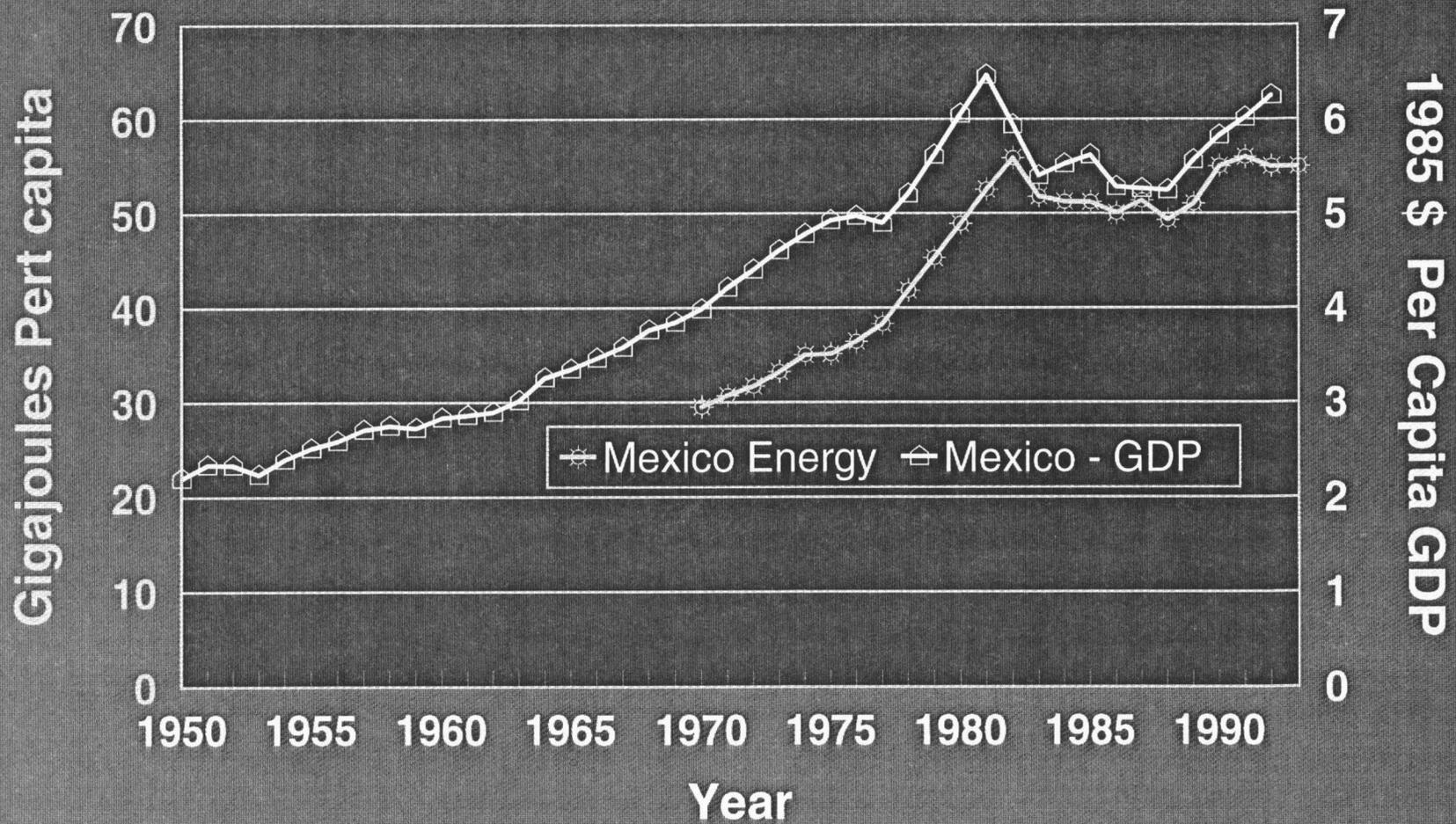
GDP and Energy Consumption, USA 1970 - 1993



Source: World Resources Institute, 1996

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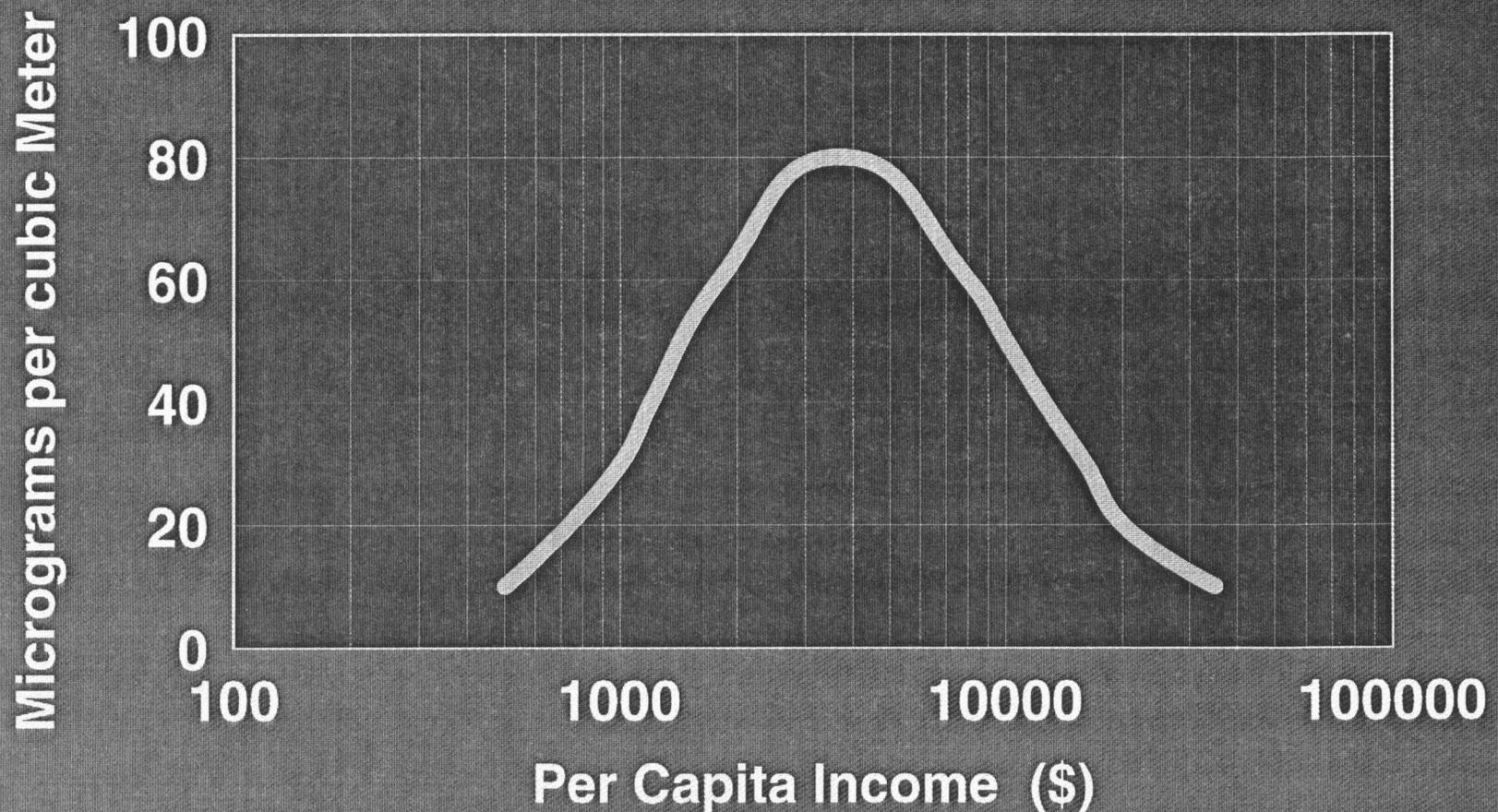
GDP and Energy Consumption, Mexico 1950-1993



Source: World Resources Institute, 1996

USGS

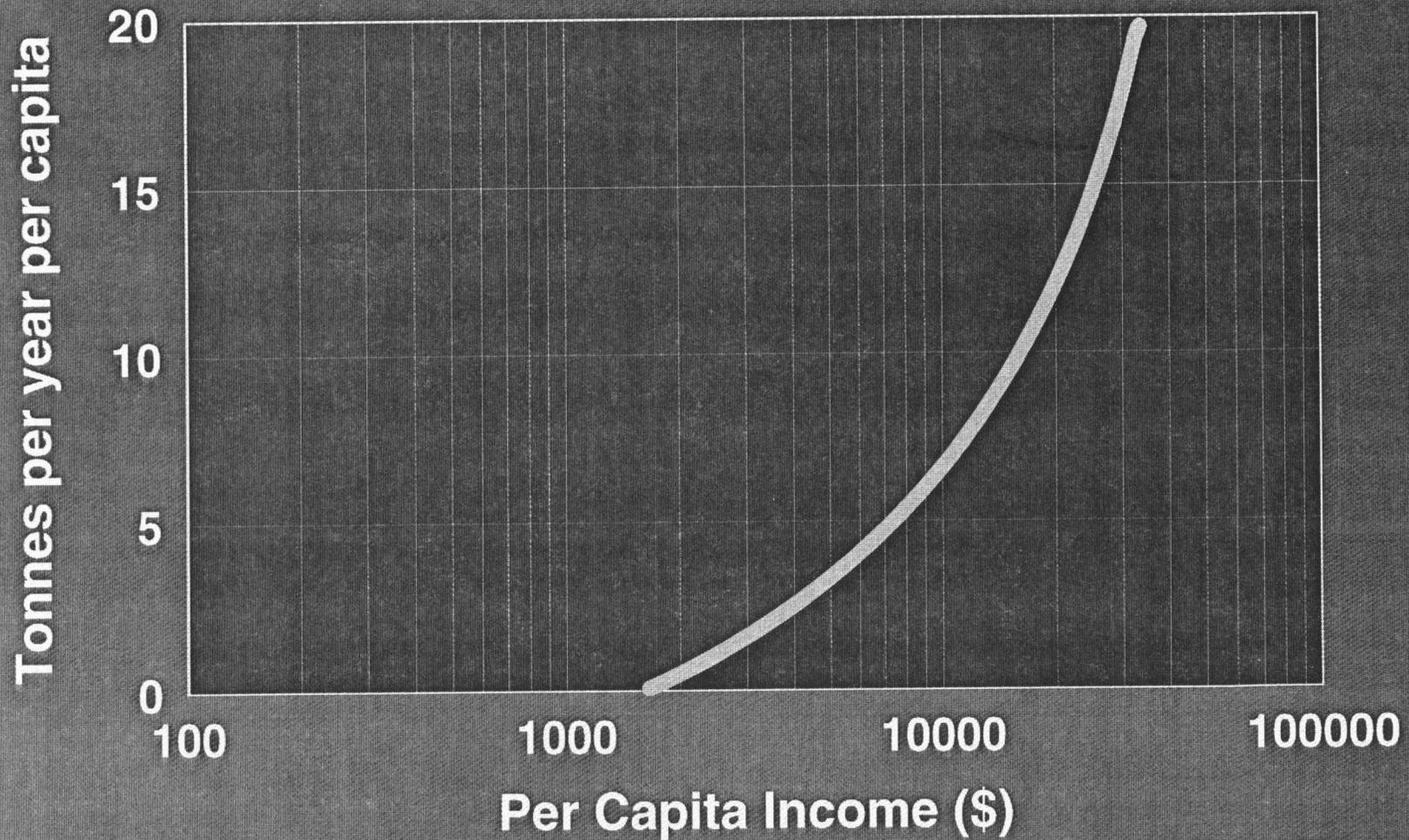
Kuznets Curve - Ambient Sulfur Dioxide



After Shafik, 1994

USGS

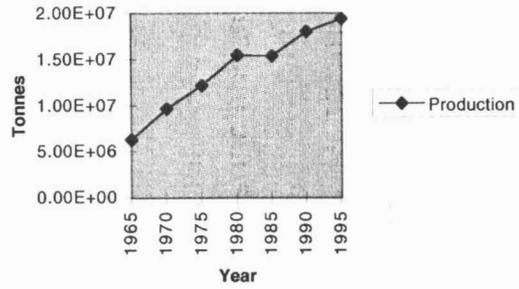
Carbon Emission Per Capita



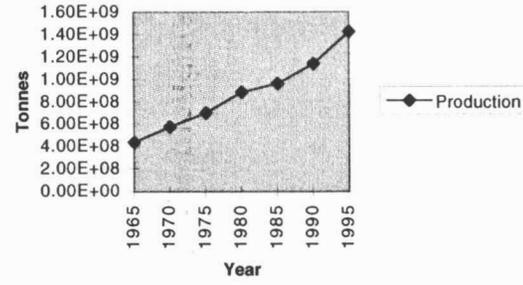
After Shafik, 1994

USGS

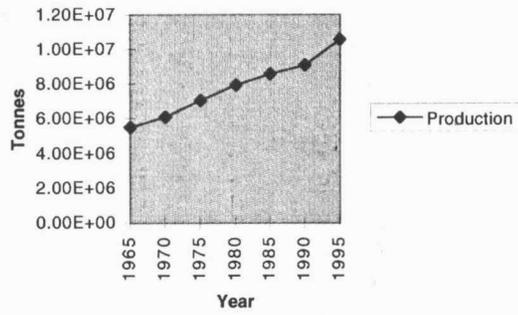
World Aluminum Production



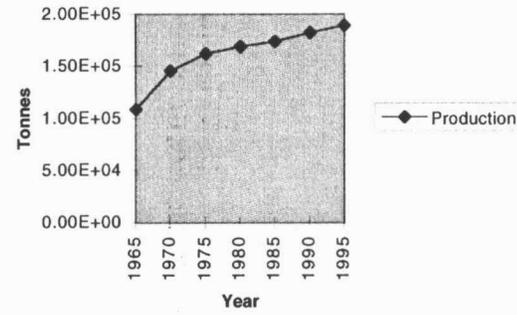
World Cement



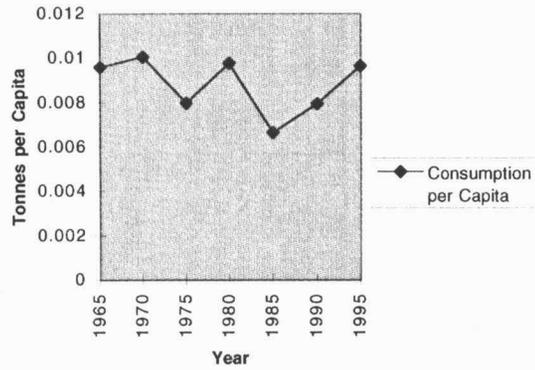
World Copper (Smelter)



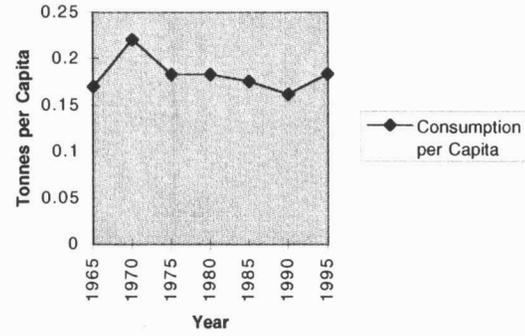
World Salt



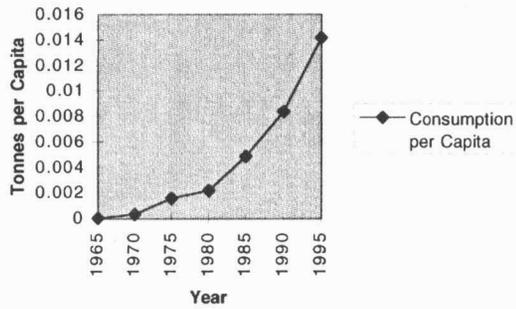
USA Copper Consumption per Capita



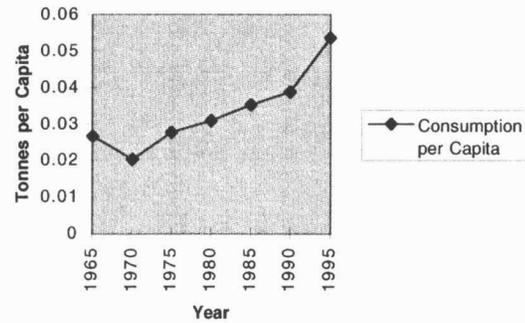
USA Salt Consumption per Capita



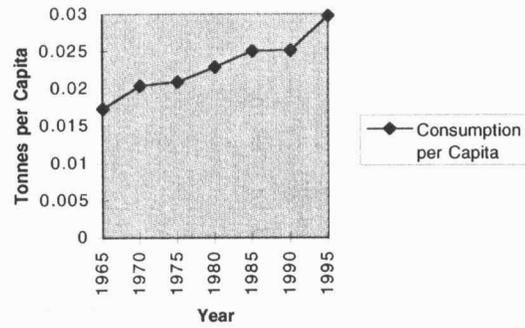
Korea Copper Consumption per Capita



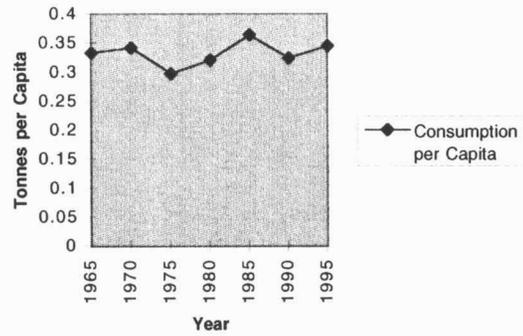
Korea Salt Consumption per Capita



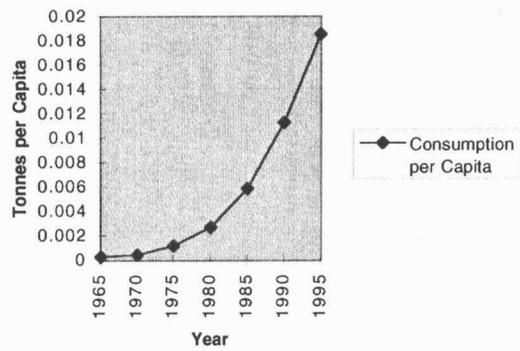
USA Aluminum Consumption per Capita



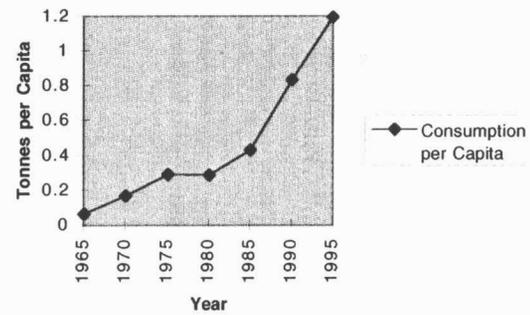
USA Cement Consumption per Capita



Korea Aluminum per Capita

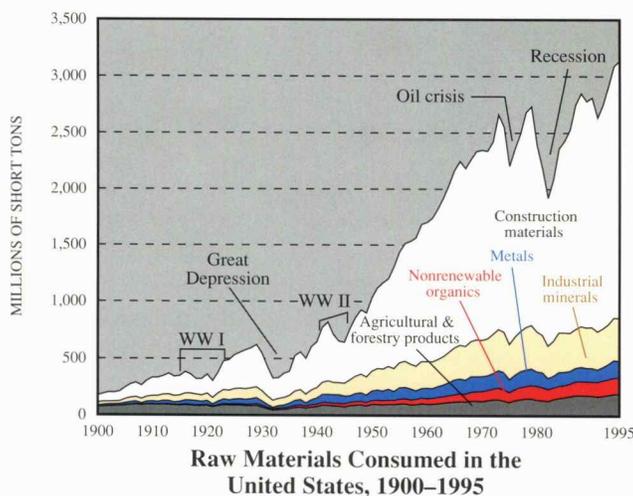
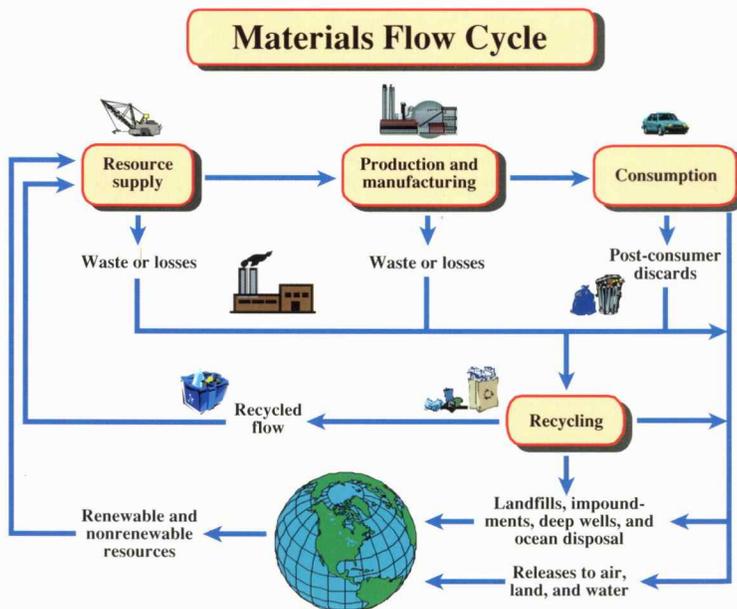


Korea Cement Consumption per Capita



Materials Flow and Sustainability

Materials extracted from the Earth are necessary to produce our most fundamental needs – food, clothing, and shelter. Materials are needed to maintain and improve our standard of living. Understanding the whole system of materials flow, from source to ultimate disposition, can help us better manage the use of natural resources and protect the environment.



Since 1900, use of construction materials such as crushed stone and sand and gravel has increased from about 35 percent to 60 percent of total non-food, non-fuel raw materials consumption in the United States. Consumption of non-food and non-fuel agricultural and forestry products has dropped from about 60 percent to 5 percent of total raw materials consumption during the same period.

Materials Flow

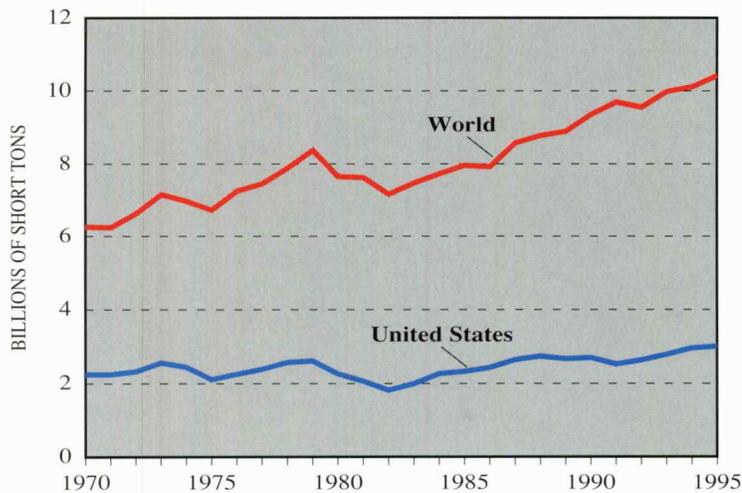
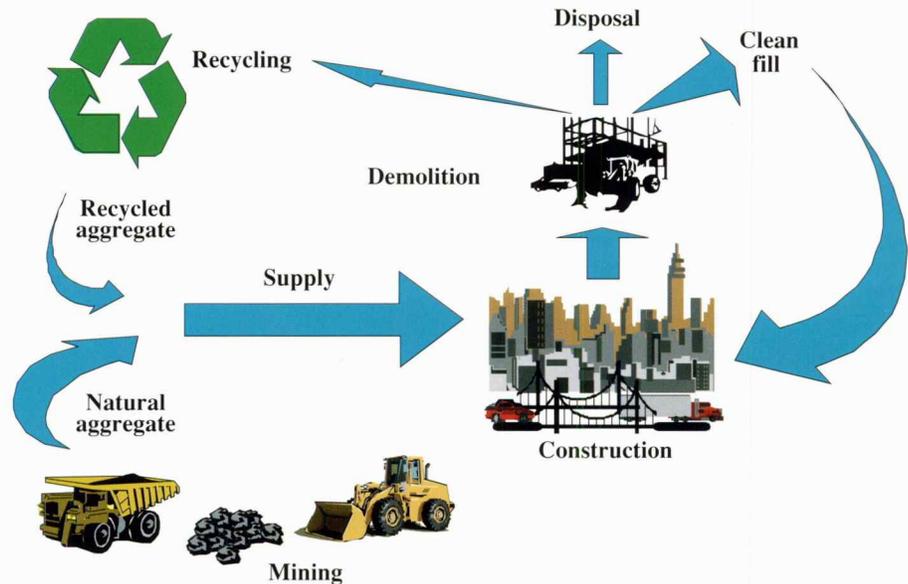
Materials flow, in its most literal sense, is a systems approach to understanding what happens to the materials we use from the time a material is extracted, through its processing and manufacturing, to its ultimate disposition. The U.S. Geological Survey (USGS) investigates how materials affect the economy, society, and the environment. The purpose of this work is to understand how and why we use our resources and to identify policies and practices that make resource use more efficient and more protective of the environment. Some materials-flow studies identify and trace trends that, if they continue, could have worldwide economic and environmental impacts. For example, when considering the total domestic non-food, non-fuel material consumption, a current significant trend is the declining share of renewable resources, such as agricultural and forestry products (i.e., cotton and wood), and the increasing share of nonrenewable resources, especially construction materials. Another type of materials-flow analysis is the commodity mass balance study, which follows and quantifies the flow of a single commodity through its entire cycle. These analyses identify areas where adverse impacts could be minimized through reducing wastes at the source of the materials, improving waste utilization, and enhancing efficiencies. Commodity mass balance studies have been completed on arsenic, boron, cadmium, chromium, cobalt, lead, manganese, mercury, salt, tungsten, vanadium, and zinc.

Reports

Current reports include Aggregate from Natural and Recycled Sources; Economic Assessments for Construction Applications; Consumption of Materials in the United States, 1990 to 1995; Crushed Cement Concrete Substitution for Construction Aggregates; Energy Consumption for Recycled and Natural Aggregates; Mercury – A Materials Flow Study – An Update; Recycling of Metals; Sulfur – A Materials Flow Study; Total Materials Consumption – An Estimation Methodology and Example Using Lead; and Trends in Minerals Exploration. When completed, selected reports will be posted on the USGS Minerals Information web page at:

<http://minerals.er.usgs.gov/minerals>

Materials Flow Cycle for Aggregates



World & U.S. Materials Use, 1970–1995

People worldwide consumed about 10 billion short tons of non-food, non-fuel raw materials in 1995, almost double the materials consumed in 1970. Over this period, the United States has been consuming about one-third of the world's total materials production.

Partnerships/Customers

The USGS works with other Federal, State, and local agencies and private interests to develop an understanding of materials flow and sustainability concepts and to form partnerships to address materials-related sustainability issues. U.S. governmental partners and customers include the President's Council on Environmental Quality, the Environmental Protection Agency, the Interagency Materials Flow and Industrial Ecology Work Group, the President's Council on Sustainable Development, the U.S. Department of Commerce, the U.S. Department of Energy, and the U.S. Department of Agriculture.

For more information contact:

**U.S. Geological Survey
(303) 236-8747, Ext. 238
Minerals Information Team**

*Prepared by John L. Sznopek
and William M. Brown*

Learning to use our natural heritage in ways that do not diminish it

By Tamara Nameroff

Natural resources are the historical foundation of America's prosperity, and remain so even in the modern, information-driven age. Although an enormous gift, the sheer abundance of resources we enjoy has contributed to our tendency to spend our natural capital inefficiently. In many cases, we choose to use our resources for short-term rewards without regard to the long-term economic, environmental, and societal costs of those decisions. As our understanding of natural systems has improved, we increasingly have become aware that limits do exist (although they are not well-defined at present), and that the consequences stemming from resource-use decisions are much greater than ever anticipated. Ensuring that our remaining resources continue to meet our own needs as well as the needs of future generations will be a major challenge for the next century. We must protect our natural heritage by learning to use it in ways that do not diminish it.

Nothing is inherently wrong with using natural resources to meet the material needs of a growing population and economy. However, upward trends in many of the indicators that we use to gauge our quality of life (from life expectancy to per capita income to education) have not come without a price. During the last 100 years, human impact on the environment has risen dramatically as the scope and scale of our activities has grown. Large-scale alterations of the landscape, and increasing intensity of industrial and agricultural processes already have induced changes in global biogeochemical cycles--most notably for carbon and nitrogen---that underpin the functioning of natural systems. Loss of biodiversity due to habitat destruction, as well as increasing competition from nonnative species, may precipitate widespread changes in these systems as well.

Protection and use of natural resources both are woven into the fabric of American society. Some elements of our resource base shape our environmental ethics, cultural values, and aesthetic sense. Wilderness and parklands, biodiversity, and certain species are a source of spiritual sustenance for many. Plants and animals, soils and minerals, clean air and water are among the many goods and services provided by our natural capital that have clear economic value. Except for petroleum, bauxite, and potash, 70 percent or more of the minerals and metals consumed in the U.S. are domestically produced, according to the World Resources Institute. These resources help the U.S. provide about one-fourth of the world's goods and services, and contribute to the high standard of living we enjoy. Although we are fortunate that we can meet many of our own requirements using our own resources, the result is that many

of the environmental impacts of mining, processing, and transporting minerals and metals also are realized in the U.S. Use of domestic resources also contributes to transboundary environmental problems such as coastal marine water quality degradation, acid rain, and climate change.

It is clear that in some cases society's demand for resources outstrips the ability of natural systems to reliably provide them now and in the future; in other cases, wastes generated in the process of extracting or using the resource cannot be assimilated over the long term. In these instances, we have chosen (implicitly or explicitly) to sacrifice the long-term viability of the resource base for the sake of short-term economic gain. Sometimes these decisions are driven by the failure of economics to capture the full monetary cost of using the resource. The use of wood and disposal of non-toxic mine tailings illustrate these concepts. Although the use of wood is not damaging per se, timber-dependent communities are vulnerable if overharvest compromises the ability of children to follow in their parents' footsteps, or if poor forestry practices lead to serious intervention in order to protect scarce habitat for vanishing species. Similarly, non-toxic mine tailings are not inherently detrimental. But when so many tailings piles are generated that they blight entire landscapes, strain the capacities of communities and local governments to control their disposal, or compromise water quality, then they are a problem.

A sound economy and a vibrant society are inextricably linked and irrevocably dependent on the health of the natural environment. The physical condition and extent of natural systems in the next several decades likely will depend on how we manage large-scale landscape changes such as deforestation, expansion of agricultural land, and urban and suburban growth, as well as resource extraction practices. The approach we take must recognize that environmental threats are not always comparable or additive, since the scale, timing, and effects of each problem are different. A better balance between resource use and environmental protection is particularly important for those natural resources that are not renewable over human time scales, and for those environmental problems linked to resource use that are not easily solved, even with anticipated advances in technology.

The earth and biological sciences both are critical inputs in shaping new approaches that recognize conservation of resources is an essential societal asset rather than an economic constraint. By integrating these disciplines, we augment our understanding of how ecosystems function, why biological resources are found in particular locations and not others, and how they have changed over time and are likely to change in the future. Better communication among scientists, while a step in the right direction, is not sufficient. Cooperative and interactive dialogues among scientists and decision-makers will be required if our nation is to use science to reshape its natural resource policy.

Specific areas where greater understanding needs to be fostered in both the scientific and policy-making communities include:

1. developing standard data collection and reporting methods to monitor conditions and evaluate quality of biodiversity and natural resource stocks;
2. disseminating data on mineral and biological resources;
3. identifying indices and integrative measures of natural systems that can gauge rapid change;
4. degradation, or improvement of those systems;
5. developing methods to fully value the environmental services of natural resources and the costs of using them;
6. establishing metrics and methods to evaluate tradeoffs for all natural resources uses;
7. integrating valuation tools into new technologies to make land-use and conservation decisions;
8. developing new technologies to minimize the "footprint" of resource extraction activities and minimize the amount of resources needed to produce a good or service;
9. developing better models to evaluate appropriate temporal and spatial scales for resource management;
10. developing the capacity to assess cumulative effects of resource use decisions and predict the broad range of biological, physical, environmental, social, and economic consequences of human actions.

Although by no means a complete inventory of the many steps that must be taken to ensure we learn how to use our natural heritage in ways that do not diminish it, this list illustrates the types of challenges and opportunities we will encounter as we strive to do so. Only a handful of these tasks can be accomplished by either scientists or policy makers acting alone. By working together and using the results of scientific research to improve management of our natural capital, we can fulfill today's needs without compromising those of future generations.

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A chemical oceanographer by training, Tamara Nameroff is the Climate Task Force Coordinator for the President's Council on Sustainable Development. Prior to her appointment at PCSD, Dr. Nameroff was the 1996-1997 Geological Society of America Congressional Science Fellow. These experiences honed her interest in developing effective solutions to natural resources and environmental policy problems that are informed by the best available scientific information. The views expressed in this article are her own and do not necessarily reflect those of the Council or the U.S. Government.

APERC OIL AND GAS ASSESSMENT

MAY 26-28, 1998

DENNIS J. O'BRIEN, PH.D.

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APERC OIL AND GAS ASSESSMENT May 26-28, 1998

Institute for Energy Economics & Policy
Sarkeys Energy Center

7/6/98

APERC review of oil and gas

- The Institute for Energy Economics and Policy was commissioned to review oil and gas exploration and production by the Asia Pacific Energy Research Center, Tokyo in support of the APEC Energy Ministers
- A team of experts including Marian Downey, Chief Scientist, Sarkeys a former President, ARCO International; Mika Forest, SVP, Maxus; Nick De'ath, SVP Triton, Jim Jensen, Jensen & Associates; Bruce Bawls & Junko Ogaawa, APERC; Steve Burns, PECC Energy Forum; Dennis O'Brien, IEEP; and representatives from ARCO and CONOCO participated in the review

7/6/98

Building a scenario

If the APEC region has slower growth for the next decade what is the likely effect on oil supply and the development of gas infrastructure from well head to the burner tip

1

7/6/98

Vision Statement

- To assess the resource base and likely production path of oil and gas development in selected APEC economies and external gas supply into the region

2

7/6/98

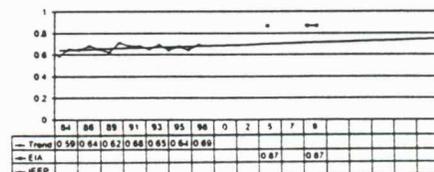
Goals and Objectives

- Establish a production path for APEC internal oil and gas supply by economy through 2010
- Assess external gas supply into the region
- Assess the impact of major technology developments on supply
- Evaluate the impact of investment in the oil & gas sectors
- Evaluate potential of new areas
- Evaluate reserve, production, and transport of gas from external areas in the APEC region
- Recommend resource staff development program

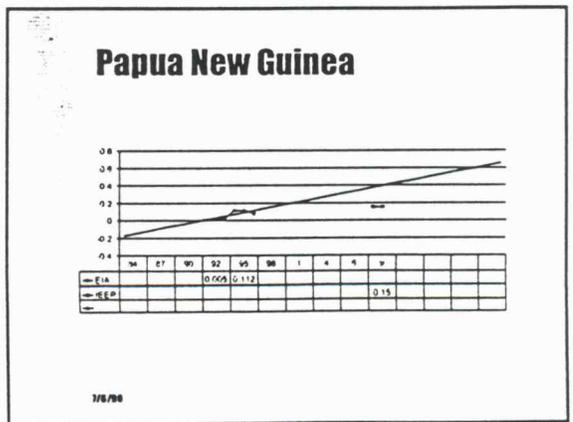
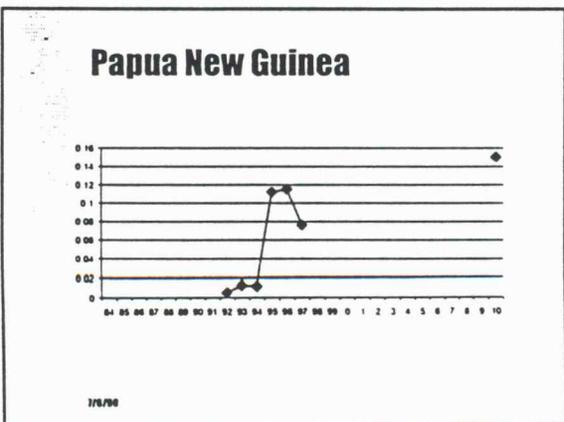
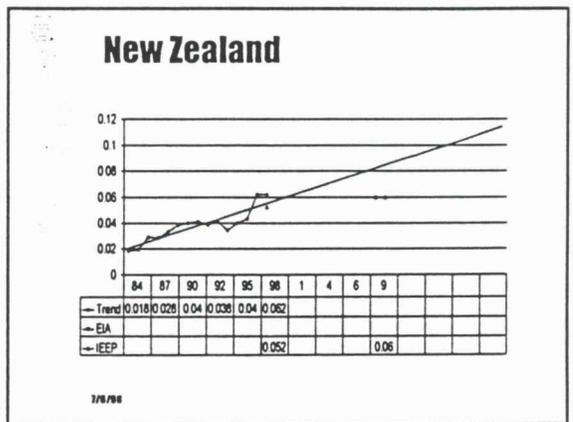
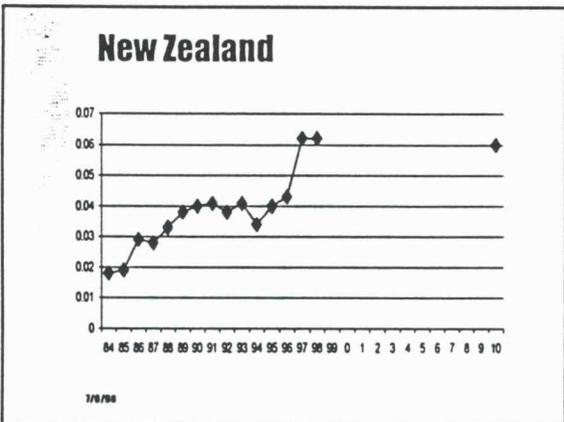
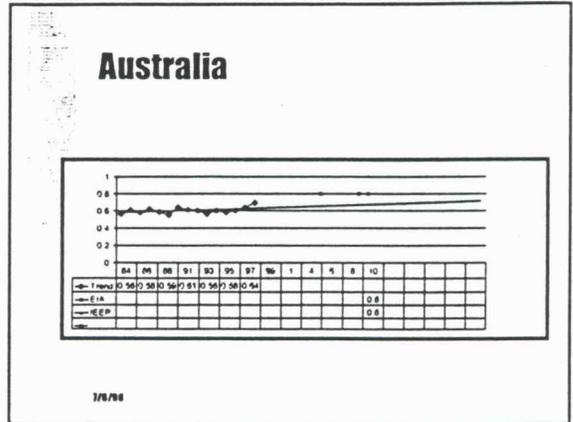
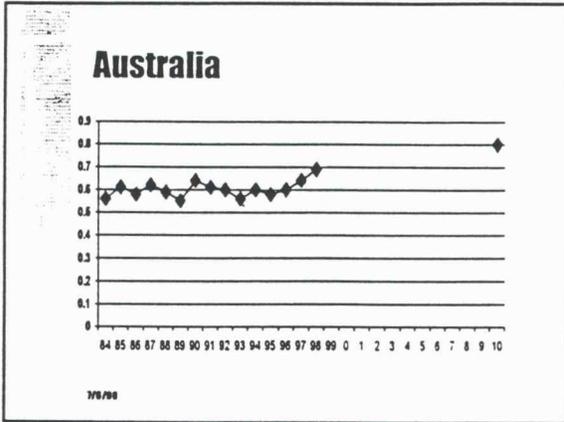
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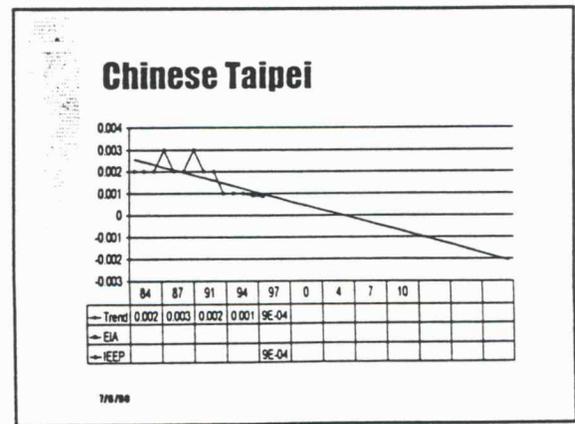
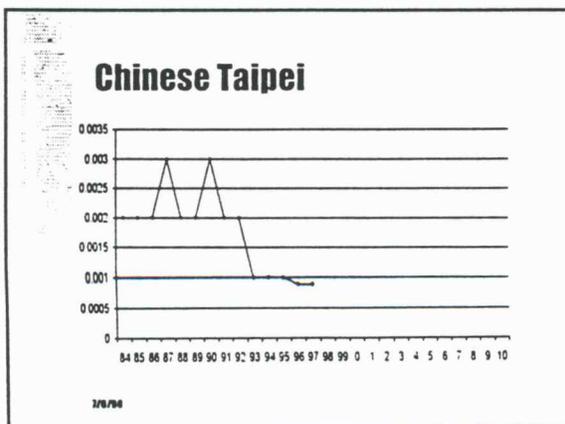
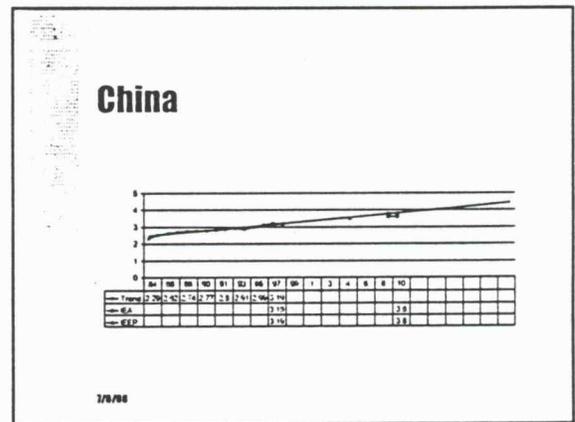
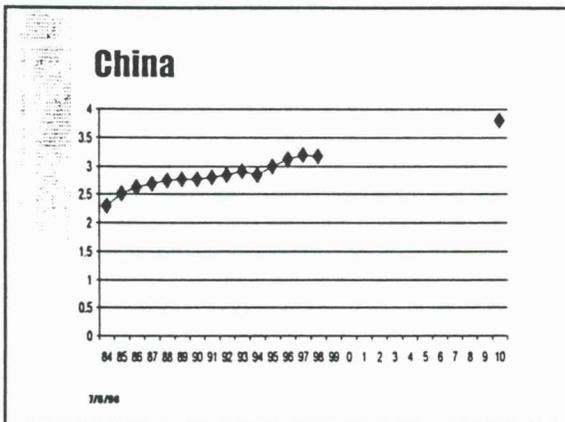
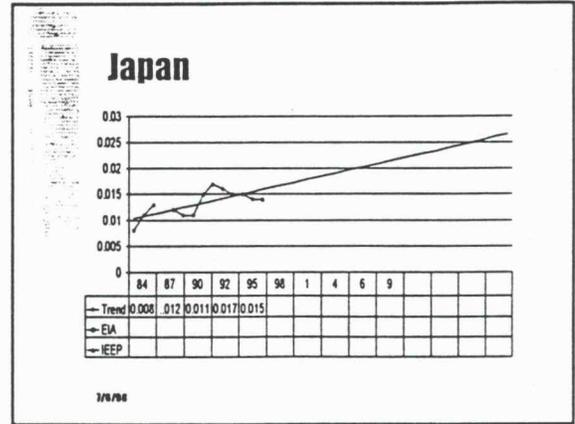
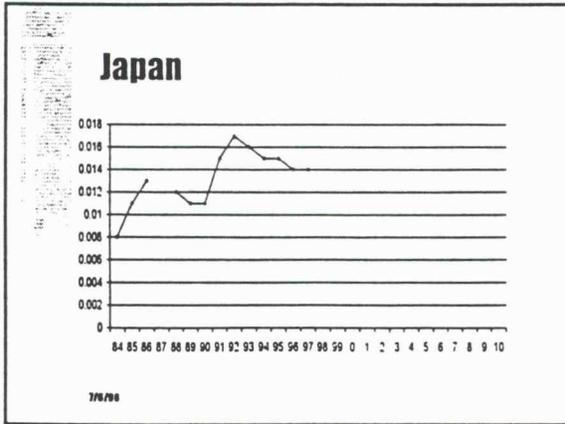
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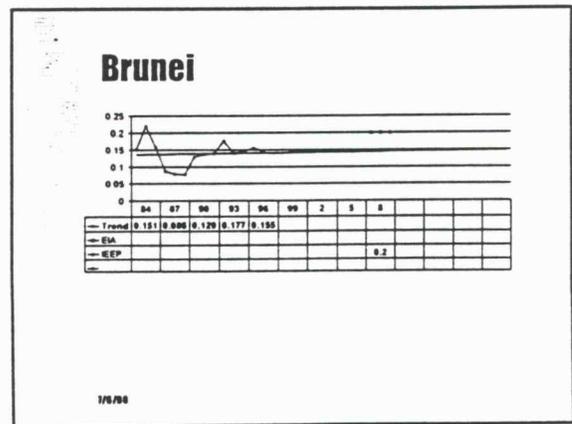
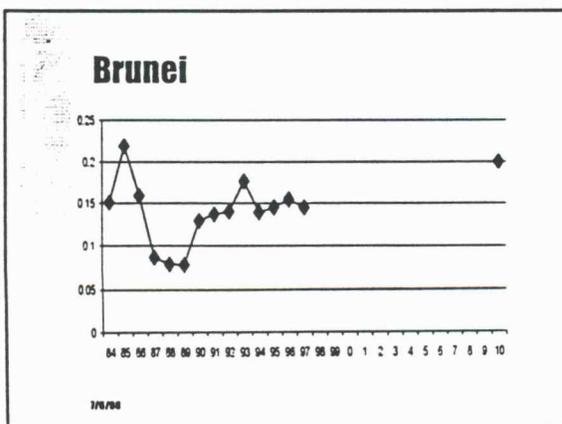
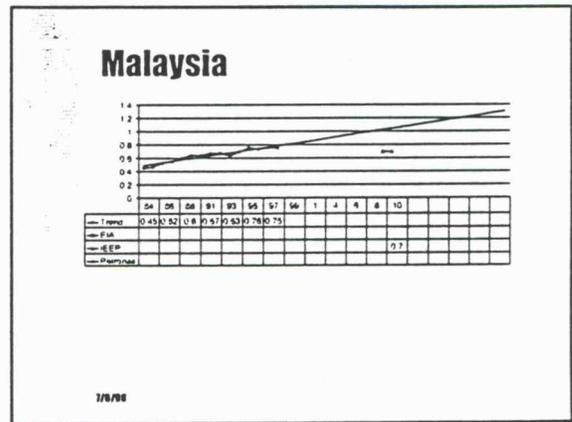
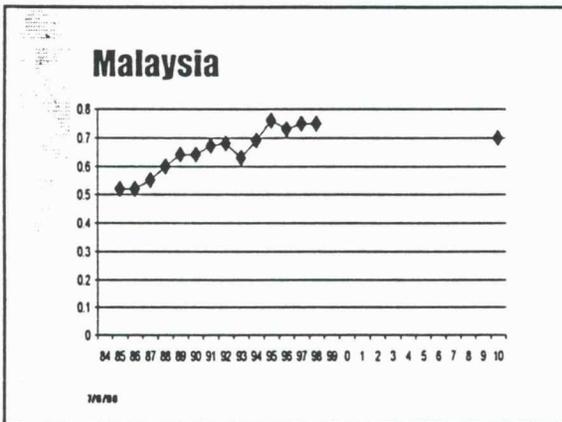
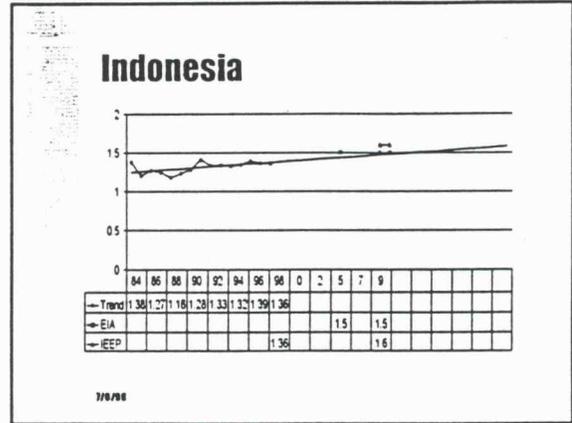
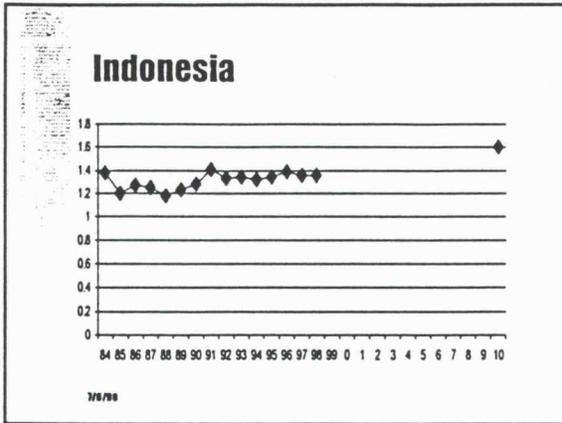
Australia, New Zealand, Japan

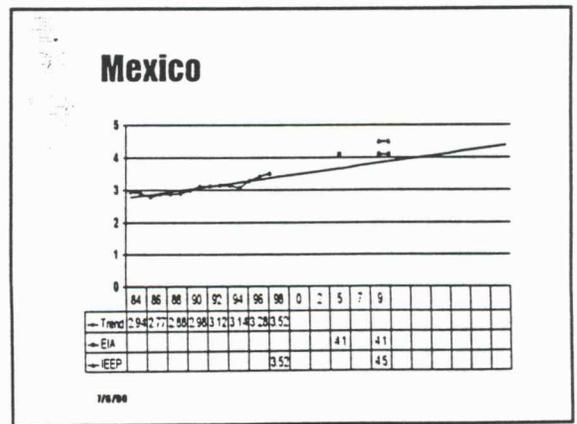
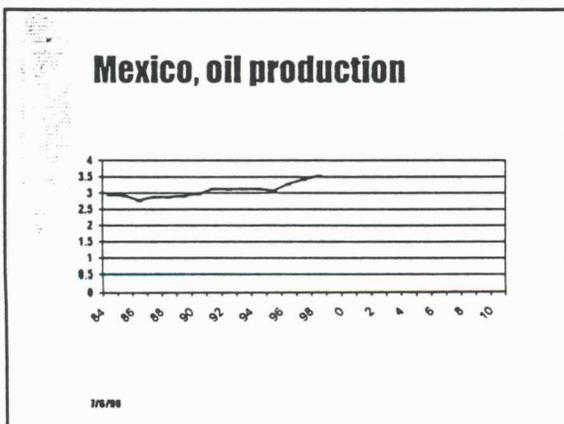
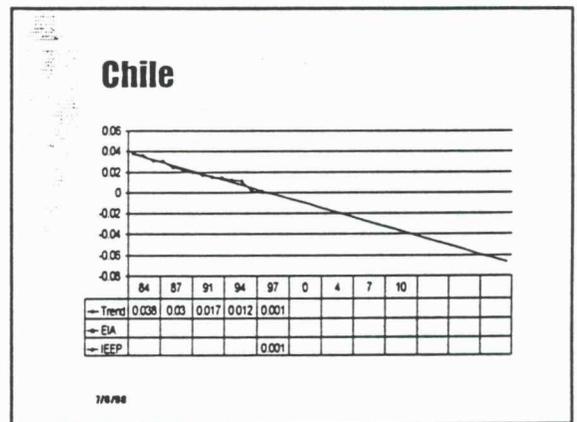
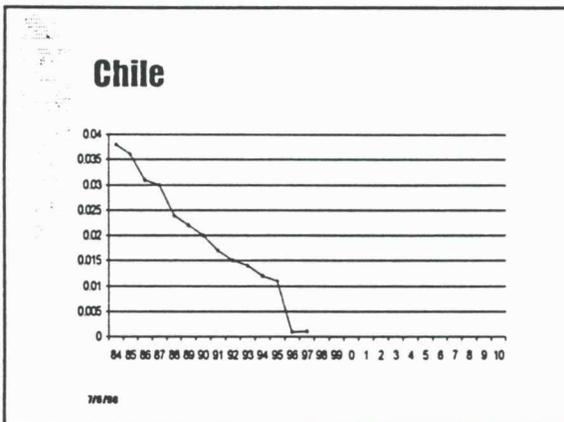
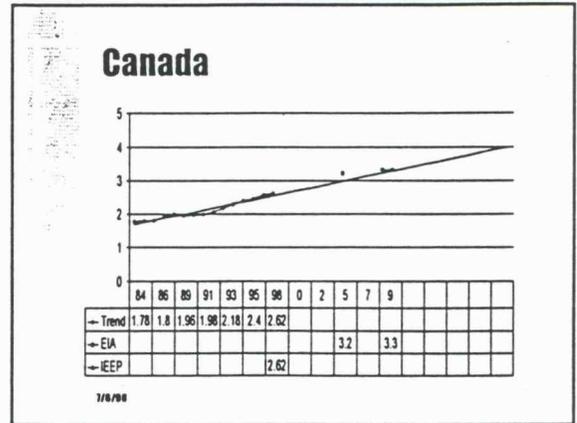
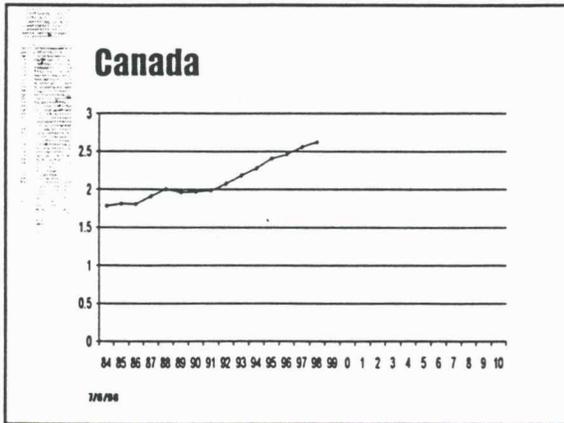


7/6/98









Deregulation and Privatization in Asian Energy Markets

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Deregulation and Privatization in Asian Energy Markets

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We are

- Institute for Energy Economics and Policy, Sarkey's Energy Center, University of Oklahoma, which provides integrated technical, economic, and political analysis and assistance drawn from the extensive hydrocarbon sciences programs of the Center and the world hydrocarbon industries. (dobrien@ou.edu)
- PECC Energy Forum Technical & Policy Center works on important energy issues for member economies. PECC Energy Forum is a 23 member economy forum associated with PECC which has observer status in APEC Energy Working Group and Ministerial meetings. (pecc@aol.com)
- petroad which helps clients develop vision and strategy for energy planning and investments. (dobpetroad@aol.com)

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2

Institute for Energy Economics and Policy Deregulation & Privatization Capabilities

- Participation in global work on deregulation, privatization in oil, gas, electricity
- Expertise, experience with IEA, OPEC, APEC, major oil exporting economies, global and regional industries and governments
- Strong information, information technology sources, capabilities and management
- Working relationships with key leaders in world oil and gas industry, governments, international agencies
- Backed by the technical oil expertise of Sarkeys

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3

Vision Statement

Asia has made great strides in meeting her energy needs and security in the last two decades. Some major challenges remain, however, as the energy economy expands, grows complex, and expanding consumer needs place more demands on the system. Meeting fuels requirements and health, safety, and environmental needs will require carefully integrated solutions with a dynamic energy economy

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4

Purpose

- To look at the new role of Asia in global energy markets and energy security in the development of sound global, national, and regional electric power, petroleum, and transport strategies for the 21st Century.
- Deregulation and privatization are critical for the future of Asia.

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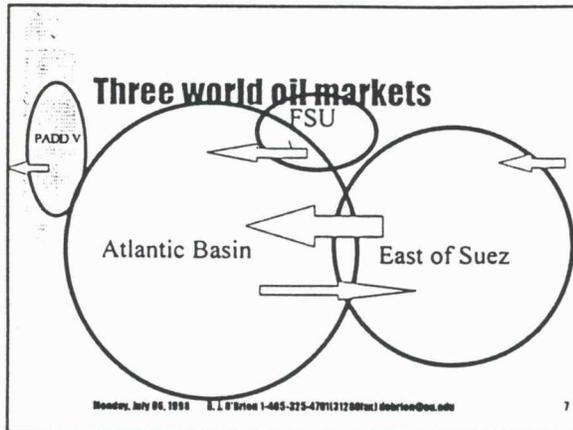
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To liberalize

- "to make liberal, free, belong to the people"
- In energy to liberalize means to remove price regulation, promote competition, privatize state owned companies, establish local markets which interact freely with international markets
- US has provided the models for regulation, deregulation, and limited regulation
- Most economies have limited regulations which include environmental, health, safety rules

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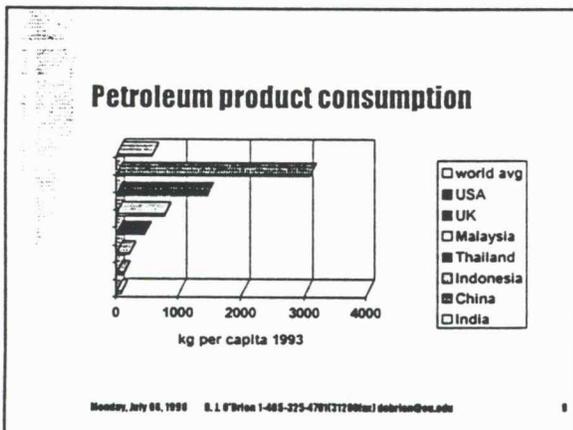
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Oil markets are very transparent, efficient

- Today's market is like a Toyota factory
- Crude, product supplies arrive just in time
- Information, information technology are critical
- Risk management—futures—are key factors
- Less, little spare crude, product capacity required
- Buyers, refinery supply managers drive the market
- External factors—weather, politics—are critical

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What is the status of oil regulation, privatization in Asia, APEC?

- Full dereg and privatization in US, Canada, New Zealand, Singapore, Australia, Japan
- Partial dereg and privatization in Malaysia, Philippines, Thailand, Korea, Chile, Peru
- Beginning and just underway in Indonesia, India, Mexico, the Chinas

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What is the status of deregulation and privatization of electricity in Asia, APEC?

- Advanced privatization in US, Australia, New Zealand, Japan
- Partial privatization in Canada, Mexico
- Privatization under study in most other nations
- All countries still have price regulation, local monopolies

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The origins of regulation

- US moved from laissez faire in the 19th Century with Sherman Anti Trust (1890) and Clayton Act (1914)
- WWI & II brought strict controls and oil shocks brought price regulation which was copied world wide
- Repeal of allocation (1981) and market economics encouraged global oil deregulation and privatization
- Electricity deregulation, privatization more complex
- Health, safety, environmental regulations acceptable, necessary, desirable when developed with industry

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Energy security

- Oil markets have become more efficient, transparent, global
- Deregulation and privatization trends give open petroleum economies great advantage in world markets in periods of supply interruptions
- Many options for supply security including strategic stocks, demand restraint

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Impact on energy security

- Concern over energy security promoted state companies and regulation in the 1970's
- Oil markets have become transparent, efficient, globalized, and free floating
- Regulated economies and state companies are at a disadvantage in today's market
- Many options for supply security, strategic stocks, efficiencies, demand restraint

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Impact on public need

- Deregulation and privatization are making the global industry more efficient and has reduced the cost of production, manufacturing, transport, and marketing
- Accountability shifts from public to private sector
- The quality of products and services have been greatly improved
- All has been passed on to the customer who demands more and gets more
- Retail marketing outlets have replaced service stations and offer much more than petroleum products

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Impact on environment quality

- Customers value environmental quality
- Refiners and marketers compete on quality, price
- Major industry players dedicated to high quality health, safety, environmental standards
- Local refiners and marketers must compete
- Governments set rules on HSE
- Examples: meeting mandated targets in Europe ahead of schedule and unleaded fuels in some Asian markets before mandated

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The US experience

- Large federal pluralistic, multicultural democracy
- Well established industrial and financial sectors
- Highly efficient, competitive oil sector operates in mature efficient market
- Lowest x refinery product prices, taxes in world
- Wide range of price and quality choices
- Industry highly accountable for actions
- Liability risks are great
- Fast, painful approach to deregulation

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Sanctions are a remnant of the imperial past

- Imperial regulation on a grand scale
- In reality they are self imposed non tariff barriers against the national interests of the nations which impose them
- In most cases they don't work and they damage the economy of the nation which imposes them
- Reflect internal political weakness of the nations which attempt to impose them
- Sanctions interfere with global energy security interests and should be opposed by all nations

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The Japan Experience

- Large, monocultural, consensus democracy
- Oligopolistic industry, financial sectors
- Mature, inefficient oil industry, market
- Highest x refinery costs/prices and high taxes
- Slow, very painful deregulation in oil sector
- Electricity sector just beginning
- MITI has stated deregulation critical to maintaining Japan's competitive role in world economy

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The Korea Experience

- Maturing, monocultural, industrial democracy
- Oligopolistic industrial and emerging financial sectors
- Competitive refinery and marketing industry
- Moderate x refinery costs/prices and high taxes
- Concern over future external competition has brought large expansion of refining capacity
- Moderate painful route to deregulation

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The Thai experience

- Developing constitutional monarchy
- Volatile emerging industrial and financial sectors
- Mixed state and international companies
- Strong competition at the pump
- Lower x refinery costs/prices
- Lack of HSE regulations over retail outlets
- Fast, less painful track to deregulation, slower privatization

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The Philippine Experience

- Pluralistic, multicultural democracy
- Emerging industrial and financial sectors
- Mixed state, international oil companies. Four companies left because of bad regulation
- Highly competitive refining and marketing within the economy.
- Lower X refinery costs/prices and high taxes
- Fast track to deregulation progress

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The India Experience

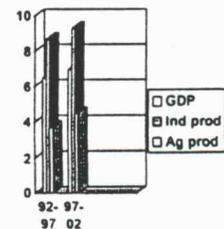
- Large federal, pluralistic, multicultural democracy
- Emerging industrial and financial sectors
- State owned oil and electricity companies
- High x refinery costs/ prices and high taxes
- Electricity sector very mixed
- Deregulation plan yet to be adopted

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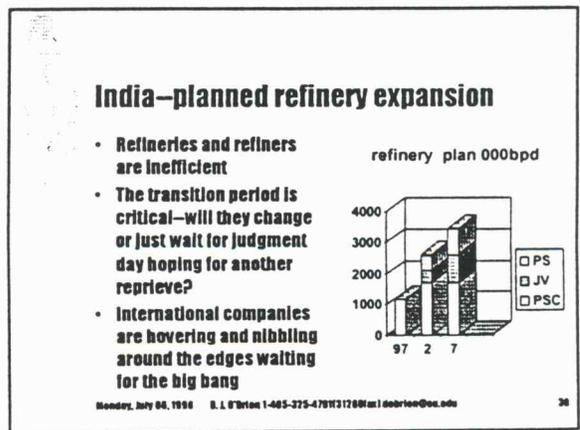
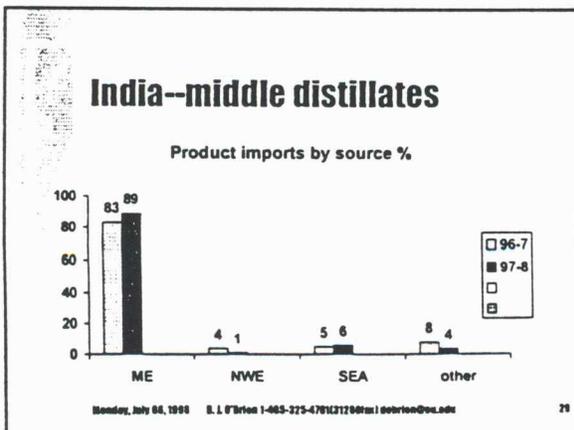
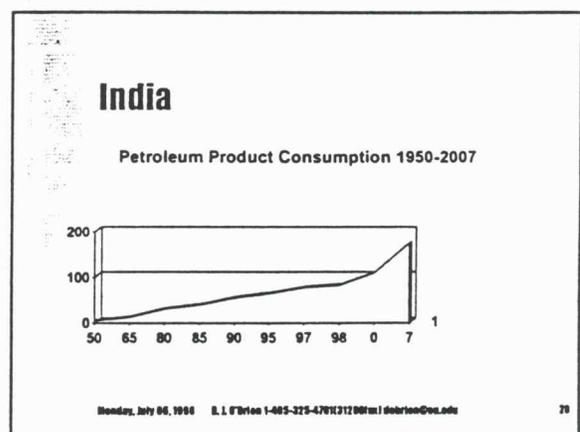
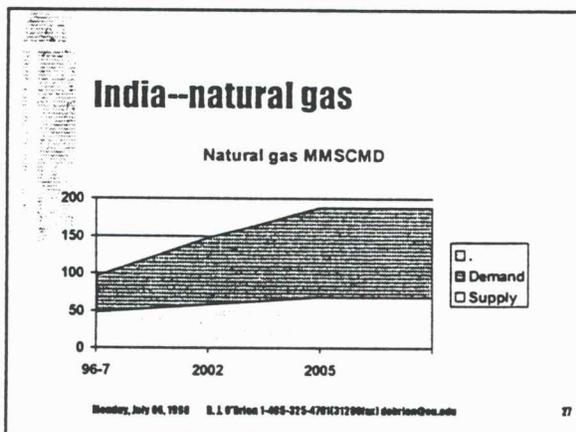
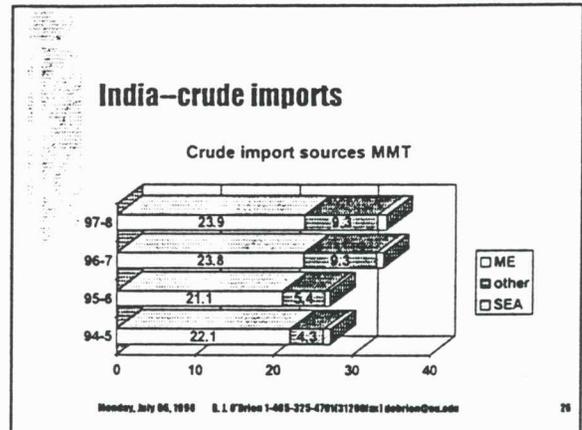
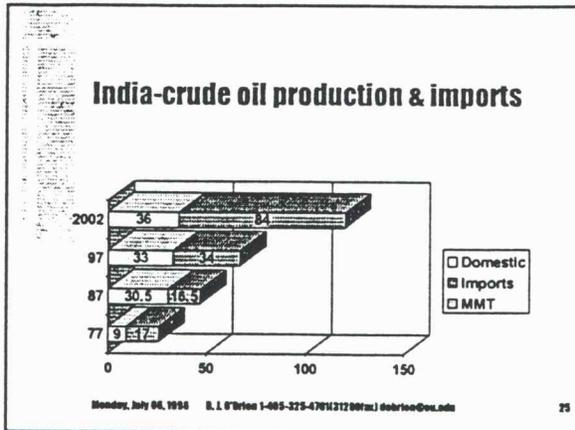
India—the economic base

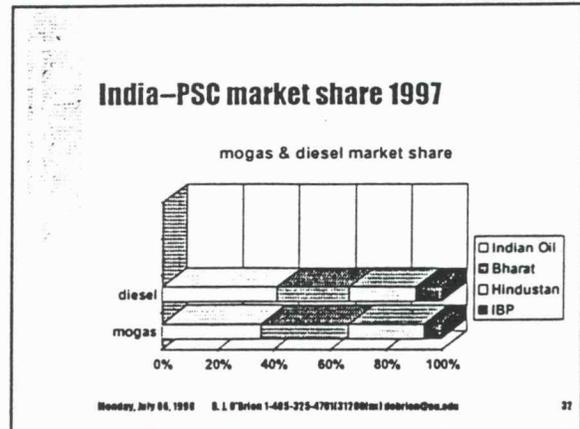
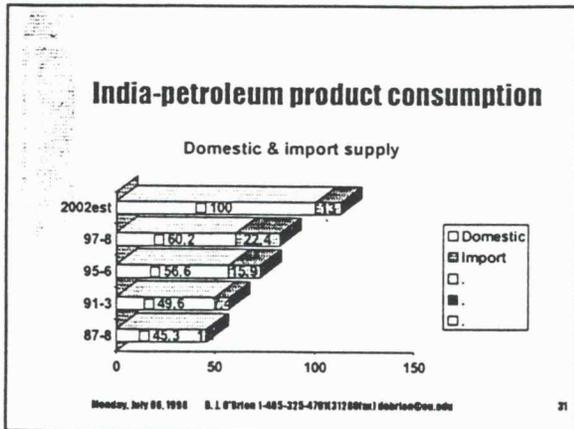
- India's economy has not been greatly affected by the Asian financial crisis



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India—self reliance to open economy

- Self reliance and sustainable development favored traditional fuels, transport, and bureaucratic regulation in both rural and urban environments
- Infrastructure development has lagged far behind and environmental quality of life is major problem
- Opening of the economy in 1990's has brought world standard energy and petroleum requirements
- India's consumers are leading the government deregulation and higher quality service, fuels
- The old system prevails and change is slow

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India—present regulatory system

- Extreme bureaucratic regulation of production, import, manufacture, distribution, and marketing of energy, natural gas, petroleum, petroleum products
- Ministry of Petroleum and Natural Gas is primary and (1) approves major programs and budgets (2) administers pricing of petroleum products—APM (3) allocates crude oil to refineries (4) oversees national companies—PSCs
- APM provides 12% return to PSC, parity to import crude price, FX changes, fixed product margins, and covers 98% of all products sold

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India—deregulation downstream 1998-2002

- Phased decontrol and decanalisation of import/export of some petroleum products
- Withdraw APM for domestic crude producers
- Refiners buy crude at import parity
- Phased reduction of APM for products
- Tariffs on imported products & crude phased down
- Two phases 1998-9 and 2001-2

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India—downstream deregulation 1998-9

- Petroleum products decontrolled—naphtha, heavy ends, aviation fuels, paraffin, asphalt
- Crude, NGL, diesel, mogas, ATF not yet included and subject to high import tariffs
- Major products to be phased to market prices
- Crude imports decontrolled and can be imported by licensed refiners
- Decontrolled products sell at MDP
- Controlled products sell at adjusted import parity

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India—downstream deregulation 2001-2

- Subsidies reduced on kero, LPG
- Domestic crude prices allowed to rise to international levels
- Crude and product tariffs reduced but not eliminated
- New market entry for players who invest minimum \$51K usd or E&P with 3mmt crude
- Full deregulation by 2002?

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India—the national companies

- ONGC is a classic established on the USSR mode—model after USSR and state socialist mindset—horizontal integrated company—bureaucratic monster with board room consultant doing study
- Public Service Company refiners & marketers—Indian Oil, Bharat Petroleum Hindustan Petroleum, IBP

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China

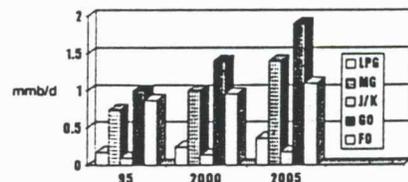
- China appears to have a three state plan which begins with restructuring the oil and gas industry with emphasis on creation of bite size pieces
- Next might be a partial sell of shares
- Then an aggressive joint venturing strategy with international partners

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China oil demand 1995-2005

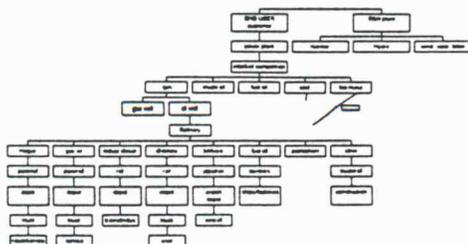
Petroleum product demand growth



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Interfuel competition for power and transport and the investment maze



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Investment implications

project	finance	cost	links	location	return
oil field	easy/mod		source	market	high
gas field	mod/cfl		source	market	low
gas pipe	mod/high		field/rail	between	low
oil pipe	mod/high		field/rail	between	low
ref expan	cd	to 37b	market	market	low
ref new	most/cfl	\$2b	market	coastal	low
ref mod	mod/cfl	\$2b	export	coastal	low
prod pipe	mod	low	ref/depot	market	low
dist. inter	mod	150m	ref/depot	market	low
depot/rail	mod	\$50m	aviation	airport	low
depot/rail	easy	r2c	rail	airport	low
retail mar	easy	\$1-5 m	consumer	market	low/mod

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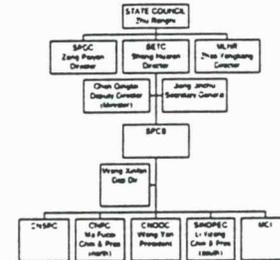
Restructuring China's oil industry

- As part of the general overhaul of all state industries, the National People's Congress approved a major reorganization of the entire oil and gas industry on 10 March 1998
- The new framework follows but will not be flushed out until mid year
- Oil industry has always been the darling industry and has escaped many hardships
- The restructuring, peeling away or non-core assets and liabilities will create new capital access, strategic alliances, and joint ventures.

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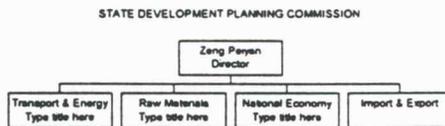
China--Restructuring



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SDPC

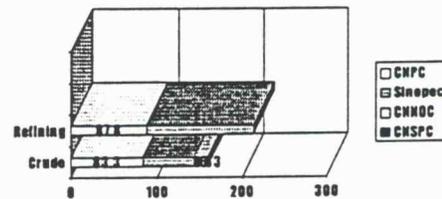


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China--crude & refining capacity

Share by company in MMT

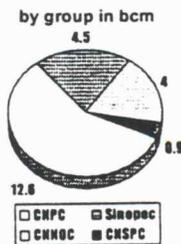


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China--natural gas production

- CNPC retains largest potential and has plans to increase downstream markets
- SINOPEC is in better position to develop markets and utilization
- CNSPC & CHNOC will likely focus on power

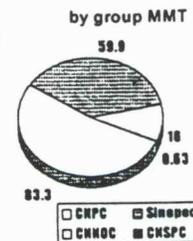


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China--crude oil production

- CNPC has retained the key, mature areas and the Western provinces
- SINOPEC has an mixed bag and the need for upstream management knowledge
- CNSPC and CHNOC are the same for the moment but the future?

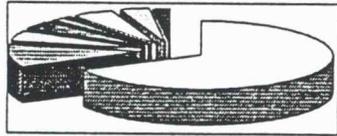


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CNPC Group oil production 1997

83,275.4 (000mt)



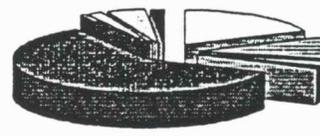
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- Xinjiang
- Jilin
- Chongqing
- Yumen
- Sichuan
- Yancheng
- DianQC
- Jidong
- Tarim
- Taha
- Anhui
- Qinghai

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CNPC Group gas production 1997

12,637 (mcm)



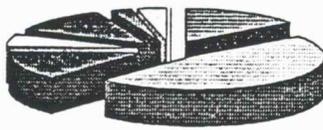
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- Tarim
- Taha
- Anhui
- Qinghai

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SINOPEC Group oil production 1997

599,474,000 mt



- Shengli
- Huabei
- Liaheo
- Dagang
- Henan
- Zhongyuan
- Jiangsu
- Slice 9
- Slice 10
- Slice 11
- Slice 12
- Slice 13

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SINOPEC Group gas production 1997

4,538mcm



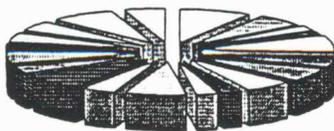
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- Huabei
- Liaheo
- Dagang
- Henan
- Zhongyuan
- Jiangsu
- Slice 9
- Slice 10
- Slice 11
- Slice 12
- Slice 13

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SINOPEC Group refinery capacity 1997 retained

(106,000(0000mt)



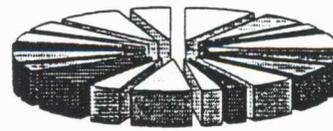
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- Jiazhong
- Cangzhou
- Gaoqiao
- Shanghai
- Jinling
- Yangzi
- Anqing
- Hujiang
- Zhenhai
- Fujian
- Jilin

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SINOPEC Group refinery capacity 1997 former CNPC

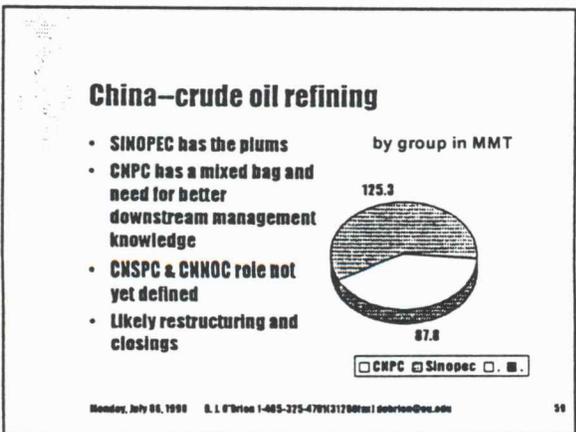
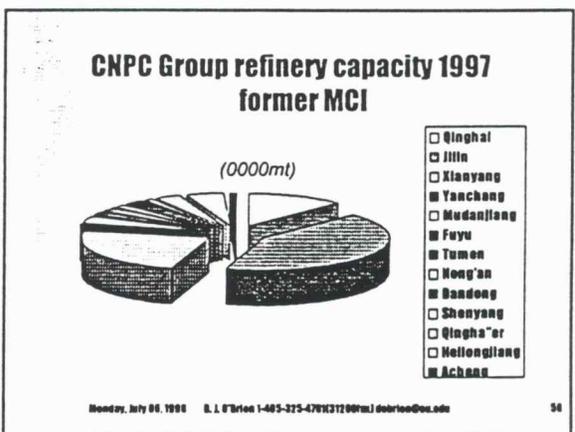
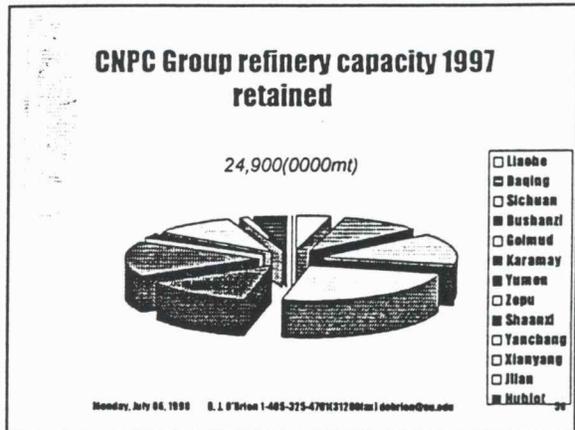
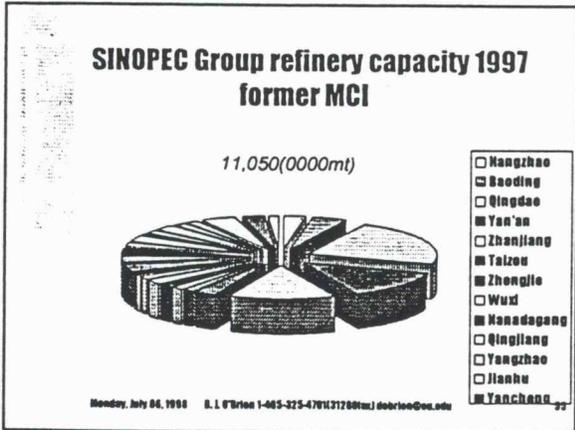
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- Henan
- Shengli
- Dagang
- Huabei
- Jiangsu
- Nanyang
- Zhongyuan
- Slice 9
- Slice 10
- Slice 11
- Slice 12
- Jilin

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Keys to the path

- **Preparing leadership** in all sectors for global competition through understanding, training, learning
- **Often economies emerging from protected regulated environments have fears about foreign competitors**
- **On the contrary former protected companies can be strong competitors with preparation**

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Steps on the oil path

- **Mixture of U S and Thai experience**
- **Market timing is critical—both financial and oil—when world market is steady or declining**
- **Privatization first—followed quickly by opening markets to global investment**
- **Open imports of products with high HSE requirements**
- **Require new infrastructure to be HSE substantial—bring existing infrastructure up to same standard**

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Gas Reserves and Production Potential in APEC

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**APEREC Tokyo
17-18 June 1998**

APERC
Tokyo
17-18 June 1998

Gas Reserves and Production
Potential in APEC

D. J. O'Brien
Institute for Energy Economics and Policy
Sarkeys Energy Center

The graphic features several icons: an oil rig on the left, a lightbulb with a plug on the right, a bar chart with a line graph below it, and a factory on the right. Arrows connect these elements, suggesting a flow of information or a process.

IEEP

- The Institute for Energy Economics and Policy (IEEP) is located in the Sarkeys Energy Center, University of Oklahoma. Sarkeys Energy Center is the most comprehensive center of knowledge in the oil and gas industry with seven institutes dedicated to applied research with partners in over 30 countries and over 30 private, public and state oil companies worldwide. Sarkeys technical research is on the cutting edge of technology and has over 160 research associates and graduate students from nearly all the APEC economies.
- IEEP has a global energy vision and has the mission of developing quality energy economics based on quality research and technical understanding of energy systems, organization, and global supply and demand. The IEEP works closely with the Caspian Petroleum Technology Institute and the PECC Energy Forum and is the home of the PECC Energy Forum Technical and Policy Center.

IEEP Centers of Excellence

- The Center for Energy Market Analysis (CEMA) will develop an annual global energy outlook beginning in 1999 in addition to forecasts for the supply/demand for oil products for North America (NAOPS) and the Eastern Hemisphere (ESOPS). CEMA is also developing EWxAS which will provide a unique tool to plan and risk manage weather for energy companies world wide.
- The PECC Energy Forum Technical and Policy Center (PEFTP) vision is to provide the 24 PECC member economies quality energy analysis and support (all APEC economies are members) PEFTP is currently developing a major study of PECC gas infrastructure with policy recommendations for member economies
- The Center for Energy Policy Analysis (CEPA) vision is to provide energy policy analysis and recommendations based on quality technical and economic understanding and research. CEPA also is developing an Energy Technology Assessment System (ETAS) which will provide a time and cost evaluation of emerging energy technologies. CEPA has provided extensive advice to public, private, and state energy companies and governments regarding organization, deregulation, finance, and privatization.

Objective

- To provide the Asia Pacific Energy Research Center a review of gas supply and potential for the APEC region in support of the ongoing work for the APEC Energy Ministers
- The review was conducted by a team of experts at Sarkeys in May 1998

Gas is . . .

- different than oil (stating the obvious)
- different from economy to economy
- infrastructure sensitive
- complex in some and simple in others
- impossible to forecast but easy to assume
- driven by the markets and firm offtake agreements
- markets first, supply second, and transport/investment next
- delivered to the market by pipes, LNG, and in liquid form. Technology and economics—say GTL—can alter the supply patterns

Gas and the Asian crisis

- Flat to negative growth in key Asia APEC economies
- Improving economies in Western Hemisphere
- China, Japan are critical
- Large investment in gas utilization in N Asia could meet post Kyoto targets, boost all of Asia, and develop gas markets
- Many gas supply projects delayed and on hold.
- Oil projects will continue since markets are efficient and Asia crude easily fits. This will add gas reserves and production
- Gas projects need offtake agreement
- Without stimulus package gas demand/supply will grow slowly

APEC gas assumptions to 2010

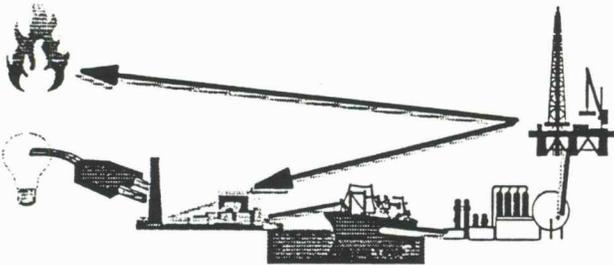
- NAFTA three are integrating and OK is the center
- Peru, Chile have small domestic markets with transborder export potential
- Japan, Korea, C Taipei, Philippines are LNG receivers
- China will develop uncertain domestic potential with possible coastal LNG
- SE Asia will have limited market and pipe development and LNG exports will be driven by N Asia
- Australia, New Zealand have domestic market growth and LNG exports are driven by N Asia
- PNG is stranded and pipe to Australia is the best hope
- Russia has the gas potential for N Asia but it is beyond 2010

Reserve and capacity assumptions

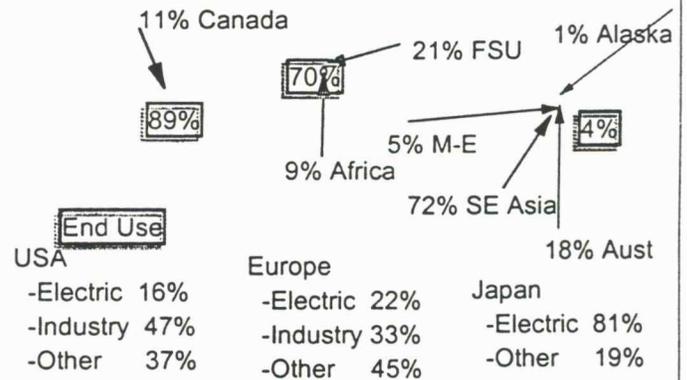
- Crude oil, gas, and NGL are difficult to sort out
- Sustainable production capacity=85%nameplate
- Gas has been underexplored and undefined in most of APEC except the U.S. Once regarded as a curse
- Reserve numbers are really guess work which have a rather large margin of error
- Investment and operation economics normally require maximum thruput for gas transport systems
- Both LNG and pipeline systems will not be built on spec without firm offtake agreements or sovereign guarantees

IEEP believes APEC gas capacity IN 2010 will be . . .

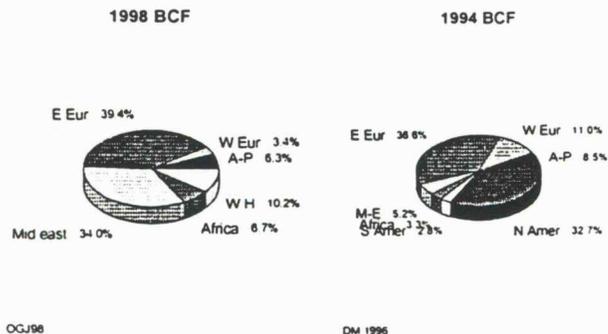
- DEMAND=SUPPLY+15%=GAS CAPACITY



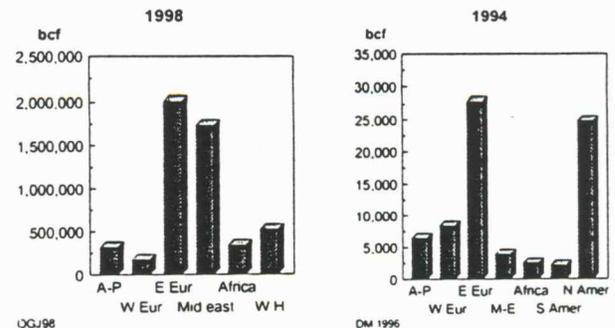
Market structure supply for Gas 1994



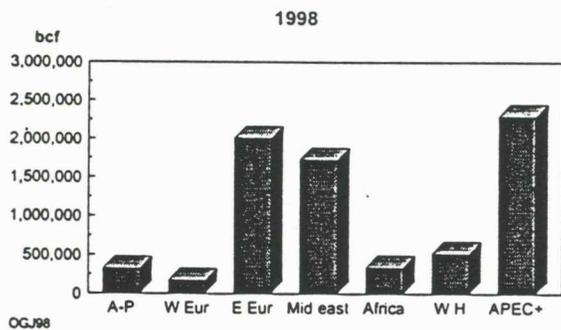
Global Gas Reserves vs Production



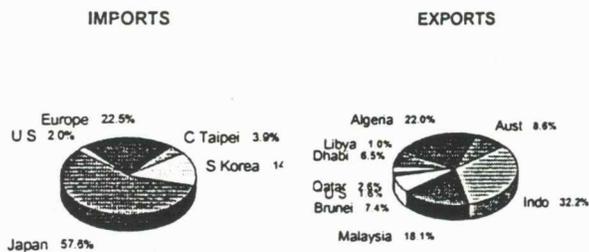
Global Gas Reserves vs Production



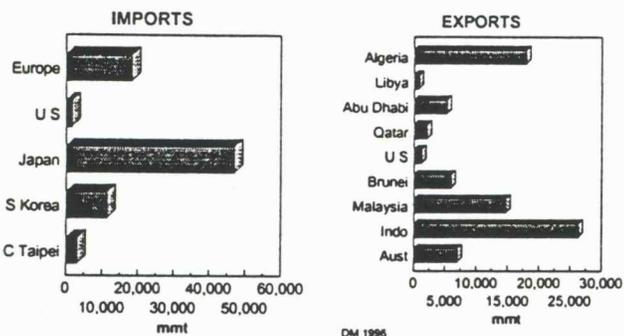
Global Gas Reserves vs APEC



Global LNG imports & exports 1997



Global LNG imports & exports 1997



APEC Asia LNG Projects, 1998

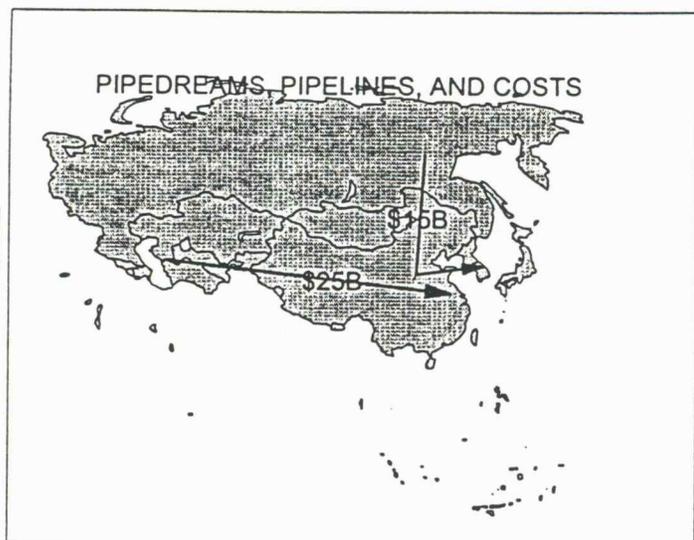
Placename	start	end	cost	capreserves	dist
Mal MLNAG3	00	D		6.8mmt	
Indo Tanggah	03	D	\$3.0B	6.0mmt	
Indo Natuna	03	D	\$4.3B	5-15mmt	45tcf
Aus Woodside	03	?	\$4.0B	7.0mmt	
Aus WAPET	03	?			22tcf
Aus Timor				3.0mmt	
Aus Darwin	03	?		3.0mmt	
Rus Sak I, II	10			6.0mmt	
Can Pac Rim	01	?	\$1.3B	4.0mmt	
US TAGS	07		\$14B	14.0mmt	
Oman	00	?	\$2.5B	6.6mmt	
Qat Qatarrgas	97		\$4.0B	6.0mmt	
Qat Ras Laffan	98		\$3.4B	10.0mmt	
Qat Enron	01	?	\$5.0B	5.0mmt	
Yem	01	?	\$3.0B	5.3mmt	10tcf
Chin PGGLNG	04			6.0mmt	

LNG projects under study or development 1995 . . .

Country	tmt per yr	Start	Participants
Qatargas	12000	1997	QGPC
Qatar (RL)	10000//	2000	QGPC/Mo
Oman	6200	2000	Oman/Shell
Yemen	5000	2000+	Hun/Ex/Yu
Malaysia	5200	2000	Pe/Ox/Nip
Indonesia	14000	2005+	Per/Exxon
Australia(G)	5500	2000+	Santos et al
PNG	5000	2000+	Ex/BP/Chev
USA/Alaska	14000	2000+	Ex/Arco/BP
FSU/Sak 2	6000	2000+	4 M
FSU Sak 1	6000	2000+	Sodeco/Ex
China/Turk	10000	2005+	CNPC/Mits
FSU Sak 3	?	?	Ex/Mo/Tex
FSU Yakut	?	?	OMV/Max/K

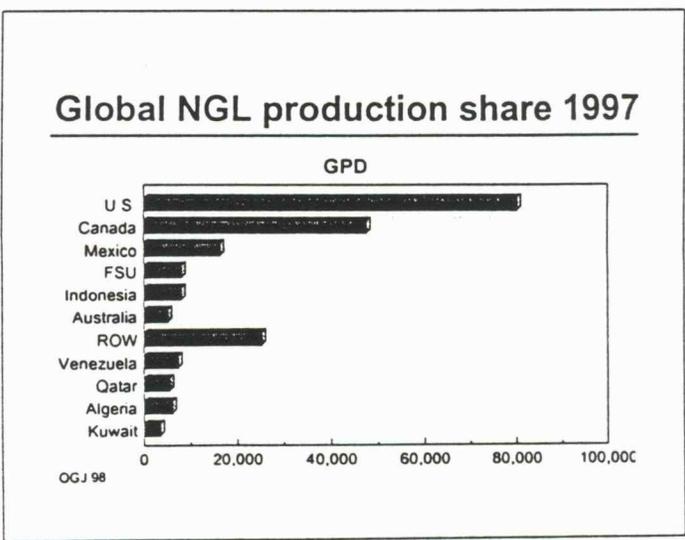
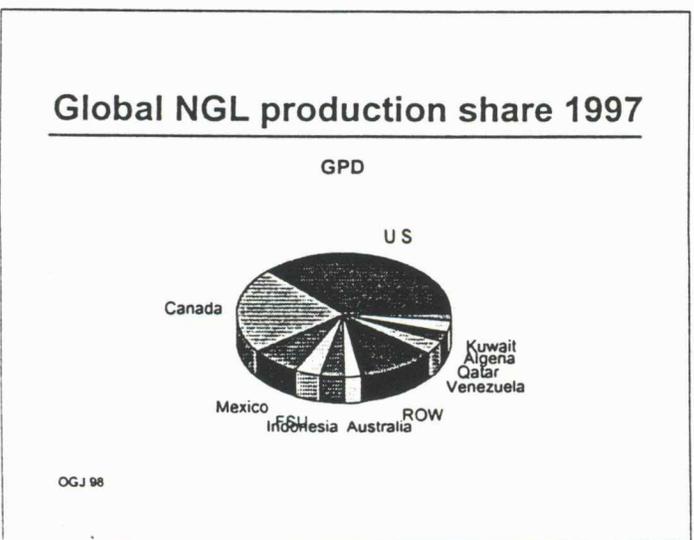
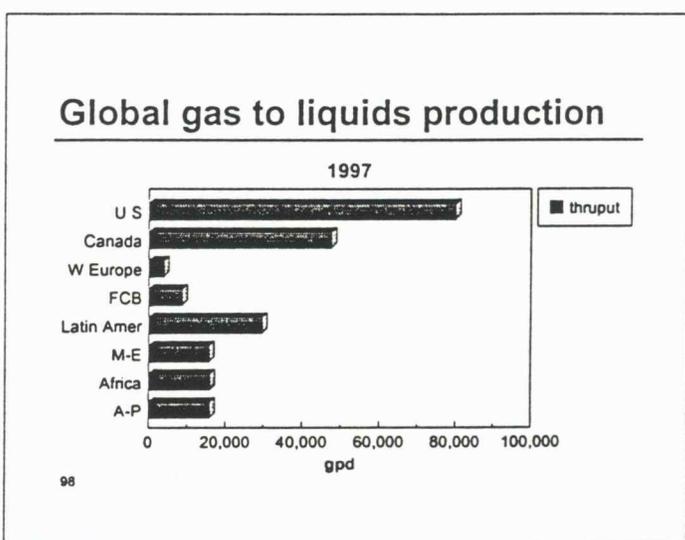
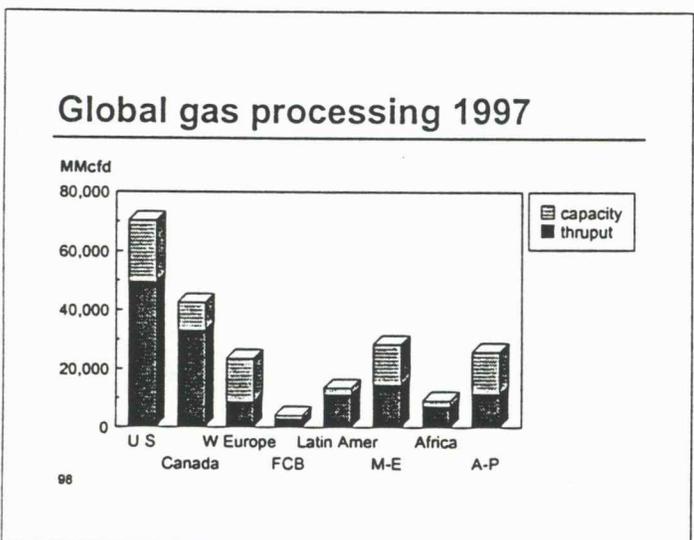
PIPEDREAMS, PIPELINES, AND COSTS





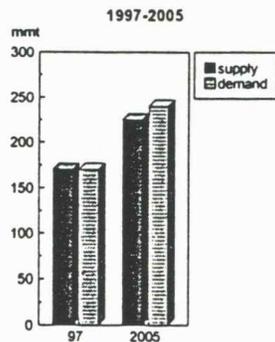
APEC/ASIA Gas Pipeline Projects

Placename	start	end	cost	capreserves	dist
Indo Corridor	98		\$1.1b	300	540
Phil Camago	00		\$4.0b	400	500
Mal PPG					
Thai/Mal JDA	01		\$277m	3-500	500tcf
PNG Kutubu	00		\$1.3B		4.0tcf
Thai/My Yadana	98			525	5.7tcf
Thai Anbaman	00			200	
Indo Natuna	00		\$1.1B	325	480
Thai/My link	00			6-1500	10tcf
ASEAN TAGP			\$20B		300
Kazak					
Irkutsk	08		\$20B		3000
Yakutsk	08		\$14B		1500
Sakhalin	10				

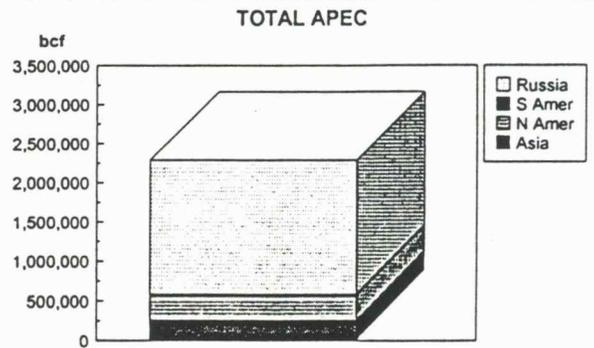


Global LPG supply & demand

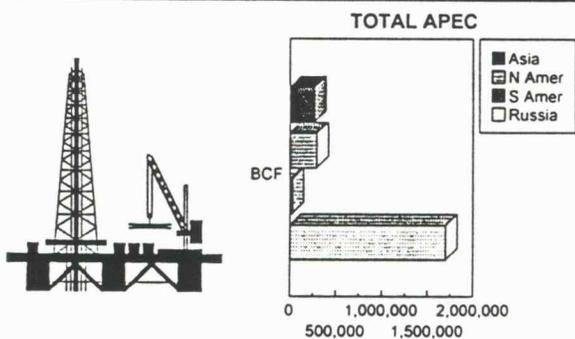
- LPG competes with pipeline and LNG
- The first step in developing gas infrastructure



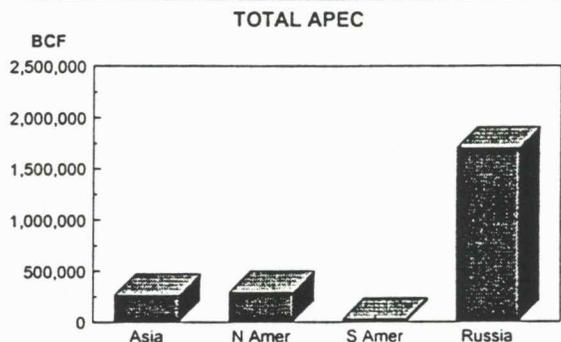
APEC gas reserve distribution 98



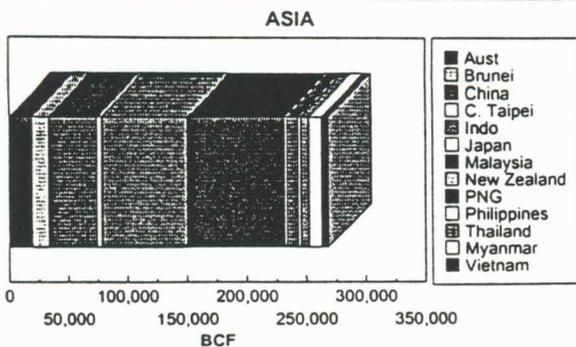
APEC gas reserve distribution 98



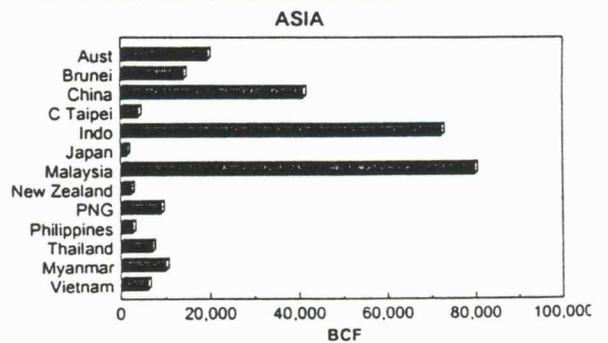
APEC gas reserve distribution 98



APEC gas reserve distribution 98

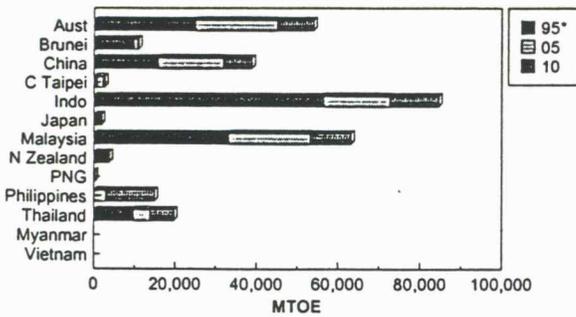


APEC gas reserve distribution 98



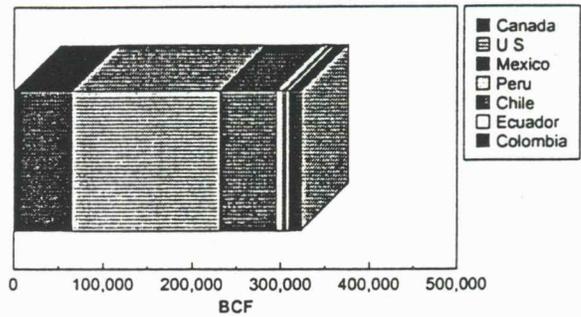
APEC gas production 1995-2010

APERC ASIA AFC CASE



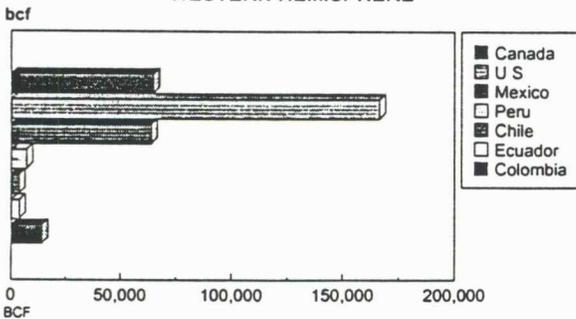
APEC gas reserve distribution 98

WESTERN HEMISPHERE



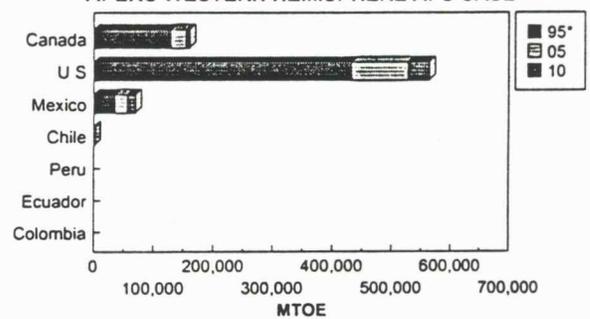
APEC gas reserve distribution 98

WESTERN HEMISPHERE



APEC gas production 1995-2010

APERC WESTERN HEMISPHERE AFC CASE



APEC Gas Reserves 1998 vs 2010

	Gas (bcf)
1998	
2005	
2010	

APEC Gas Reserves 1998 vs 2010

RUSSIA

	Gas (bcf)	NGL (1000bb)	Crude (1000bb)	GAS R/P
1998	1,700,000		48,573,000	73.4
2005				
2010				

APEC Gas Reserves 1998 vs 2010

COLOMBIA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	14,200		2,800,000	50.7
2005				
2010				

APEC Gas Reserves 1998 vs 2010

ECUADOR

	Gas (bcf)	NGL	Crude (1000bbl)
1998	3,700		2,115,000
2005			
2010			

APEC Gas Reserves 1998 vs 2010

CHILE

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	3,460		150,000	95.9
2005				
2010				

APEC Gas Reserves 1998 vs 2010

- Camisea may hold up to 7x current reserves with 11tcf gas & 0.6bb condensate

PERU

	Gas (bcf)	NGL	Crude (1000bbl)
1998	7,024		800,000
2005			
2010			

APEC Gas Reserves 1998 vs 2010

MEXICO

	Gas (bcf)	NGL (BB) 97	Crude (BB)	Gas R/P
1998	63,456	6.43	41,392	52.1
2005				
2010				

APEC Gas Reserves 1998 vs 2010

UNITED STATES

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	166,474		22,017,000	8.9
2005				
2010				

APEC Gas Reserves 1998 vs 2010

CANADA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	65,020		4,839,189	14.2
2005				
2010				

APEC Gas Reserves 1998 vs 2010

VIETNAM

	Gas (bcf)	NGL	Crude (1000bbl)
1998	6,000		600,000
2005			
2010			

APEC Gas Reserves 1998 vs 2010

MYANMAR

	Gas (bcf)	NGL	Crude (1000bbl)
1998	10,000		50,000
2005			
2010			

APEC Gas Reserves 1998 vs 2010

THAILAND

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	7,000		295,260	18.1
2005				
2010				

APEC Gas Reserves 1998 vs 2010

PHILIPPINES

	Gas (bcf)	NGL	Crude (1000bbl)
1998	2,700		212,700
2005			
2010			

APEC Gas Reserves 1998 vs 2010

PAPUA NEW GUINEA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	9,000		325,000	100
2005				
2010				

APEC Gas Reserves 1998 vs 2010

NEW ZEALAND

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	2,400		145,290	17.3
2005				
2010				

APEC Gas Reserves 1998 vs 2010

MALAYSIA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	79,800		3,900,000	66.5
2005				
2010				

APEC Gas Reserves 1998 vs 2010

JAPAN

	Gas (bcf)	NGL	Crude (1000bbl)
1998	1,388		60,189
2005			
2010			

APEC Gas Reserves 1998 vs 2010

INDONESIA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	72,268		4,979,710	33.4
2005				
2010				

APEC Gas Reserves 1998 vs 2010

CHINESE TAIPEI

	Gas (bcf)	NGL	Crude (1000bbl)
1998	4,000		4,000
2005			
2010			

APEC Gas Reserves 1998 vs 2010

CHINA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1998	41,000		24,000,000	94.9
2005				
2010				

APEC Gas Reserves 1998 vs 2010

BRUNEI

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1997	14,100		1,350,000	38.4
2005				
2010				

APEC Gas Reserves 1998 vs 2010

AUSTRALIA

	Gas (bcf)	NGL	Crude (1000bbl)	Gas R/P
1997	19,429		1,800,180	19.2
2005				
2010				

bcf

Global vs APEC reserves 1997

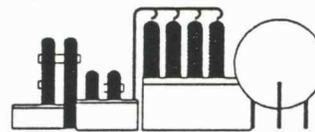
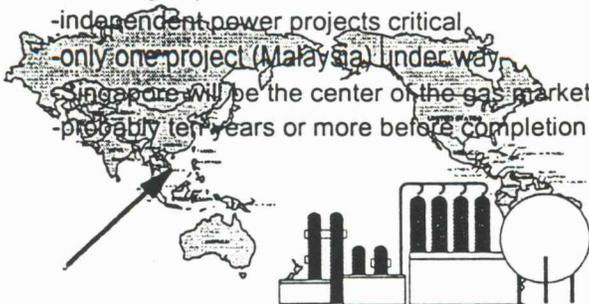
The Geopolitics of gas

Many geopolitical strategists believe that gas provides both environmental and security benefits

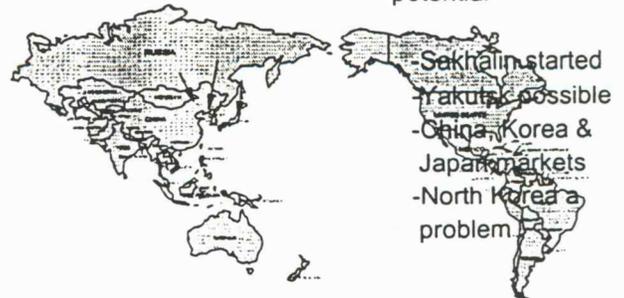
- diversifies supply
- provides fuel for electric power projects
- has a wide geographic range
- provides environmental benefits
- 55% global demand increase 1994 to 2010
- decline in gas demand in FSU masks world growth
- World gas demand in 1994=213 bcf/d

Southeast Asia (ASEAN) is considering a major expansion of infrastructure and pipelines for gas

- area is gas prone
- independent power projects critical
- only one project (Malaysia) under way
- Singapore will be the center of the gas market
- probably ten years or more before completion



Eastern Siberia has potential



- Sakhalin started
- Yakutsk possible
- China, Korea & Japan markets
- North Korea a problem

**Future Trends in Oil and Gas Supply and Demand
in the Asia-Pacific Region: Uncertain Future**

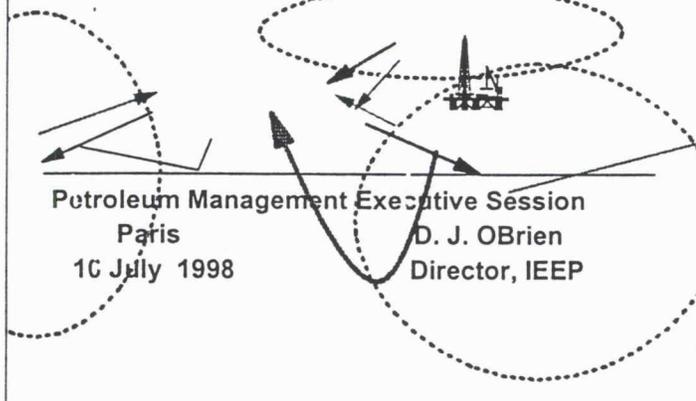
DENNIS J. O'BRIEN, PH.D.

**BROCK CHAIR, PROFESSOR AND DIRECTOR
INSTITUTE FOR ENERGY ECONOMICS AND POLICY
SARKEYS ENERGY CENTER
THE UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA 73019-1006**

**Petroleum Management Executive Session
Paris
10 July 1998**

Future Trends in Oil and Gas Supply and Demand in the Asia-Pacific Region:

Uncertain Future



Petroleum Management Executive Session
Paris
10 July 1998
D. J. O'Brien
Director, IEEP

IEEP

- The Institute for Energy Economics and Policy (IEEP) is located in the Sarkeys Energy Center, University of Oklahoma. Sarkeys Energy Center is the most comprehensive center of knowledge in the oil and gas industry with seven institutes dedicated to applied research with partners in over 30 countries and over 30 private, public and state oil companies worldwide. Sarkeys technical research is on the cutting edge of technology and has over 160 research associates and graduate students from nearly all the APEC economies.
- IEEP has a global energy vision and has the mission of developing quality energy economics based on quality research and technical understanding of energy systems, organization, and global supply and demand. IEEP is experienced facilitator and provider of strategic advice for energy organizations. The IEEP works closely with the Caspian Petroleum Technology Institute and the PECC Energy Forum and is the home of the PECC Energy Forum Technical and Policy Center.

IEEP Centers of Excellence

- The Center for Energy Market Analysis (CEMA) will develop an annual global energy outlook beginning in 1999 in addition to forecasts for the supply/demand for oil products for North America (NAOPS) and the Eastern Hemisphere (ESOPS). CEMA is also developing EWxAS which will provide a unique tool to plan and risk manage weather for energy companies world wide.
- The PECC Energy Forum Technical and Policy Center (PEFTP) vision is to provide the 24 PECC member economies quality energy analysis and support (all APEC economies are members) PEFTP is currently developing a major study of PECC gas infrastructure with policy recommendations for member economies

IEEP Centers of Excellence

- The Center for Energy Management (CEM) provides executive energy management training and assistance in developing strategic visions and planning for clients.
- The Center for Energy Policy Analysis (CEPA) vision is to provide energy policy analysis and recommendations based on quality technical and economic understanding and research. CEPA also is developing an Energy Technology Assessment System (ETAS) which will provide a time and cost evaluation of emerging energy technologies. CEPA has provided extensive advice to public, private, and state energy companies and governments regarding organization, deregulation, finance, and privatization.

Sarkeys international outreach

- The Energy Institute for the Americas (EIA) headed by Ambassador Ed Corr works with research organizations and public and private sectors in the Americas
- Caspian Petroleum Technology Institute (CPTI) works with the Caspian States.
- Institutes of Gas Utilization, Environment, Rock Mechanics, Reservoir Characterization, Geosciences, have consortia based research with over 40 companies in 30 countries in addition to most of the major companies and organizations in the U S and Oklahoma
- More than 300 international research associates, faculty, and graduate students participate in Sarkeys Energy Center

petroad . . .

- is the short name for petroleum advisors.
- is dedicated to helping organizations develop global and regional strategic visions, presence, planning, human resources, and business.
- associates are experienced leaders in industry, government, and professional organizations.
- can assist in matters concerning image, risk, regulation, executive education, and tax.

Agenda

- The Asia background
- Impact of Asia financial crisis
- The new economics of energy in Asia
- The supply outlook for oil in Asia
- Deregulation, privatization, restructuring
- The outlook for gas
- Implications for business development & investment

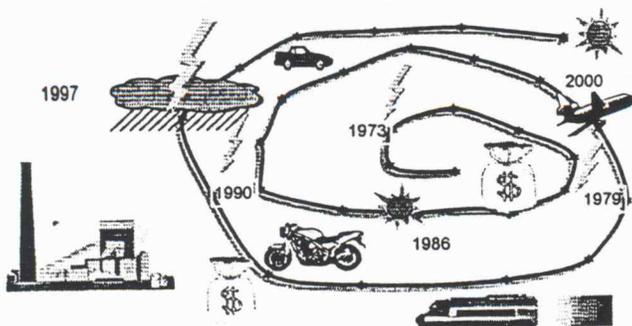
Critical issues . . .

- The financial crisis . . .
- Recovery?
- Is there a supply security issue?
- Can Asia refiners obtain a full menu of crudes to meet product supply/quality requirements?
- Can Asian nations take a price shock?
- Can product imports continue to meet import requirements?
- Is there an capital avails problem for energy projects in Asia?
- Will the oil industry meet environmental & product quality requirements?

Key environmental issues relating to global energy . . .

- Transborder air quality (acid rain)
 - China's emmissions to Korea, Japan
 - Eastern Europe and Western Europe
 - US coal use and Canada
- Urban air quality
- Water quality issues
 - oil spills
 - industrial waste
- Kyoto and global warming
- Retail marketing of oil products is impacted by all the above

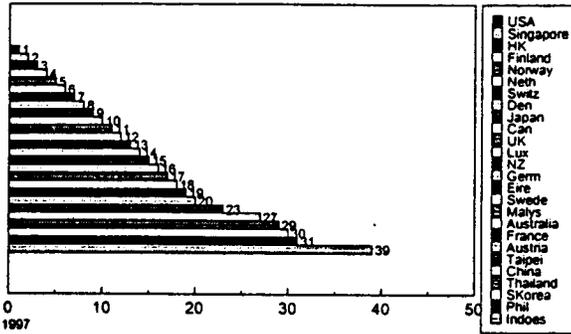
Background: explosive economic & energy growth . . .



Challenges in the Asia-Pacific . . .

- Economic growth and infrastructure
- Infrastructure constraints
- Meeting energy, oil demand
- Meeting supply requirements
 - refined products
 - regional crude sources
 - LNG and electric power
 - balancing supply/demand by imports of crude and products
 - global implications
- Structure of the energy industries

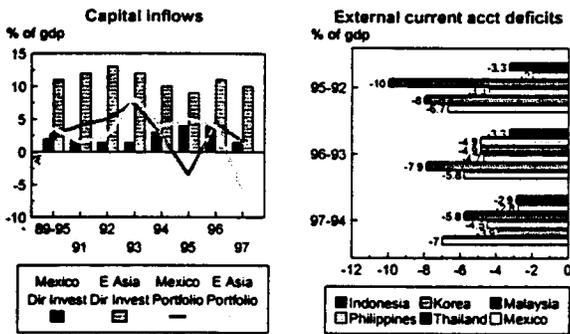
The World Economic Forum (Davos) has ranked the top world economies based on competitiveness (1997)



Anatomy of a crisis

- A world wide realignment of currencies rolled in Thailand in Fall 97
- Capital flows had stimulated demand, equities and real estate values, growth of bank assets and loans, and built large external current account deficits
- The inflated Thai balloon economy burst and triggered similar reactions in Malaysia, Indonesia, Korea and to a lesser degree in the Philippines
- Mahatir and Suharto made a bad situation worse for their economies
- Japan's weak financial structure was exposed
- The rest of Asia has been less affected
- The next shoe is China, Hong Kong, and Taipei

Mexico (92-4) vs E Asia (95-97)



Currency depreciation, share price values, and interest rate risk in a crisis

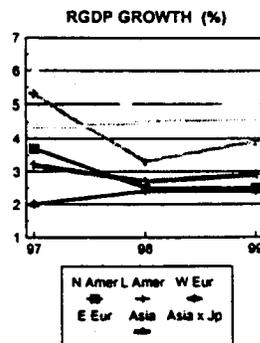
- Mexico may provide some hints on timing of recovery
- Fiscal and monetary adjustments, X rate float, structural & market liberalization and emergency financial packages contained crisis
- Internal reform of banks and opening financial markets
- cost=14.4% of 1997 GDP amortized for 30 yrs
- GDP was 5.2 & 7% in 96-7 & CPI fell from 52 to 15%

E Asia 7-1-97 to 2-16-98
Mexico 12-1-94 to 3/31/95

	Currency Share index Interest rate		
	change (%)	change(%)	base points
Indonesia	231	-82	2,388
Korea	63	-43	885
Malaysia	55	-68	373
Thailand	87	-48	-25
Mexico	88	-38	5,875

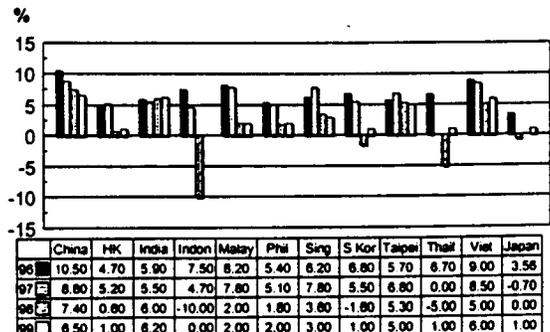
The global economy 1997-9

- Global economy moderates
- Asia slows then recovers
- Japan finally moves
- World survives Asian flu



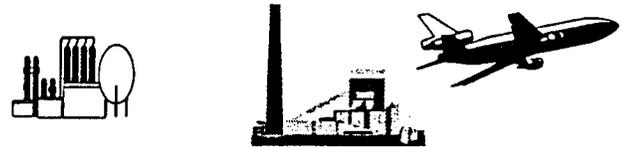
Crisis in Asia

Economic Growth



Thailand: melt down and fire sale

- Stock markets crash
- Bhat crisis
- Property tumbles
- Labor market slows
- Auto sales drop
- Wall Street worries
- Oil demand drops?
- Tourists invade
- Bhat stabilizes?
- Global players enter
- Investment expands
- Export trade expands
- Labor market increases
- Oil demand increases!

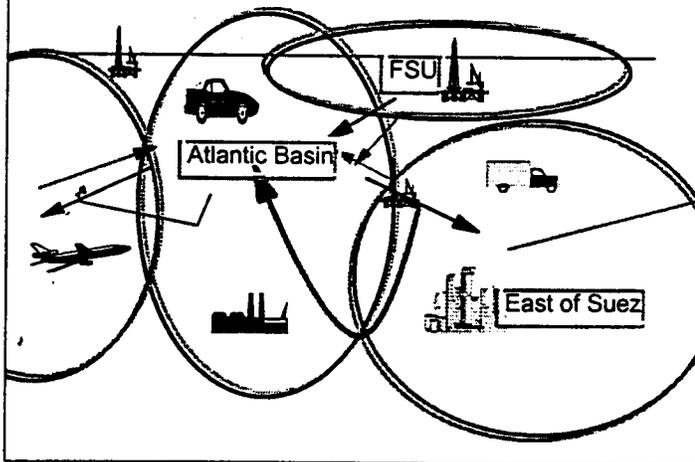


The new economics of energy is Asia

Finding the new base



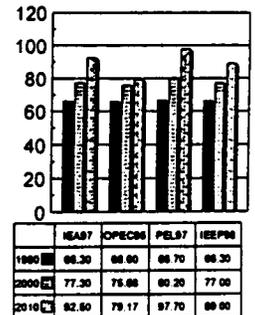
THREE WORLD OIL MARKETS



LONG TERM DEMAND OUTLOOK

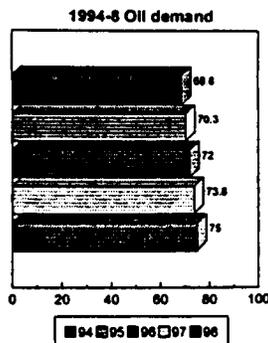
- Experts agreed on 77-78mmb/d in 2000 and over 90mmb/d by 2010
- New crude capacity additions have exceeded demand annually since mid 1980's
- Gas, alternate fuels, efficiencies will moderate oil demand growth
- Revised IIEP factors growth and alternative fuels into new (2-98) forecast

FORECASTS BY IEA OPEC AND PEL



GLOBAL OIL DEMAND 1994-8

- World grows at 1.8%
- Strong growth in Asia-Pacific is flat in 98 & Latin America grows
- Marginal impact of economic growth on oil demand
- Asia currency crisis and weather will shave demand in 1997-8.
- Need to understand seasonal weather effects



Oil market outlook 1998

- Weather & AFC have made a significant impact
- Global economic growth uncertain
- Information technology has/will play a major role
- Technology continues to drive costs down
- Environmental quality will raise costs
- Politics & science of global climate change uncertain
- Global refining capacity/economics very tight
- Volatile seasonal markets for oil and gas
- Global gas infrastructure and markets expand
- Adequate investment capital—lack of good economics
- Alternate fuels and vehicles a decade out
- Studid sanctions and politics continue
- Significant industry restructuring continues

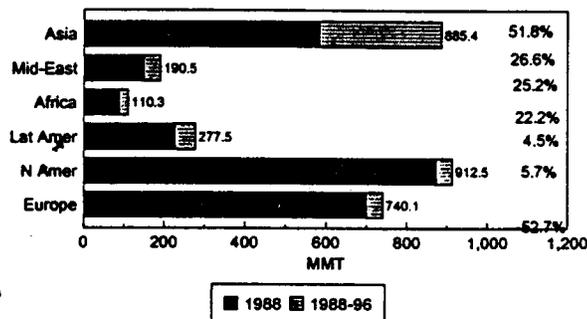
What is driving the current oil market?

- Efficiency, transparency
- Oil market came into balance in early 1997 after two years of weather driven product market imbalances
- Continued non OPEC crude capacity expansion plus increased refinery expansion in Asia increased supply of both into the markets
- Warmer and other demand reducing weather factors have further softened markets
- Economy driven factors in Asia--petrochem, jet fuel, and other demand just now showing some effects.

The new energy economics in Asia

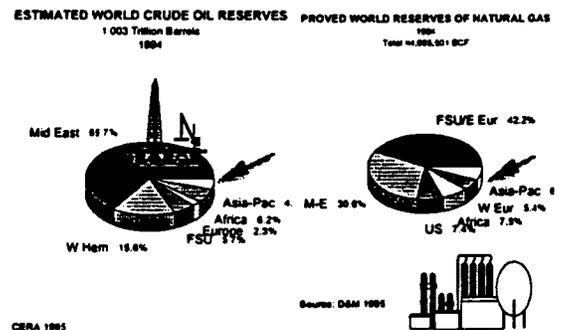
- Oil supply side will not be impacted significantly
- Future gas supply faces increased uncertainties
- Petroleum product demand base picture will not sort out for another 6-12 months
- Coal etc benefit in electric power and industry
- IPP's need to be recalibrated
- Liquidity problem but no capital shortfall
- Deregulation, privatization, restructuring are stimulated

Global Product Demand 1988-96



11/87

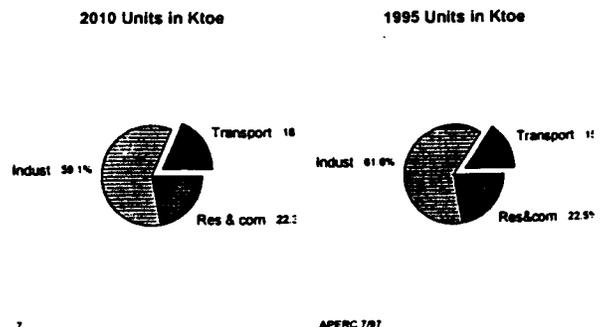
Asia has 4.6 % of world oil and 6.8% of world gas reserves . . .



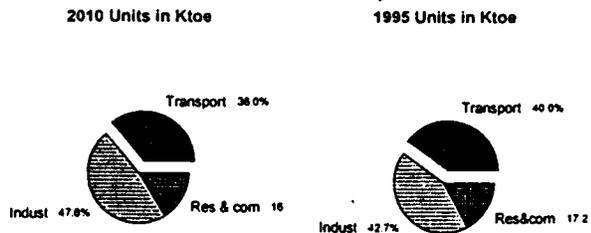
Meeting Asia-Pacific oil product supply requirements . . .

- Major refinery capacity additions on stream in 1996-7 (planned in 1991-2)
- Slow-down post 1997 (poor margins in 1994-5)
- Overbuilding of gasoline capacity
- Global surplus of attractive light crudes
- Global avails of gas oil, jet kero
- Theoretical tightness 2000 and beyond

East Asia(APEC) energy balances 1995/2010

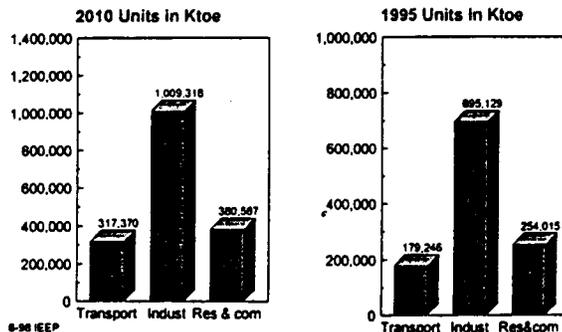


S E Asia(APEC) energy balances 1995/2010



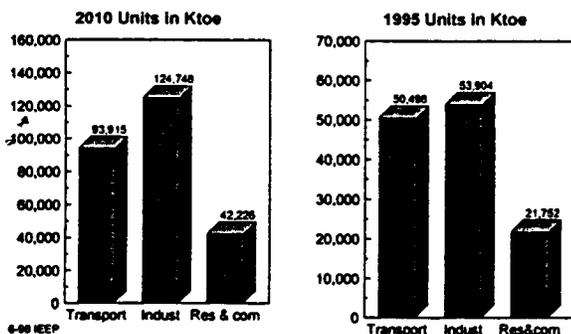
6-98 IEPP

East Asia (APEC) energy demand 1995/2010



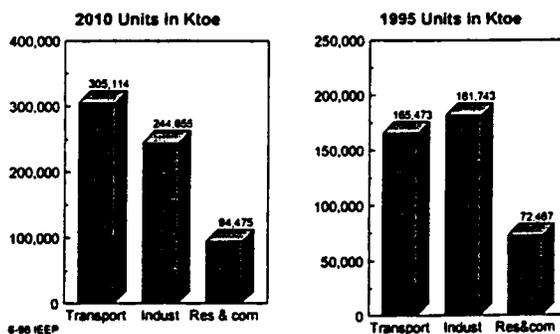
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S E Asia(APEC) energy balances 1995/2010



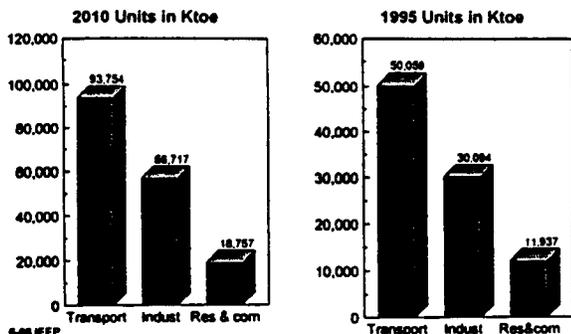
6-98 IEPP

East Asia (APEC) oil demand 1995/2010



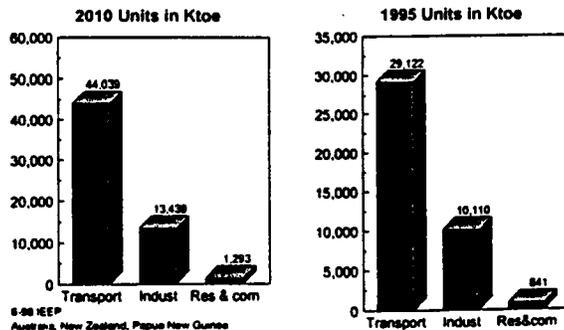
6-98 IEPP

S E East Asia (APEC) oil demand 1995/2010



6-98 IEPP

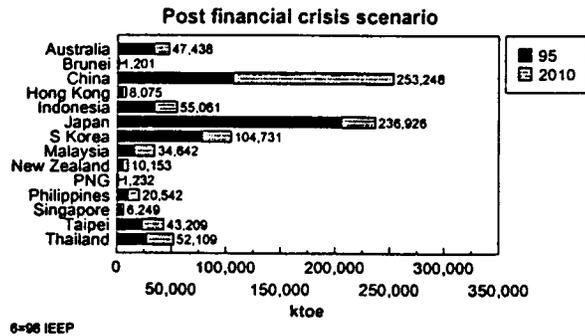
Oceania (APEC) oil demand 1995/2010



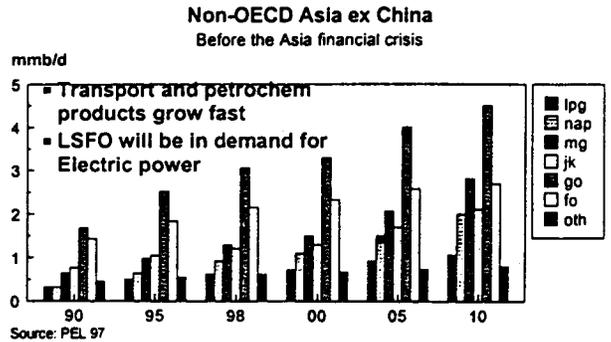
6-98 IEPP

Australia, New Zealand, Papua New Guinea

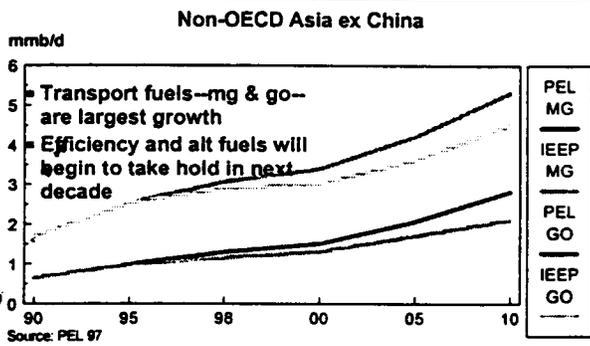
APEC Asia oil demand 1995/2010



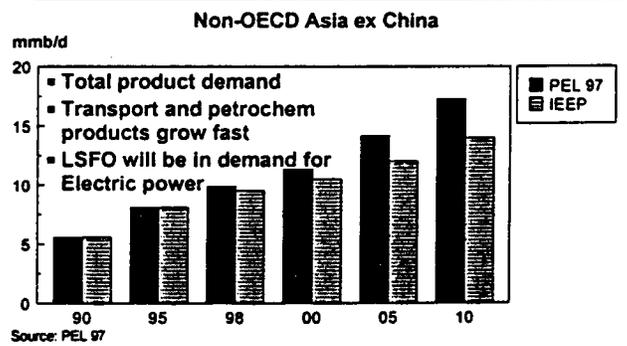
World oil product demand 1990-2010



World oil product demand 1990-2010

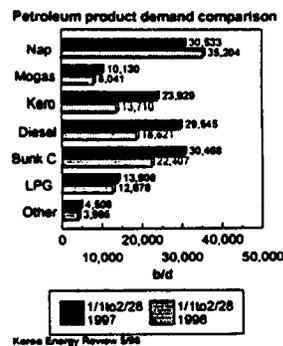


World oil product demand 1990-2010

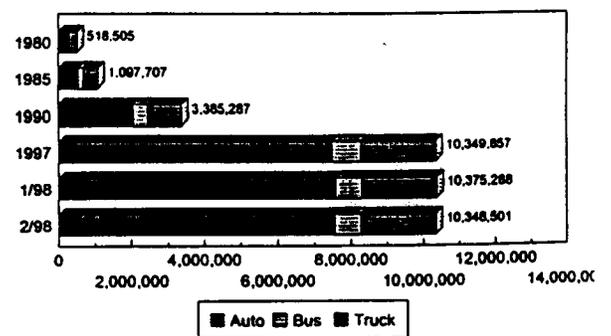


Korea after the financial crisis

- Korea was visited by El Nino
- Kero, Bunker C, LPG, and Diesel are weather related
- AFC drives transport & industrial fuel decline
- Auto, bus, & truck registrations decline in Feb 98 for the first time in history
- Town gas demand up 5.5% in Jan-Feb 98 over 97

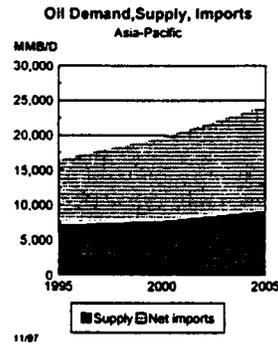


Korea motor vehicle registrations

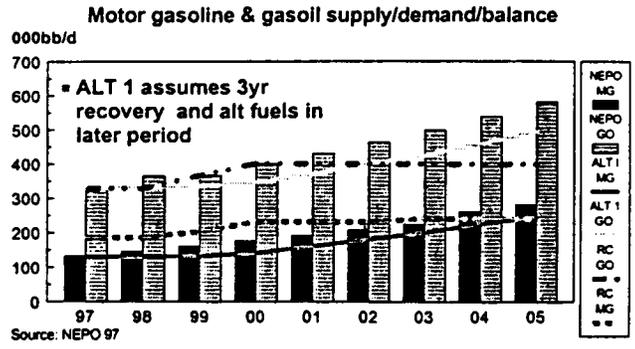


The import story

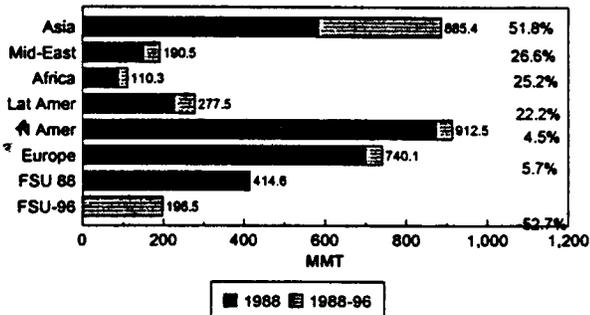
- Net product import grows from 2.0 to 5 mmb/d in 2005
- Net oil imports could grow from 9 to over 15 mmb/d
- Mid-East major source but PADDV & other areas will supply



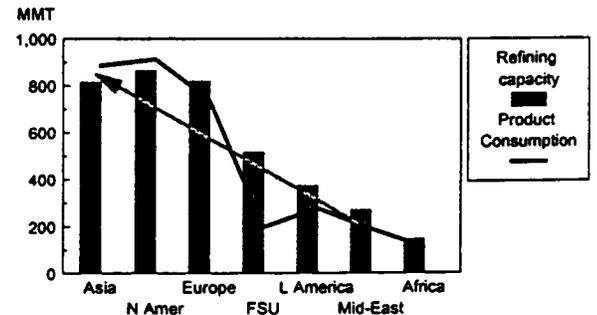
Thailand transport fuels 1997-2005



Global Product Demand 1988-96



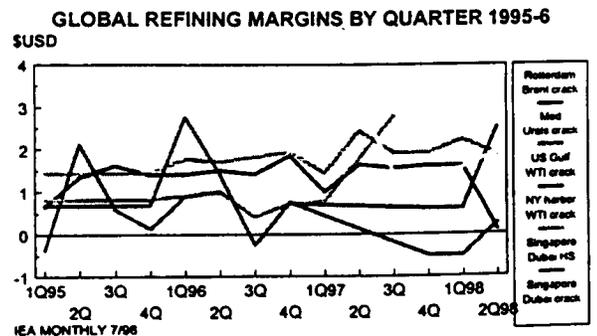
Refinery Capacity vs Product Consumption 1996



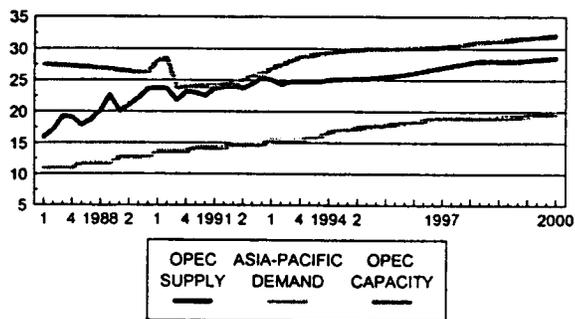
Refining capacity, consumption, exports and imports 1996

MMT	Ref Cap mbd	Ref cap MTPa	Consumpt	Imports	Exports
Japan	4090	249.5	269.9	47.7	7.3
China	2867	143.4	172.2	16.7	5.3
S. Korea	2211	110.6	101.4	24	12.9
India	1088	54.3	76.7	12.9	4.3
Indonesia	805	40.2	42.9	6.9	9.1
Thailand	558	27.9	38	8.5	0.3
Australia	771	38.5	36.7	3.1	3.6
Taiwan	770	38.5	35.3	8.8	0.6
Singapore	1157	57.9	26.7	26	47
Malaysia	330	16.5	16.8	7.9	0.2
Philippines	323	16.2	17.5	2.4	0.6
Pakistan	137	6.9	17.1	7.9	0.2
Hong Kong	91	4.6	4.0	0.7	0.2
N Zealand	91	4.6	5.8	0.6	0.2
N Korea	713.5	3.5	4	0.7	
Vietnam			4.0		
Bangladesh	31	1.6	2.4	1.0	
Sri Lanka	48	2.4	2	0.3	0.2
Myanmar	32	1.6	1		
Brunei	9	0.4	0.6	0.1	
Nepal			0.5	0.5	
TOTAL	16266	814.3	663.5	194.6	100.3

Global refining Margins 1995-97



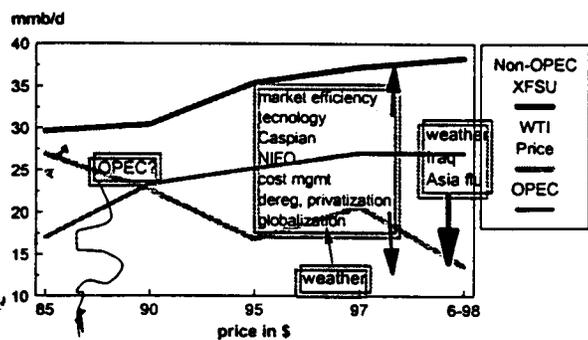
ASIA-PACIFIC OIL DEMAND DRIVES OPEC 1987-2000



What is driving the current oil market?

- Efficiency, transparency
- Oil market came into balance in early 1997 after two years of weather driven product market imbalances
- Continued non OPEC crude capacity expansion plus increased refinery expansion in Asia increased supply of both into the markets
- Warmer and other demand reducing weather factors have further softened markets
- Economy driven factors in Asia--petrochem, jet fuel, and other demand just now showing some effects.

Wagging the oil dog 1985-98

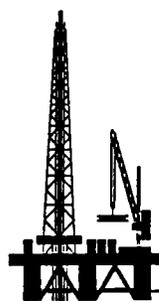
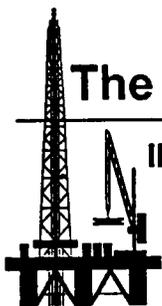


A simple thesis

- Significant new supply growth of high quality crudes emerged in the Atlantic Basin in 1993 and continue to place downward pressure in a globalized market
- This was checked by weather in the Winter 95-6 and strong Asia demand provided a floor to Dubai crude
- Product markets--inbalances--provided an uplift to crude prices through mid 1997
- Oversupply pressures in both crude and product returned
- El Nino has created a major problem
- Asia demand will not provide a floor this time
- The fundamental oversupply does not change in the next five years--only weather and politics can change

The supply of oil in Asia

IEEP/APERC review, May 1998



Deregulation, privatization and restructuring

Freelance & Power point Presentation

Thailand--Deregulation plan

Objectives

- allow market forces to set oil price
- get politics out of pricing
- achieve energy efficiency

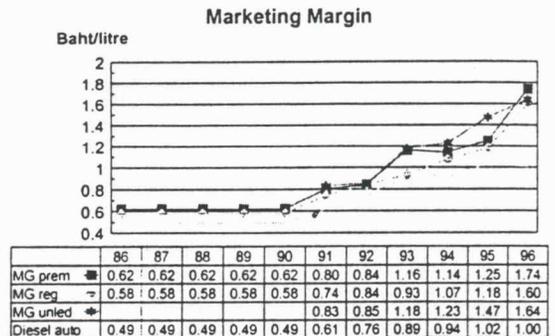
Steps to deregulation May 27, 1991

- interim price controls based on Singapore/spot prices
- weekly changes in wholesale pricing
- minimal taxes and Oil Fund
- marketing margins set by company

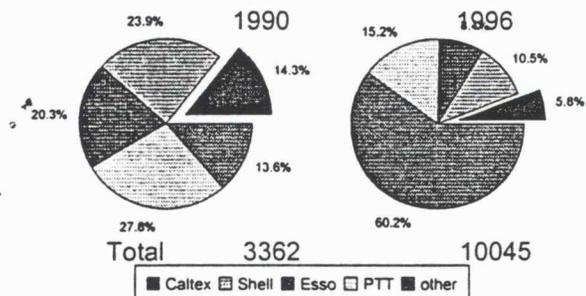
Full deregulation August 19, 1991

- govt sets taxes and oil fund
- free pricing ex refinery, imports, wholesale, retail including margin (PTT defacto sets prices)

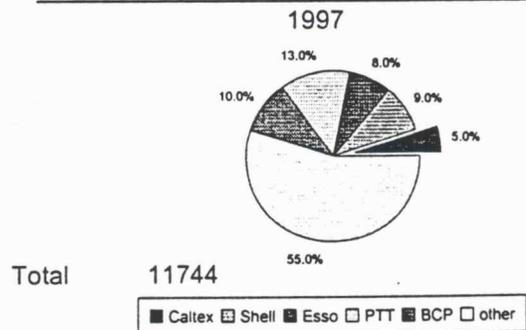
Thailand marketing margins 1986-1995



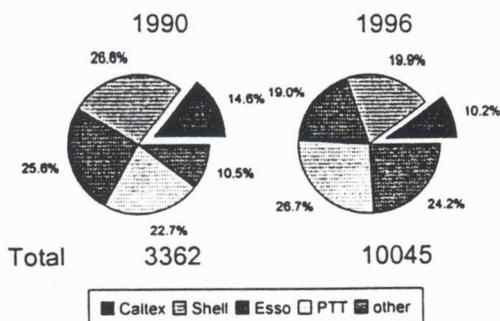
Thailand service stations



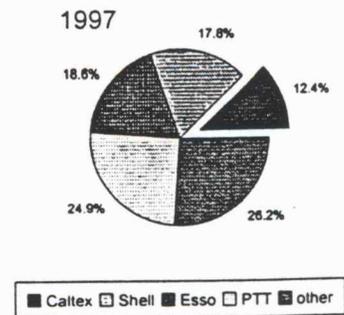
Thailand service stations



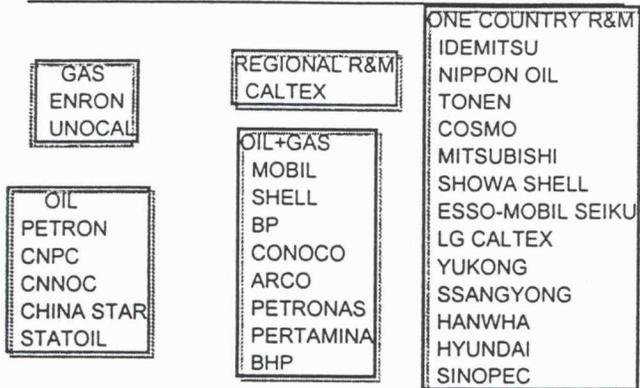
Thailand market share



Thailand market share



Alliances and competition



Caltex: a strategic alliance evolves

- Purchased BP service stations
- Strategic alliance with Shell in refining
- Aggressive brand strategy
- Sponsors Asia Games
- Restructuring from traditional regional to six business lines: marketing, lubes, trading, support services, aviation, refining, new business development
- Search for leadership
- Texaco has an increased presence downstream

What is the next move?

Chevron's role?

Three competitor strategies

- ARCO**
- "ARCO has no ideas"
 - new ideas-Lukoil, China, Algeria Qatar, N Sea, Indonesia
 - Hainin-HK pipeline good move

- UNOCAL**
- reinvented
 - shift to Asia
 - Thailand gas base
 - pipeline focus

- TOTAL**
- small domestic role in gas
 - strong role in gas in Europe
 - reserves & LNG focus-Qatar, Oman, Yemen, Indonesia
 - pipeline Myanmar to Thailand with UNOCAL
 - electric power in Myanmar, Vietnam, Thailand, Argentina Colombia
 - Strat alliance with Petronas on Iran gas-

Opportunities and risks

- "time of concern, worry, pause, reflection"
- recent investments in Asia are in trouble
- new players under pressure
- window for new players if they get it right

Three strategies for Asia

- Look for assets in trouble
- Plant new assets and start new ventures
- Find strategic partners

Critical issues . . .

- Is there a supply security issue?
- Can Asia refiners obtain a full menu of crudes to meet product supply/quality requirements?
- Can Asian nations take a price shock?
- Can product imports continue to meet import requirements?
- Is there an capital avails problem for energy projects in Asia?
- Will the oil industry meet environmental & product quality requirements?

China

- Position long term for big bang
- Upstream
 - CNPC opens onshore in 2000
 - CNNOOC always looking for something
 - gas utilization is now on agenda
 - China Star an old & new player
- Downstream
 - SINOPEC reorganizing
 - Alternative fuels for transport
- Tactics
 - Tarim
 - Technology to mature fields- Canadian Fracmaster
 - gas, gas, gas

India

-
- Position for long term
- Re regulation & privatization
- Gas to power
- Many strategic alliance possibilities

Indonesia

- Position for big bang
- Upstream
 - gas to LNG
 - tech to mature fields
 - fuels, CNG, LPG, Other
- Downstream
 - Refining linked to marketing
 - retail marketing outlets
 - engineering & construction opportunities
- Small power generation opportunities after sort out

The rest of Asia

- Korea--gas infrastructure
- Japan--position for long term
- Taipei--CPC & TPC privatize and re reg
- Philippines--power
- Malaysia--position long term
- Thailand--PTT privatization
- Singapore--crowded
- Cambodia--small but interesting
- Vietnam--E&P, downstream
- Myammar--E&P, downstream

The vision of the global business environment . . .



vision>strategy>structure>culture>implement>adjust>vision



Business environment is the key to the future . . .



- Asia-Pacific leads the world in cooperation between the oil industry and government but others can learn--and they have. It is time to restore confidence by example



Ecological Footprints: Evaluating Sustainability

A. R. Palmer, Institute for Cambrian Studies, Boulder, Colorado

Introduction.

The concept of ecological footprints was introduced to the general public by Wackernagel and Rees (1996). Its premise is that each of us has real areas of Earth's surface dedicated to our consumption of food and wood products (footprints of the same name); to our use of land surface for buildings, roads, garbage dumps, etc (degraded land footprint); and to forests necessary to absorb the excess carbon dioxide produced by our burning of fossil fuels (energy footprint). The sum of these footprints can be calculated and constitutes our ecological footprint.

If I drink orange juice and eat oranges, the quantity I consume in the course of a year requires some or all of an orange tree and the land it occupies dedicated solely to me. The paper and wood products I use annually require some part of the world's forest to be dedicated to my personal consumption. The land under our houses, parking lots, streets, businesses, etc. is degraded ecological land that is taken out of production, and this loss is shared by all of us, as is the area of our garbage dumps. These are real areas, and form parts of a zero-sum calculation.

We need to eat; it would be hard to imagine a world without lumber, books, newspapers, magazines, wrapping materials and cardboard boxes, so we need some forest; and we are addicted to building cities, highways, airfields, etc. and to the disposal of trash. Earth has finite and recognizable areas of arable land, pastureland, and forest. Degraded areas encroach on all three of these, and expansion of any one of these components must be at the expense of another. Ecological Footprint Analysis of these real demands can give us some measure of the degree to which Earth's surface can sustainably support humanity's patterns of consumption as population grows and standards of living in developing countries rise.

Our energy footprint is not subject to areal constraints. It is a theoretical area of forest that would be needed to sequester the excess carbon (as carbon dioxide) that is being added to the atmosphere by the burning of fossil fuels to generate energy for travel, heating, lighting, manufacturing, etc. If we fail to sequester the excess, it will build up in the atmosphere and create the potential for a possibly catastrophic rate of global warming or other environmental stress. To evaluate sustainability, we must decouple the real demands on Earth generated by our food, wood products and degraded land needs from the theoretical demands generated by burning fossil fuels. They reflect different kinds of sustainability problems and are not additive.

The evidence that human-induced increases in atmospheric carbon dioxide are already detectable has spurred international concern reflected at the Kyoto conference in early 1998. The corollary of this evidence is that the natural global systems for carbon sequestration are not handling the human contributions fast enough. Only about half of the carbon we generate burning fossil fuels can be

absorbed in the oceans and existing terrestrial sinks (Suplee, 1998). The most effective way to sequester the excess carbon would be to ADD appropriate amounts of NEW forest, because, on a global scale, forests are the largest absorbers of CO₂ that can be increased. Energy footprint analysis shows that the amount of new forest needed is unrealistically huge, and thus there seems to be no satisfactory mitigation available to limit the buildup of carbon dioxide in the atmosphere.

If we deem the carbon dioxide problem severe enough, we can speed up attempts to find alternative energy sources that would reduce the amount of fossil carbon being added to the atmosphere. In the long run, the carbon dioxide problem will be reduced for us anyway by the practical exhaustion of the finite quantities of oil, gas and coal on the planet. The supply of oil and its derivatives, upon which we rely heavily not only for their obvious use in manufacturing and transportation, but also for pharmaceuticals, plastics, fertilizers and tires, will begin to decline by the middle of the next century (Edwards, 1997) or earlier (Campbell and Laherrère, 1998) and be practically and perhaps politically unavailable within the lifetimes of the grandchildren of young parents today.

Wackernagel and Rees (1996, p. 15) concluded that the message from their footprint analysis is "If everybody lived like today's North Americans, it would take at least two additional planet Earths to produce the resources, absorb the wastes, and otherwise maintain life-support." Re-analysis of our United States footprint shows that the problem of living sustainably on Earth is somewhat less daunting than Wackernagel and Rees asserted, but it is by no means a non-problem.

The footprint of the average U.S. citizen.

In order to understand why there is a problem with sustainability of our lifestyle, we need to think globally. Any good almanac or encyclopedia will provide information about the areas of the Earth that are in any way ecologically available. When areas of true desert, and those covered by water or permanent ice are eliminated, this ecologically available land area, according to my almanac source, is slightly less than 29,000,000,000 (billion) acres. A significant part of this area, such as tundra, semi-arid regions, areas above timberline, and swamplands is not practically accessible for our food, wood products and land degradation demands. United Nations estimates of areas of arable land, cropland, and pasture (FAO, 1995) and U.S. Environmental Protection Agency estimates of world forest cover (Brown et. al., 1996) indicate that there are only about 22 billion acres of usable land. This sounds like a lot, but there are 6 billion people on Earth today and most reasonable projections conclude there will be about 10 billion people on Earth by 2050. Because our concern is for a sustainable future, we need to think in terms of these 10 billion rather than today. Thus, by 2050, the ecologically usable surface of the Earth, will allow an average total footprint of slightly more than 2 acres per person. This number is fairly well constrained because the usable land area on Earth is not going to change on a human time scale, and population will probably not be significantly less than the projected 10 billion persons.

Table 1 shows the components of the ecological footprint of the average U.S. citizen, which total 3.3 acres. If we keep living as we do, our footprint will be about 50% more than the fair share of usable land on Earth by 2050. If all of Earth's population tried to live as we live, we would need almost an additional half-Earth, clearly an impossibility. Our marketers seem oblivious to this limitation of selling "the American way" to all citizens of Earth!

Perhaps we need to change our lifestyles, but what might we have to give up? Three categories of consumption contribute to our ecological footprints. In order of decreasing magnitude, these are wood products, food, and degraded land, i.e. the land taken out of ecological availability by buildings, roads, parking lots, etc. As shown in Table 1, the overwhelming contributors to our footprint are wood products and food. The following sections will focus on these two aspects of our footprints.

The wood products problem.

According to figures from the U.S. Forest Service (Richard Hanes, personal communication, 1995) the annual U.S. demands for wood products of all kinds require about 0.04 acre of forest dedicated to each one of us. A slightly larger wood products footprint can be calculated from data in Wernich et. al. (1998). It takes anywhere from 40 to 70 years to restore an acre of forest following harvesting. Thus, if we wish our current level of demand to be sustainable, we really need at least 40 times 0.04 acres of forest dedicated to our per-capita consumption. This is the basis for our wood products footprint of 1.60 acres.

Earth has an estimated 10,130,000,000 acres of forest (Brown et. al., 1996). A global population of 10 billion in 2050 that is consuming wood products as we do now would need 16 billion acres of forest for sustainability, IF all forest was dedicated to human consumption. We must not forget that a significant fraction (probably more than 10%) of earth's forests and other ecological land needs to be preserved in more or less pristine condition to maintain a minimum base for global biodiversity. Declining quality and quantity of Earth's forests do not bode well for this aspect of sustainability. Some cutback in our use of wood products or changes in forest management will probably be required in the next half-century.

The food problem.

Not all of Earth's ecological acreage is capable of producing food. According to the United Nations Food and Agricultural Organization (FAO, 1995), Earth has only 3.3 billion acres of currently utilized arable and cropland, and 8.4 billion acres of pastureland of all qualities. About 5 billion acres of the pastureland could be converted to farmland, but much of it would be of relatively low quality. If we utilized ALL potential farmland by 2050, the "fair share" of this food production area for each global inhabitant would be about 0.8 acre. Quality of existing farmland is declining worldwide (Pimentel et. al., 1995), but creation of new areas of arable land, especially if it is at the expense of forest, is probably not a realistic solution.

The food footprint for the average U.S. citizen, based on data compiled by the U.S. Departments of Agriculture (DOA) and Commerce (DOC) between 1992 and 1996, is a minimum of 1.50 acres. Comparable eating habits for the world population in 2050 would require a 60% increase in available arable land and cropland, and pastureland. It would appear that the whole world of 2050 could not sustainably eat as we eat! However, when our food footprint is broken down into its food components, using per capita consumption figures from the DOA, the overwhelming culprit in our footprint is beef (Table 2).

Why is the beef footprint so large? Using DOC figures on numbers of beef cattle and acres of pasture in some of the biggest beef-producing counties in Nebraska, Texas and Colorado, the average beef cow requires about 10 acres of pasture land. Before most of these cows go to the slaughterhouse, they spend 120 to 150 days being fattened in a feedlot where the average cow consumes about 2600 pounds of grain. This grain on average represents 0.4 acre of arable land. Thus each beef cow has a footprint of about 10.4 acres. At slaughter, the average cow weighs an estimated 1,200 pounds, only half of which shows up as meat in the supermarket. Each pound of meat that we buy therefore represents 1/600 of the beef cow's footprint, or about 0.017 acres. That doesn't seem like much, but the average U.S. citizen consumed 63 pounds of beef in 1994 (DOA), so that our per-capita beef footprint was about 1.07 acres. Some of that acreage is arable land that could be used to raise foods with smaller footprints. If each of us would simply reduce our beef consumption to about half of our present consumption on a yearly basis (about 30 pounds - slightly more than 1 pound per week), and substitute chicken or pork, for example, which are the meats with the next largest footprints (both about 0.0009 acres/pound), we would go a long way toward permitting a world population of 10 billion to have a potentially sustainable diet comparable to ours. Our food problem may be manageable with minimum pain.

The energy problem.

Our energy footprint, as shown in Table 1, presents a more serious problem. The reason for this is that coal, oil, and gas, which fuel much of our immense global economy represent carbon that was gradually taken out of the atmosphere many millions of years ago by the burial of dead plants and animals in swamps and stagnant seas and lakes. Release of this carbon (as CO₂) into the atmosphere has potentially troubling ecological consequences. The biosphere adapts to changes in its surroundings, given enough time, so the gradual and natural fluctuations in amounts of carbon dioxide in the atmosphere, which are documented in the geologic record, could in most cases be accommodated. However, when environmental conditions change too fast, the geologic record shows that biospheric disasters of varying magnitude can result.

When we began to burn fossil fuels in great quantities to provide energy for the industrial revolution, we began adding extra carbon, as CO₂, to the atmosphere. For a while, the natural systems could handle this extra load, but in the past several decades, a clear increase in the amounts of atmospheric CO₂ has been documented and the consensus among serious scientists is that this is the effect of human activity. The RATE of increase is disturbing because it may be

faster than the rate at which many components of the biosphere can adapt. Everything in the biosphere, which includes humans, is interconnected. Unless we don't care about the effects on humanity of increases in atmospheric CO₂ and the potential consequences of rapid global warming, we need to get the excess CO₂ that comes from our burning of fossil fuels out of the atmosphere.

Forests store a large amount of CO₂ in growing trees. The present global forest is already nearly fully occupied with the re-cycling of natural carbon dioxide that results from the breathing of animals, the decay of organic matter that is not buried, and from volcanic gases. Recent calculations by Brown et. al. (1996) suggest that only about 15% of the carbon in the CO₂ produced from the burning of fossil fuels worldwide could be absorbed by global forests under optimum management of existing forests. About 35% can be absorbed by the oceans (Suplee, 1998). In order to remove the remaining 50%, we would need to create new areas of forest, or other biomass equivalents because we cannot make larger oceans. The dimensions of this task are formidable.

In 1996, the U. S. alone added almost 1.5 billion tons of carbon to the atmosphere by burning fossil fuels. After accounting for the part absorbed by the oceans and existing forest, the footprint for each one of us is about 1.7 acres of new forest. This new forest acreage needed to absorb 50% of just the carbon generated by the U.S. is about 450 million acres, which represents somewhat more than half the total acreage of forest in the U.S., excluding Alaska and Hawaii! Thus, if we wish to continue to burn fossil fuels at the 1996 rate and not add to the CO₂ problem, somewhere in the world we must create and maintain new forests equal to at least half the area of all the forests in the lower 48 states! This is probably an unrealistic expectation, so either we have to find an energy source from something other than fossil fuels, or we have to live with the consequences of atmospheric buildup of carbon dioxide.

The messages from ecological footprint analysis.

Four major conclusions can be reached from the information presented above.

1. The assertion by Wackernagel and Rees that we would need two more Earths to sustain the world population of 2050 with consumption levels comparable to those of present North America is a bit over-stated. Part of this was a consequence of adding the energy footprint to the food, wood products and degraded land footprints. However, the new calculations still show the U.S. per capita footprint to be unsustainable as a goal for the world.

2. From Table 1 it is clear that we can only sustain our present footprint at the expense of other communities of the world. The whole of humanity cannot consume as we do because there isn't enough ecologically productive land on Earth for them to do so. Thus, the "selling" of the American Way is not only short-sighted for the long-term health of the world, but also immoral.

3. The good news is that the our food footprint may be mitigated fairly easily by simply reducing our consumption of beef to about half of our present levels and substituting other meats with smaller footprints. If we could accomplish this, a world of 10 billion people might be able to eat more or less at the quality level of our food consumption today, but the problems of increasing agricultural pollution and decreasing quality of arable land will have to be addressed.

4. The challenging message is that carbon dioxide in the atmosphere will continue to increase unless we find alternative energy sources of sufficient magnitude to greatly reduce our current dependence on fossil fuels. This is primarily a problem for the next century because we will be forced to alternative energy sources for petroleum, at least, by about 2100 as the finite pool of world oil is used up (Edwards, 1997). Depletion of other fossil fuels will follow shortly thereafter.

Problems for the future.

All sustainability problems are population-driven. We need to work seriously to see that long-term global population stabilizes at 10 billion or fewer. While attempting to accomplish this, we need to preserve our best quality farmland from ravages of poor farming practice and conversion to alternative uses, such as housing developments and industrial parks. Water quality and soil degradation, and the capacity of the world's fisheries, are not involved in the footprint calculations, but are essential components of food production and human health.

We need to assure adequate supplies of clean water for all people, and fresh water for all food production. We need to face up to the evidence of declining soil quality and the already troubling over-fishing of the world's oceans. We also need to face the political problem of declining petroleum supply and increasing world competition for this diminishing resource. It is in our best interests to get off of our petroleum addiction while we can still do it peacefully and develop sustainable consumption habits while we can still do it humanely.

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Slightly modified from a manuscript submitted to the University of Idaho "Green Journal" web page, May, 1998

Table 1
The U. S. Ecological Footprint

Category	acres/capita
Food	1.50
Degraded Land	0.08
Wood Products	1.60
Total	3.18
(Energy	1.70)

Table 2
U.S. Food footprint - summary of components

	Commodity	footprint*
1.	Grain	0.074
2.	Vegetables	0.017
3.	Fruit	0.010
4.	Dairy Products	0.205
5.	Eggs	0.017
6.	Beef (minimum)	1.070
7.	Pork	0.048
8.	Chicken	0.044
9.	Turkey	0.016
10.	Lamb/mutton	0.002
	TOTAL	1.503

*U.S. national figures in acres/capita

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IMPORTS AND EXPORTS, PETROLEUM AND CARBON EMISSIONS: WHAT IS THE BALANCE OF PAYMENTS?

JOHN A. PEDERSON

The past twenty-five years have seen concerns for 'shortages' of fossil fuels, especially petroleum products in the past, to the present where there is an adequate supply. There has been a shift in concerns from shortage to the implications of energy use on the environment. Concerns for not too distant future fuel shortages are well outlined by John Edwards, who presents the future decline of fossil fuel availability. However the concerns of the moment are in the other direction, how to limit the effects of fossil fuel consumption possibly limiting the consumption of fossil fuels, to enhance the environment.

The United States has been a net petroleum importer for 50 years, and a net energy importer for 45 years, signifying that petroleum has been the main leg at 39 percent in 1995 of the country's energy system for the second half of this century. The energy imports have increased steadily with the peak of expenditures for petroleum products in 1980, when they expended \$70.88 billion. The quantity imports are at their maximum in 1998, based on midyear data at 9.64 million barrels per day, which is 51 percent of U.S. consumption. U.S. consumption and imports will continue growing unless changed by some decree. So, by year 2000, they calculate that consumption will be 19.39 mbpd, with 52 percent imported at a cost of \$71.35 billion. For the year 2020, they show that consumption will be 24.4 mbpd, two-thirds imported at a cost of \$133.54 billion or \$366 million per day.

The December 1997 Kyoto accord presents some serious challenges to the consumption of fossil fuels in the U.S. In addition, the administration is proposing additional cuts in the green house gas (GHG) emissions beyond that outlined in this accord. "On April 21, 1993, President Clinton committed the United States to the stabilization of green house gas emissions by 2000 at 1990 levels . . . On October 22, 1997, President Clinton proposed a stabilization of emissions by developed countries at 1990 levels between 2008 and 2012, with reductions below the 1990 levels . . . In 2008 an emissions trading system would be in place, with credit for early reductions."

More discussion on these aspects has followed as per the comments by John Ferriter. "The central commitments are greenhouse gas emissions reductions for the world's industrialized countries, the so-called, Annex I countries . . . The specific reductions from 1990 levels vary from country to country . . . The United States agreed to 7 percent, . . ." Weiner reviews the idea of a world market for green house gases, or emissions trading, "allowance trading could direct the flow of substantial resources from richer to poorer countries." Novak and Denhardt in their discussion of the economic effects on the economy of reduced GHG gases, more specifically CO₂ emissions, present data showing CO₂ emissions cost/ value of \$100 to \$300 per metric ton of carbon. Given these values, monetary costs of direct compliance, bearing the emissions cost for CO₂ alone have been prepared.

Achieving the goal of reduced carbon dioxide emissions may be difficult. The EIA said "There are several reasons that the target specified by the Climate Change Action Plan (CCAP) is unlikely to be realized. First the U.S. economic growth has been higher than assumed at the time the CCAP programs were formulated. Secondly, energy prices have increased at a more moderate rate than initially assumed in the early 1990s. Third, funding levels for a number of the CCAP programs are lower than those initially requested."

Currently, petroleum is the most prevalent source of energy, at 39 percent in 1995, followed by natural gas at 24 percent, coal at 22 percent, nuclear 10 percent and renewable at 9 percent. Petroleum is the leading emitter of GHG, followed by coal, then gas. On a unit of energy basis, coal is the highest emitter, with gas at the low end and petroleum between.

Since the U.S. has been a net importer of fuels for nearly a half century, the cost of these imports has steadily increased as the fuel imports fraction of total domestic fuel consumption has increased. In addition, this has had its impact on the difference between exports and imports or balance of payments. They recently highlighted the issue of the balance of payments or trade gap in the Denver Post newspaper, which discussed the increased level of imports this year without any compensating increase in exports.

RESULTS

The above discussion has provided a setting for the results which are shown on five tables.

Table I using Energy Administration for petroleum production, costs and imports for the historical period 1970 to 1998, followed by projections from 2000 to 2020. Table II carries these petroleum data forward and translates them into their equivalent CO₂ emissions, expressed as metric tons carbon. The increase in emissions over the 1990 base and the 7 percent reduction of the 1990 base are also presented as some separate entries. While there is no proposal to penalize production of CO₂ above 1990 levels prior to 2000, the data are presented for planning purposes. In addition, early reductions are encouraged. Comparing the bottom lines of calculations, the cost of imports is greater than the cost of CO₂ emissions trading (or tax in like amounts). These calculations use that these \$100, \$200 and \$300 per ton metric ton of carbon disposal costs.

Table III shifts the scheme of things from petroleum to the composite of petroleum, natural gas and coal consumption or fossil fuels, their emissions issues and costs. Line 1 shows the EIA projections translated into carbon emissions, with line 2 presenting the 1990 base level followed by the 7 percent reduction factor. Translating these carbon emissions into costs follows the same pattern as before. The accompanying line showing the historical and projected future costs of importing fossil fuels using the EIA schedules. These data show that at \$100/mt, fuel imports cost more than carbon emissions exports, at \$200/mt, they are conceivably in the same range, and at \$300/mt, CO₂ disposal costs are greater than fuel import costs.

Table IV, provides historical data on the exports and imports of goods and services and their difference, the balance of payments, along with the net imports of fuels for comparison purposes. We provide these data for the historical period 1980, with 1998 updated based on year to date information. The data show that the balance of payments took a sharp hike in 1984, held high for a period, then dropped significantly in 1991, and have generally increased since then. The 1998 import increase, fueled by the Asian market price drops has had a great increase, overriding the significant drop in crude oil and product prices.

Table V is the future projections from 2000 to 2020 of balance of payments (BOP) at various rates and fuel imports vs. varying the cost of excess CO2 emissions. We project the BOPS at 2, 4, and 6 percent per increases. The 2 to 6 percent increase in BOP clearly include the range of costs associated with CO2 disposal. These disposal and fuel import costs however are some far greater amounts than the country has seen. Accordingly, we need significant reallocations of exports, imports, or alternative means of resolving CO2 emission. In addition, apparently the unasked and unanswered questions about what stage in the production, transportation processing, distribution or consumption cycles are the emissions costs to be imposed and on what basis?

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PETROLEUM & IMPORTS - TABLE I

Factor	1970	1980	1990	1995	1996	1997	1998	2000	2005	2010	2015	2020
Millions of Barrels												
Product Supplied												
BOPD	14.70	17.06	16.99	17.75	18.37	18.62	18.91	19.39	21.12	22.63	23.60	24.40
BOPY	5,366	6,227	6,201	6,479	6,705	6,796	6,902	7,077	7,709	8,260	8,614	8,906
Net Imports												
BOPD	3.16	6.36	7.16	7.89	8.50	9.16	9.64	10.17	12.10	13.67	14.92	15.98
BOPY	1,153	2,321	2,613	2,880	3,103	3,343	3,519	3,712	4,417	4,990	5,446	5,833
Cost of Imports												
\$ per barrel	1.92	33.67	21.13	17.5	20.48	19.08	13.63	19.11	20.19	20.81	21.48	22.32
billions \$ per year	2.22	70.88	56.32	50.34	62.27	63.78	47.42	71.35	90.49	106.39	120.20	133.54
Import share supplied	0.22	0.37	0.42	0.44	0.46	0.47	0.51	0.52	0.57	0.60	0.63	0.66

PETROLEUM & CO2 EMISSIONS - TABLE II

Factor	1990	1995	1996	1997	1998	2000	2005	2010	2015	2020
Carbon Production (mt)										
Petroleum	583.20	599.50	620.80	635.46	645.24	655.80	708.10	761.50	795.70	822.10
1990 Base Level Prod.	583.20	583.20	583.20	583.20	583.20	583.20	583.20	583.20	583.20	583.20
Excess Emissions I										
Increase over Base Level	0.00	16.30	37.60	52.26	62.04	72.60	124.90	178.30	212.50	238.90
Excess Emissions II										
7 percent over Base Level	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82	40.82
Total Excess Emissions:	40.82	57.12	78.42	93.08	102.86	113.42	165.72	219.12	253.32	279.72
Export Cost of Emissions:										
\$100/mt	4,082	5,712	7,842	9,308	10,286	11,342	16,572	21,912	25,332	27,972
\$200/mt	8,165	11,425	15,685	18,617	20,573	22,685	33,145	43,825	50,665	55,945
\$300/mt	12,247	17,137	23,527	27,925	30,859	34,027	49,717	65,737	75,997	83,917
Cost of Imports (millions \$)	56,320	50,340	62,270	63,780	47,420	71,350	90,490	106,390	120,200	133,540

FOSSIL FUEL & CO2 EMISSIONS - TABLE III

Factor	1990	1995	1996	1997	1998	2000	2005	2010	2015	2020
Carbon Production (mt)										
Fossil Fuels	1,338.00	1,411.40	1,462.90	1,480.45	1,498.22	1,577.30	1,688.80	1,803.20	1,888.30	1,956.20
1990 Base Level Prod.	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00	1,338.00
Excess Emissions I										
Increase over Base Level	0.00	73.40	124.90	142.45	160.22	239.30	350.80	465.20	550.30	618.20
Excess Emissions II										
7 percent over Base Level	93.66	93.66	93.66	93.66	93.66	93.66	93.66	93.66	93.66	93.66
Total Excess Emissions, mt	93.66	167.06	218.56	236.11	253.88	332.96	444.46	558.86	643.96	711.86
Export Cost (millions \$)										
\$100/mt	9,366	16,706	21,856	23,611	25,388	33,296	44,446	55,886	64,396	71,186
\$200/mt	18,732	33,412	43,712	47,223	50,776	66,592	88,892	111,772	128,792	142,372
\$300/mt	28,098	50,118	65,568	70,834	76,164	99,888	133,338	167,658	193,188	213,558
Fossil Fuel Imports (millions \$)	54,630	49,840	60,130	68,330	50,300	76,870	93,540	113,770	125,600	138,660

EXPORTS, IMPORTS & CO2 EMISSIONS - TABLE IV

	1980	1981	1982	1983	1984	1985	1986	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1,998
Exports (millions \$ per year)																		
Merchandise	224,250	237,085	211,198	201,820	219,900	215,915	320,230	362,120	389,307	416,913	440,352	456,832	502,463	575,940	611,669	379,325	682,402	
Services	47,584	57,354	59,516	60,085	66,483	73,155	110,933	127,022	147,477	163,810	177,305	186,119	195,839	210,590	223,907	258,268	256,857	
Subtotal:	271,834	294,439	270,714	261,905	286,383	289,070	431,163	489,142	536,784	580,723	617,657	642,951	698,302	786,530	835,576	637,593	939,259	
Imports (millions \$ per year)																		
Merchandise	(249,750)	(265,063)	(247,642)	(268,900)	(332,422)	(338,088)	(447,189)	(477,365)	(498,337)	(490,981)	(536,458)	(589,441)	(668,584)	(749,364)	(799,343)	(877,279)	(896,694)	
Services	(41,491)	(45,503)	(47,415)	(50,616)	(63,739)	(72,862)	(99,491)	(103,535)	(118,783)	(119,614)	(119,464)	(125,549)	(134,097)	(142,230)	(150,440)	(170,520)	(173,845)	
Subtotal:	(291,241)	(310,566)	(295,057)	(319,516)	(396,161)	(410,950)	(546,680)	(580,900)	(617,120)	(610,595)	(655,922)	(714,990)	(802,681)	(891,594)	(949,783)	(1,047,799)	(1,070,539)	
Ex - Im , Balance of Payments, (-)	(19,407)	(16,127)	(24,343)	(57,611)	(109,778)	(121,880)	(115,517)	(91,758)	(80,336)	(29,872)	(38,265)	(72,039)	(104,379)	(105,064)	(114,207)	(110,201)	(152,480)	
Total Fossil Fuels Net Imports billions \$	70,880	70,090	51,630	46,280	48,570	43,600	35,530	44,350	54,630	43,820	45,700	47,640	48,180	49,840	60,130	68,330	50,300	

BALANCE OF TRADE - TABLE V

	2,000	2,005	2,010	2,015	2,020
Balance of Payments, Various Rates					
2%	119,048	131,429	145,098	160,188	176,848
4%	126,230	153,621	186,957	227,527	276,900
6%	133,635	178,804	239,239	320,102	428,297
Export Cost of Emissions:					
\$100/mt	33,296	44,446	55,886	64,396	71,186
\$200/mt	66,592	88,892	111,772	128,792	142,372
\$300/mt	99,888	133,338	167,658	193,188	213,558
Petroleum Imports & Emis Exports					
\$100/mt	104,646	134,936	162,276	184,596	204,726
\$200/mt	137,942	179,382	218,162	248,992	275,912
\$300/mt	171,238	223,828	274,048	313,388	347,098

“MEETING SOCIETAL RESOURCE AND ENVIRONMENTAL REQUIREMENTS FOR THE 21ST CENTURY”

Jonathan G. Price

Barring a major economic catastrophe (such as outbreak of disease or war that kills many people), the increasing world population and the desire to raise standards of living in many parts of the world will result in continuation of the overall trend toward more use of energy, mineral, water, and soil resources.

The United States mineral and energy policies have largely been to get the needed resources as cheaply as possible from wherever they can be obtained. Policy makers rarely account for the tradeoffs between the desired minimal costs of mineral and energy supplies and the related costs of economic security, military actions, and environmental consequences.

The United States has abundant natural resources. For example, we are in the midst of the biggest gold boom ever in the history of the United States. Production in the decade of the 1990's is exceeding that of any previous decade by a factor of two or more. New deposits are being discovered, both in established mining districts and buried beneath alluvial cover. Because of favorable geology, the United States as a whole and many of the individual states are prime targets for exploration for and production of such commodities as barite, copper, gold, silver, gypsum, and industrial sand.

Federal and state environmental regulations are helping to protect the environment in the United States, but not all countries have or enforce comparable regulations. For example, in some less developed countries, mercury amalgamation is still being used to extract gold from ores, and open-furnace roasting, without scrubbers, is still being used to oxidize sulfides in ores.

Restrictive land-use and land-access policies and protracted permitting requirements tend to force industry to explore for mineral deposits outside of the United States and other developed countries. If the United States is to take a leadership role in environmental stewardship of the Earth, we should not promote environmental imperialism. That is, we should not exploit resources in other countries without their enforcing environmental controls that are as strong as we have in this country.

EDUCATING PEOPLE ABOUT RESOURCE AND ENVIRONMENTAL REQUIREMENTS FOR THE 21st CENTURY

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When people don't understand something, the standard remedy is to "educate" them. The educational process, however, must be somewhat different for two different groups of people. One group includes those who are preparing for (or already have) professional responsibilities for resource use and environmental protection. For them we must concentrate on redesign of college/university curricula so that we don't break down into "resource people" and "environmental people" who do not understand each other. This process could be simple if professors are willing to undertake it, although the natural conservatism of faculty suggests that many will probably resist the change.

The second, enormously larger, group of people includes everyone who is not, or does not intend to become, a resource/environmental professional. Without having sufficient information, many of them think that any use of resources will cause irreversible change in our natural surroundings, and many others feel that any effort to modify resource use on behalf of sustainability and environmental preservation will be unacceptably expensive. In designing educational programs for these people, my career as a college professor has led me to recognize the very limited effectiveness of schools at any level of the educational process. Particularly with the problem of the alleged conflict between the use of resources and preservation of the environment, I think schools will accomplish almost nothing unless their activities are coupled with education in what teachers commonly refer to as the "real world." I would like to

explain this position by suggesting three problems where joint educational programs have a chance of being effective.

The first problem is that most people don't know that the U.S. imports much of its crude oil. When I teach a course titled Environmental Geology, I make a survey of the students' knowledge and attitudes on the first day of class. Originally I was surprised to find that nearly 90% of the class thought that we were self-sufficient in oil and also in other necessary imports, such as most of our ferroalloy metals. I am no longer surprised, however, as I have come to realize that this lack of understanding is characteristic of almost all Americans. Also, I now correlate this belief in our self-sufficiency with the widespread isolationist feeling that the U.S. can ignore the rest of the world and run its economy without foreign trade.

This belief in self sufficiency in oil is not a problem that can be overcome solely by courses taught in schools. Simply, we reach too few people to have a major effect. Here's one idea. If petroleum companies would put a sign by the gas pumps at filling stations saying, "Half of the gasoline you just put into your tank was imported," many people might start asking questions. This would give an opportunity for people who know about petroleum resources and international relationships to make more people understand the situation.

A second problem is clearly that some parts of the country, principally in the semi-arid midwest and west, use groundwater at rates much faster than it is being recharged. With people who live in these areas having so little knowledge of this use, we apparently can do nothing until some area, perhaps a city or agricultural county, runs so low on water that water quality diminishes, people begin to move out, and property values collapse. Before that happens, we might try combining courses taught in schools with education disseminated by water companies or, more likely, by geological surveys. For example, we

might find ways for local newspapers to publish, every few months, diagrams showing past and present water tables in the basins where the papers are principally sold. As with oil imports, people who are experts on water allocation might then have a greater opportunity to explain their positions to a larger audience.

A third problem, pollution, can be exemplified by nitrogen loading in the coastal plain of my own state of North Carolina. Here rivers and groundwater are burdened by nitrogen waste produced by fuel consumption, urban sewage, and massive agricultural development (particularly hog farms). The resulting eutrophication has caused fish kills in rivers and affects the coastal swamps that nurture larvae and young fish. Because of the number of competing interests, and the massive disinformation provided by many of them, a political solution seems unlikely. Therefore, I think that education on this issue might best be provided by the legal system. If, for example, a specific group of people (possibly a fishing firm) brought a suit against a specific group of polluters (possibly a city or hog farm), then the problem would attain a greater public awareness. At that time, hopefully, the scientific and technical community would have a larger audience to whom they could explain the issues.

In short, the problems that we are discussing have arisen partly because many professionals know only their own specialty, but largely because most Americans do not know what resources we use, what efforts need to be made (or are being made already) to maintain a sustainable resource base, and what the environmental consequences of these activities are. The only solution that I can think of is not to abandon education, which is a vital part of the process, but to broaden the base of people that we reach.

MEETING SOCIETAL RESOURCE AND ENVIRONMENTAL REQUIREMENTS FOR THE 21st CENTURY

Introductory Comments by Lee W. Saperstein, Dean of the School of Mines and Metallurgy and Professor of Mining Engineering, University of Missouri-Rolla

Some Mining Issues

As a young faculty member at Penn State, where I rose through the academic ranks from 1967 to '87, I realized that surface methods for the mining of coal were growing rapidly and would soon outstrip underground methods. It was also clear that our department had no faculty member knowledgeable of those mining methods. This conclusion came before the rapid growth of coal production in the northern great plains, which when it occurred only served to reinforce my feelings. I undertook, then, to learn about these methods and quickly became aware that reclamation and environmental engineering were the areas of opportunity for course development and research. By 1987, when I went to the University of Kentucky as departmental chair, the general level of understanding of reclamation methods within the industry was quite high and the most-responsible producers were doing excellent work. I had, through this period, taught courses in surface mining, done research on reclamation of coal and non-coal mines and on the environmental effects of underground coal mining. I had also hired several people who were expert in surface methods and they, also, had added to the course and research history of the two departments. Today, coal-mine reclamation is a mature subject and it is difficult to achieve order-of-magnitude leaps as a result of research. The early struggles to pass legislation and then for industry to find the technologies that met the resulting regulatory requirements have become a matter of history.

Because of population pressures and the inexorable growth of suburbs, producers of construction materials (sand and gravel, crushed stone, and cement) have had to come up with a reclamation response similar to that of the coal industry. The literature of reclamation for quarries is extensive; the technical meetings attended by producers and their engineers have considerable programming in environmental subjects. It is no surprise to find innovative post-mining land uses for quarries. Inasmuch as they are often located close to markets so as to overcome high unit costs of transportation, many quarries have sufficient land values to warrant substantial investment in reclamation. They have become housing developments, marinas, golf courses, and even disposal and landfill sites.

A National Research Council study group in which I participated ("Surface Mining of Non-Coal Minerals," NAS, 1979) concluded that non-coal minerals did not lend themselves to the same order of national legislation as did coal. The same heterogeneity of deposits, locations, and economics that led to that conclusion also means that we cannot see the same degree of progress toward a goal of post-mining re-use of the land, particularly for some of the classic mining districts of the west. The reclamation challenge of the future is

going to be more localized yet more intense than was the challenge of coal reclamation. For example, it is very difficult to find the landscape described by Richard Llewellyn in "How Green Was My Valley." South Wales is once again green and many of the coal mine sites have disappeared. Green Valley, Arizona, however, will continue to see the effects of copper mining in the Pima Mining District for decades to come. Although there is some mining going on in Butte, Montana, most of the old production sites are now abandoned. A major effort is underway there to remediate the effects of environmentally unrestrained mining and smelting; portions of the city are designated as a Superfund site. There are only so many old mining sites that we can convert to tourist-oriented ghost towns. And, at that, we have learned that parts of Tombstone, Arizona, are subsiding into the old mine workings.

Reclamation is just one issue among many that form the research challenge of the future minerals industries. The Society for Mining, Metallurgy and Exploration, Inc. (SME) has created a Research Council and given it responsibility for following these information needs. One response to that charge has been a series of three research forums, two of which are published. The National Mining Association has recently signed an agreement with the Department of Energy for mining to become the eighth Industry of the Future. These are energy-intensive industries, such as aluminum, steel, glass, forestry, and agriculture, in which there can be tremendous energy savings from research-derived process improvements.

Broader Energy and Mineral Issues

From the time that I was a child until now, the population of the earth has nearly doubled. Projections of current rates of population growth suggest that, if I should be so lucky to live to be 100 (near enough to the mid-century), it will double again to ten billion people. If each of those persons aspired toward, and could afford, a life-style similar to the one I enjoy today, the implications for energy and material supply would be mind-boggling. To give a small example, there are 1.2 billion people in China today and somewhere around 900 million bicycles. If each of those bicycles was a small compact car, China would be a net importer of petroleum products. It would also be an exporter of photochemical smog. The demand for oil would alter global flows and make us question our love affair with sports utility vehicles and, under the pressure of the prevailing westerly winds, the smog-creating chemicals would end up crossing the Pacific.

Coincident with my arrival at UMR in 1993, and the assumption of an array of responsibilities that were broader than mining, I made connections to a larger academic community. Within the National Association of Land-Grant Colleges and State Universities (NASULGC), there is a Commission on Food, Energy, and Renewable Resources (CFERR). I am the current chair of the Mineral and Energy Resources Section of CFERR. In this section, we are striving to give our members a coherent view on the research opportunities inherent in the title subjects. Our emphasis remains with extraction and production of raw materials and not generation, transmission, or utilization.

Because the basic industries of mining and petroleum have gained the perception of maturity and of not needing federal research assistance, many had thought that there was no need for research. The closure of the Bureau of Mines was a signal in aid of this view. A longer view, however, of humanity's future material needs suggests that we have much to ponder.

At the Annual NASULGC Meeting, beginning November 15, 1998, in Atlanta, GA, there will be a plenary session for the Boards and Sections of CFERR. The topic of this session is the "Science Behind Kyoto," and the principal speaker is Dr. Martha Krebs, Director of the Office of Energy Research at the Department of Energy. The Kyoto Treaty, whether or not ratified by The United States, sets a target for CO₂ discharge that will influence our public and private energy strategies. The target is a collision course among population growth, increased energy use per capita, and the need to reduce energy-production discharges. The United States produces 57 percent of its electricity from coal and about 20 from nuclear (EIA for 1997). Of all the fuels, coal produces the most CO₂ per Btu and nuclear sources the least. Yet the citizenry of our country appears reluctant to accept additional nuclear generating capacity and the generating companies recognize that new nuclear stations have a high capital cost and an uncertain rate of return. The alternatives are substitution of natural gas for coal and carbon sequestration, which is the capture of CO₂ in the exhaust stream.

There is a growing sense of environmental responsibility that suggests that energy-intensive companies should invest in natural means of carbon sequestration at a rate that would create sufficient photosynthesis units (a good phrase for trees) equal to the discharge that results from each new investment. Inasmuch as marine disposal is unproven and other more exotic chemical means of creating solid carbonates are not yet a reality, carbon sequestration now means planting trees and encouraging forest and jungle growth. By the time of implementation of Kyoto (2010), we would hope that we would have more efficient alternatives.

Let me close these comments by suggesting that this interest in wood growth is salutary. Sometimes, an ancient technology is the best technology. For, should we run out of petroleum-based products for our energy-based economy, we can always substitute this new mass of biological materials in our oxidation processes.

lws
July 31, 1998

Comments on Conference Goals

Ira Satterfield

Missouri Geological Survey

GOAL 1:

To transfer scientific knowledge bases of geology and ecology between each other and others involved in resource and environmental issues.

Both the earth and life scientists have credible knowledge bases. These knowledge bases must be made known at the national level. Both scientific groups need to recognize each other's role in addressing the nations needs. There are several ways that this could occur. One, each group has national association with environmental divisions. Members from each association need to work together to investigate ways that their respective associations can work together. Secondly (and probably to extreme), organize a new national organization that its membership would comprise both earth and life scientists. To involve others in resource and environmental issues, there is a need to foster legislative (state level) and congressional (federal level) relationships on value of reliable knowledge bases on earth and life sciences to be integrated into public policy and decision making.

GOAL 2:

To identify and prioritize issues and to search common grounds between earth and life scientist.

To be able to identify and prioritize issues, both scientific groups must not only communicate between themselves but with public policy and decision makers. I believe that in the majority of cases, scientists are only poor to good communicators when it comes to conveying thoughts and ideas to decision makers. Therefore, capable representatives need to converse with decision makers on issues. Those key or important issues need to be addressed (project) jointly by both scientific groups working together. By working together on a common project, they will begin to understand the importance of each knowledge base, an appreciation for each profession and how each will commit for the common good. Science is generally, poorly understood by society. I feel that it is in part resulting from teaching methods in elementary and secondary education. All too often it leaves children with false and ambiguous impressions. Teaching methods need to be changed to generate more critical thinking resulting in better decision skills. The new national educational standards are designed to improve the understanding of science, but the results are several years in the future.

GOAL 3:

To find ways to add information and facts to the public discussion about resources and the environment.

Need to develop an effective plan with the media. We all are aware that the quickest means is working with reporters, television, and the like. But this usually only gets the attention of the reader or viewer on that issue or concern and they do not really grasp the significant of the problem or solution. I know what I am about to write may sound ridiculous or just plain crazy. But what about a TV series on a consulting firm of earth life scientists resolving problems from exploring for mineral and energy deposits, remediating environmental problems, identifying geologic hazards, developing mitigation plans, water sources, and the list goes on. Now the why: every human being has a natural instinct for rocks, minerals, fossils, where water comes from, and yes, even environmental issues and concerns. Can we capitalize on this natural instinct and develop a means of educating the general public? The natural interest is there but is this doable?

NATURAL AND HUMAN RESOURCES IN SOCIETY IN THE FUTURE

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The subject title of the conference conjures up multiple interpretations of "societal resources." This is addressed herein as a two-fold interpretation - as natural resource and as human resource, both of which have reached critical proportions as we near the end of the 20th Century and enter into the 21st Century. Examples of each crisis are brought into focus for thoughtful attention.

Natural Resources

One of the most critical and presently controversial of natural resources all over this country is water and its intended uses and abuses. There has to be a balance between regulatory control and society's failure to establish reasonable quality assurance and use of a valuable resource. A California case history example is the contamination of the very valuable ground water resource in the San Fernando Valley in Los Angeles County. This is a question that should be vital to those of us who were graduate students after World War II. It was apparent to the author when fellow professors and the Chairman of the Faculty Association at the college where he was teaching challenged him for comments he made in his classroom lecture dealing with what he considered obvious contamination of the ground water resource. They based their censure on the belief that, if there was really a problem, the government would obviously correct the problem. It was stated that a professor should not alarm the students because the government would not allow pollution of the ground water to happen. Unfortunately, neither the governmental agencies nor society became aware, concerned or recognized the element of contamination or pollution, and no attempt was made to correct the problem until a serious human health problem became overtly obvious - even to the news media. A spin-off of the above is reflected in our reluctance as geoscientists to become involved as seen in involvement in contamination by the aircraft industry (Lockheed) and others and support industries, the space related testing (Rocketdyne), and the utility/energy resources management. There are dozens, probably hundreds, of examples of what could have been accomplished, what technology had a handle on, and in fact and in part failed to properly manage and maintain. Problems exist related to Chromium VI, PCP, PCE, carbon tetrachloride and a whole litany of associated or independent carcinogens.

Human Resources

Recent experiences during service on the California Seismic Safety Commission dealing with the events during and after the 1994 Northridge earthquake, with the extensive losses at present totaling in excess of 40 billion

dollars and growing, we certainly have to use our knowledge and expertise to assure quality control (scientifically and structurally) and to reduce the losses. We certainly have learned significant amounts in the last few decades so the question arises as to why we are not utilizing what we have gleaned. The Seismic Safety Commission's report to the Governor issued following the Northridge earthquake emphasized that the majority of the damages appear to be related to a serious lack of quality control in conjunction with design, plan check, construction, inspection and maintenance of structures and facilities - all of which point to a critical lack of well-trained human resources and an obvious lack of responsibility on the part of all involved with the functions noted above. We must, however, not exclude the scientific world - those who, either by design or lack of adequate knowledge of fact, failed to advise sufficiently in the preconstruction studies.

Of the problem, one is at the academic level in the concept of:

- teaching ethics and professional integrity
- apparent associated problem of academia attaching its thoughts to passing fancy rather than conveying the very basics whereby professionals learn and utilize their academic training.

Many of the core/basic courses that are necessary to learn, as well as teach, are the very basic fundamental courses which are or have been replaced with theories and courses that can almost be classified as fad or fantasy.

Another problem is lack of diligence on the part of those who are charged with quality control and have been provided with governmental immunity in many states. This immunity tends to diminish the effort and inherent diligence.

Not to be overlooked in the assessment of losses and damages are factors such as:

- society's lapse into blind acceptance of the substandard work (structural and/or technical) as more acceptable because it is cheaper.
- the too-often cavalier statement of "It's no big deal."
- the often-used defense in litigation that "it met the intent of the code," which has haphazardly been interpreted that there should be acceptance of lesser quality.

Another apparent problem dealing with human resources can be found in the situation relative to high intensity rainfall as we witnessed the past winter (1997-98) during the El Nino influence - especially for the West Coast where hundreds of millions of dollars in damages and losses occurred. We cannot blame this entirely upon the meteorological control. It is possible to conduct post-disaster studies and submit evidential theory that, if the professionals, in pre-construction or pre-development stage, had honestly and knowledgeably addressed all of the factors

that could be detected through research and physical findings, we would not be witnessing so much newsworthy devastation. The landslides, debris flows, mudslide and other means of ground failure we witnessed evolved, in high percentage of cases, from negligence or misapplication of data presented by the primary professionals involved. We certainly should have the technology to address the original studies from multiple angles. If those who profited by their studies had produced complete and accurate analyses to be used in final design and construction, maybe the dollar values of the losses and the heartbreak faced by the devastated property owners may have been far less. The time and dollars lost in the sometimes futile attempts at recovery have been unnecessarily overwhelming.

Conclusions for the 21st Century

We, as geoscientists, must step forward and accept the responsibility to inform the politicians, governmental leaders, news media, the public and other involved entities that there are well-educated professionals who have integrity, and are willing to stand up and be heard and be held accountable. We, as responsible geoscientists, must aim for excellence in science and diligently strive for quality assurance in our professional work.

REASONS FOR FAILURES

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REASONS FOR FAILURES

The majority of landslides and ground deformation on developed properties studied by the authors can be attributed to the failure of geologic and/or engineering professionals to perform in a competent, diligent, and prudent manner with due regard to protecting the health, safety, and welfare of the public (original and future property owners). Petroski (1993) has made the following statement that should be the basis for methodology of investigation and mitigation of hazards: "*Design is first and foremost failure anticipation, and it is only by the proper and complete anticipation of failure that it can be avoided.*" George Sowers (1993) indicated that the three most common causes of failures are absence of knowledge (12% of failures), ignorance (33% of failures) and rejection of current technology (55% of failures).

With these observations in mind, the authors have prepared the following subjective list that represents the mistakes, misrepresentations, ignorance of physical processes, rejection of current technology, and faulty reasoning encountered in post-damage investigations during our careers which have, in our opinion, contributed to preventable failures in the past. It often takes several of these "actions" occurring sequentially to set up the situation in which failure may occur. The systems of checks and reviews does not catch all the problems. These problems are not limited to Southern California. Initial investigations of 1993 storm damage indicate a repeat of many of these problems.

Failure to Perform a Competent, Diligent, and Prudent Field Investigation Due To:

- failure to use the method of multiple working hypotheses by limiting the thought process to only one hypothesis (Schumm, 1991)
- insufficient or inadequate geologic mapping or performing poor quality mapping;
- not utilizing proper subsurface exploration technology and/or methodology;
- not recognizing, collecting, interpreting, and reporting geologic data (e.g., not recognizing and/or mapping the slide plane in a shear key excavation prior to approval);
- filtering, "massaging," or skimming of geologic data to allow the design concept to appear to work;
- not collecting oriented, undisturbed samples of the weakest materials which may affect site stability;
- not recognizing areas of highly fractured bedrock in which the fracturing causes the rock to be weaker (lower rock mass shear strength) and increases potential for groundwater flow and storage (Deere & Patton, 1971);
- not recognizing and subsequently not completely removing, during grading, colluvial/alluvial/weathered bedrock materials which act as a path for groundwater recharge and may be subject to hydroconsolidation;
- the inability to recognize evidence of prior mudflow/debris flow activity or to understand that the evidence on geomorphically active slopes may not be recognizable after a few years;
- not utilizing published guidelines such as those prepared and released by the Association of Engineering Geologists (Slosson 1984).

Failure to Analyze Geomorphic Conditions of the Site and Vicinity Due To:

- not recognizing or acknowledging the existence of probable ancient landslides readily viewed in the aerial photos or in the field;
- not using aerial photos, not learning or not being taught how to interpret aerial photographs;
- not reviewing early (older) photographs or the complete series of photographs readily available;
- not recognizing and recording geomorphic features observed in the field;
- not determining the cause of anomalous topography and other geomorphic features indicative of landslides or other geologic hazards.

Failure to Use the Method of Multiple Working Hypotheses and Failure to Make Correct Assumptions

This includes limiting the thought process to only one hypothesis (Schumm, 1991) (i.e., closed mind) and making erroneous assumptions such as:

- that it will not rain again (or within the ten year limit of liability);
- that there has been a climatic change and that it is not going to rain sufficiently to cause failures;
- that an apparent lack of calcarious or other mineral deposits indicates that there is no groundwater flow and that a dry canyon or fault zone is going to be dry in periods of high rainfall;
- that on-site private sewage disposal will not affect the stability of a landslide, via percolation of effluent;
- that fractured rock has no involvement in slope stability and that, as long as the bedding or dip is favorable, there is no problem;
- that a stabilization fill can be substituted for a buttress fill without the appropriate sampling, testing, and analysis;
- that a project is safe and stable because it was approved by a County or City agency; or
- that a regulatory reviewer will catch any mistakes or deliberate omissions that a consultant has made.

Failure to Understand the Basic Fundamentals of Hydrogeology Due To:

- not understanding the relationship of groundwater to slope failure (recognized in the last century by Cross, 1886);
- not understanding the processes of infiltration, throughflow, and development of pore-water pressure within the vadose zone;
- not recognizing that above-average rainfall can cause an apparently stable landslide to reactivate (Cronin, 1992);
- not recognizing that a fault zone may be a possible path of future groundwater flow;
- not anticipating flow from springs because field studies and grading were completed during time of drought;
- not recognizing that spring flow is often limited to times of above-average rainfall;
- not recognizing that effluent from dry wells, cesspools, seepage pits, or leach lines will raise groundwater levels and often have an adverse effect/impact on slope stability;
- not realizing that a fill behind a crib wall may become saturated or assuming that the heel drain (one cubic foot of gravel with a pipe) will preclude saturation of the fill at a higher elevation;
- not recognizing that landscape irrigation will lead to an increase in local groundwater elevation due to infiltration (irrigation conveys water to the soil and is often equivalent to 40 inches to 80 inches of rainfall in one year);
- hydrogeologic misconceptions (e.g., water from the bedrock never enters the fill, therefore drains are unnecessary or that fills never become saturated).

Failure to Properly Mitigate the Adverse Effects of Groundwater Due To:

- the inadequate design (often "cookbook") and construction or the elimination of subdrains, backdrains, and heeldrains from stabilization fills, buttress fills, and some sliver fills;
- lack of recognition of the need for subdrainage (i.e., field mapping and inspections are done during periods of drought);
- not requiring proper lot or building site drainage which is necessary to preclude ponding and infiltration of water or not correcting improper lot drainage;
- not recommending area drains where appropriate;
- not considering the development or future existence of pore-water pressure in the slope stability calculations (failure to understand hydrogeology).

Systemic Failures of Management and Supervision Due To:

- technically-incompetent administrative and staff personnel making technical decisions (see Site Investigation Steering Group, 1993, pg. 31);
- approving design concepts proposed by others that are not in accord with one's professional opinion in order to get the job and meet payroll;
- field decisions made from the office;
- decisions based on opinions/observations made by inexperienced personnel;
- lack of apprenticeship under experienced personnel and lack of supervision of inexperienced personnel;
- following company policy that dictates standard procedures that are not always appropriate for the situation;
- the selling of one's professional signature without taking "responsible charge" of the project;
- not seeking expert advice when the problem is outside the limits of one's knowledge and experience;
- failure to properly scope a property during the initial site visit to determine extent of investigation needed to identify geologic hazards;
- relegating the scoping and cost estimate to someone concerned solely with marketing.

Failure of the Government Regulatory Review Process to Function in a Responsible Manner such as:

- governmental reviewers just looking for the signature of a registered professional as a basis for approval and not at the adequacy of the report;
- political pressure forcing the approval of projects that should not be approved due to a lack of technical merit;
- governmental employees not completing a site inspection or visit as part of review and not referencing or reviewing past documents, aerial photos, and other materials/documents on file as part of the review process;
- reviews completed by unqualified/unregistered personnel;
- management concerned with budgetary factors and abandoning the homeowner/taxpayer.



Slope Failures in Southern California: Rainfall Threshold, Prediction, and Human Causes



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ABSTRACT

Rainfall during the winter of 1992–1993 reached 195 percent of normal and caused landslides and mudflow/debris flows reminiscent of previous wet years when the rainfall exceeded 140 percent, the apparent threshold for damaging flooding and slope failures. Winters with rainfall exceeding this threshold have occurred at predictable frequencies and are expected to continue. Annual losses average approximately \$200,000,000 from slope/ground failure and flooding in California for years with more rain than 140 percent of normal. Slope movements can be reasonably predicted when successful and sufficient subsurface exploration and materials testing is combined with the proper application of existing knowledge. However, the actions of humans still cause many failures through ignorance of physical processes, faulty reasoning, and rejection of current technology. Prudent and diligent engineering geology coupled with good geotechnical engineering practiced during the past three decades have helped protect sites and tracts from slope movement and flood damage, but failures are still occurring. A responsible effort by building officials in review of reports and enforcement of existing grading codes and ordinances can help reduce losses by 90 to 95 percent.

INTRODUCTION

Rainfall during the winter of 1992–1993 in California (Figures 1 and 2 and Table 1) triggered numerous landslides and exacerbated other forms of ground failure which destroyed or distressed homes, infrastructures, and lifelines. The loss caused by these slope failures and floods is estimated to be on the order of five hundred million dollars. Annual losses during high rainfall years during the past few decades has averaged 200 million for years where rainfall has exceeded the threshold for failure. It is the opinion of the authors that at least 90 percent of the losses were avoidable and that the factors

contributing to the damage such as inherent problems and/or defects were recognizable, predictable, foreseeable and preventable.

Damage in 1992–93, as well as previous winters similar to that of 1992–93, has resulted in a transfer of funds from the general public as represented by city, county, and state agencies to lawyers and relatively few of the citizens whose property or access was damaged. This transfer of funds from the public should be viewed in the context of the profit made by the developers and those they employed as consultants and contractors. The economic loss includes, but is not limited to, property devaluation, repair or demolition of damaged structures and utilities, emergency response (medical, temporary shelter, fire and maintenance crews, sand bags, plastic sheeting covering slopes, drainage diversion, debris removal), reconstruction, litigation costs including forensic studies, lost wages and taxes, and emotional trauma to affected property owners and some developers and consultants.

Similar types of slope failures and floods have occurred in southern California during past periods of above-average rainfall (Slosson, 1969; Slosson and Krohn, 1982). Rainfall amounts exceeding 140 percent of normal (mean average over 100 years) appear to be sufficient to trigger slope failures. Ray Wilson (1993) has suggested that the threshold for slope movements in the San Francisco Bay region is approximately 125 percent of normal rainfall. These threshold values represent a general rule of thumb indicating when surficial soil slips, shallow slope failures and debris flows usually begin to occur.

Slosson and Krohn (1982) observed that when rainfall at Los Angeles Civic Center is above average, (+140 percent) and at least 7 in. of rainfall has occurred within a period of 5 days, debris flows and landslides should be anticipated during individual high-intensity short-duration storms. Wieczorek (1987) and Wilson and others (1993) found that analogous thresholds and rainfall patterns caused similar events in the San Francisco Bay region. Rantz (1971) provides annual precipitation information for the San Francisco Bay region. Kuhn

Slosson and Larson

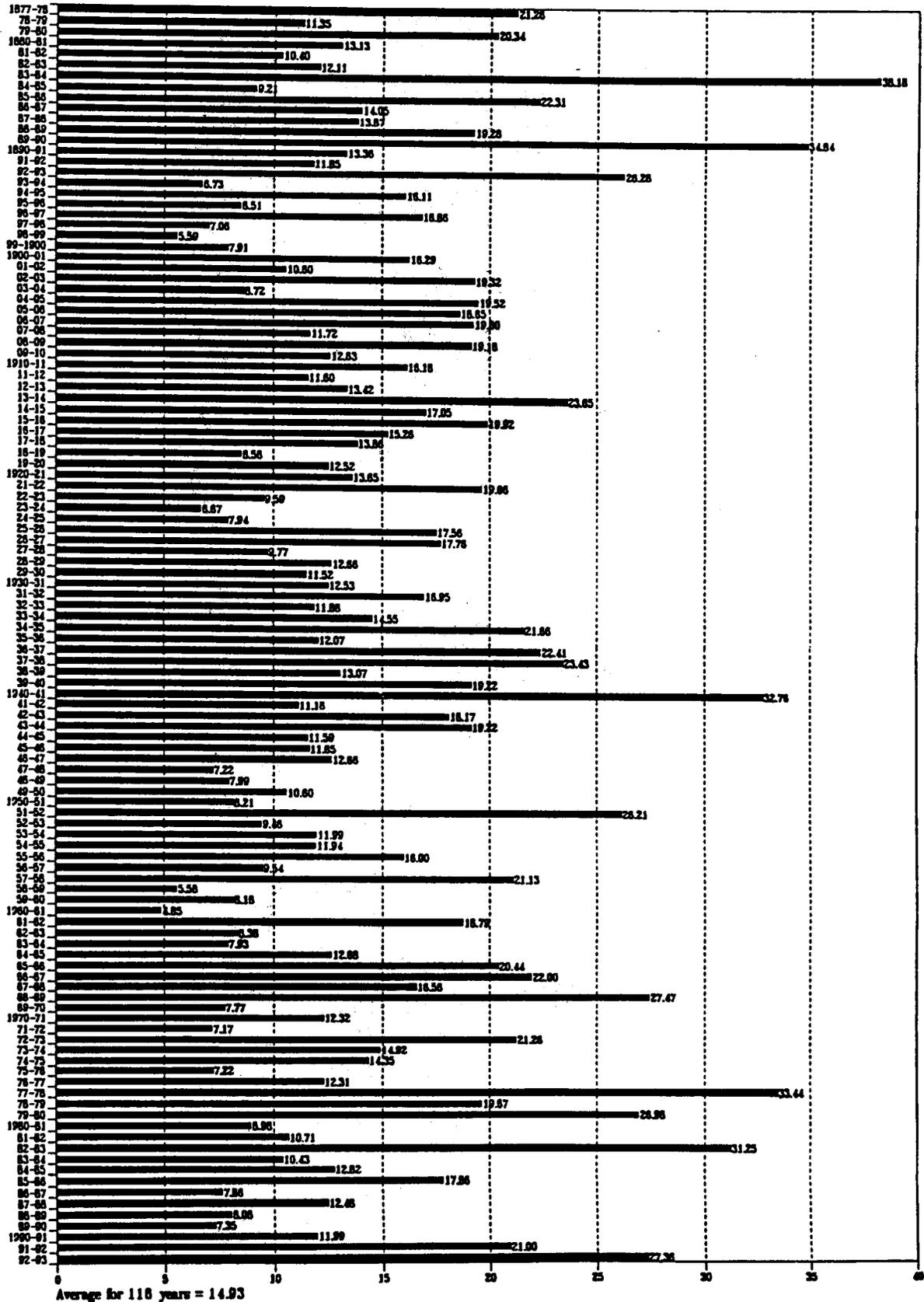


Figure 1. Los Angeles Rainfall, 1877-present. When rainfall at L.A. Civic Center exceeds 20 in. per year, and there has been 10 in. of antecedent rain and 5 days of rainfall of 6 to 7 in., then debris flows and landslides should be anticipated. Dependent upon local infiltration rates, landslides may occur as much as 6 months following this sequence of rainfall (from L.A. Times and National Weather Service).

Oct. 1, 1992 – June 7, 1993

STATION	INCHES SINCE OCT. 1	PERCENT OF NORMAL
Eureka	42.62	130
Shasta Dam	77.89	138
De Sable	79.84	124
Blue Canyon	82.91	137
Sacramento	27.70	159
San Francisco AP	26.71	140
Yosemite	44.20	123
Merced	16.78	141
Fresno	16.27	149
Glennville	23.65	134
Paso Robles	24.91	186
Bakersfield	9.32	158
Santa Barbara	26.06	151
Los Angeles AP	23.34	195
Blythe	6.81	284
San Diego	18.23	190



Figure 2. Precipitation at various locations in California (from Department of Water Resources, 1993).

and Shepard (1984) noted that this was also the case when the two largest landslides and coastal canyon cutting events of this century occurred along the coastal bluffs in Northern San Diego County in 1941, 1978 and 1980. Depending upon local infiltration rates, landslides may occur for as long as 6 months following this sequence of rainfall.

PREDICTABLE AND FORESEEABLE

Tilford (1985), in his President's Message (AEG President 1984–1985), stated:

"To me, the business of science is prediction. Scientists observe, experiment and document to achieve knowledge and understanding which can be used to make accurate predictions, hopefully with ethical concerns for the well being of mankind."

"Geologists are natural scientists whose tools in achieving predictions are observation, recording, and analysis using both deductive and

inductive methods, often with significant doses of intuition."

Brown (1984), in his synopsis of the 1982 conference entitled "Debris Flows, Landslides, and Floods in the San Francisco Bay Region," stated that:

"[Earl] Brabb expressed great confidence in the ability of the geoscientific community to predict when, where, and why many types of landslides occur, noting that the community's position on predicting landslides was far more favorable than that on predicting earthquakes. He also noted that the rapid expansion of metropolitan areas in landslide-prone terrain, particularly in the American West, is increasing the probability of a major landslide disaster such as the one that struck the Bay region."

Schumm (1991), has recognized that "with the increasing importance of environmental geology, engineering geology and geomorphology, prediction has been emphasized in the past few decades." He goes on to

Table 1. Rainfall data in ascending order, 1878–1994, in Los Angeles, California.

Inches	Year	Inches	Year	Inches	Year
4.85	1960–61	11.60	1911–12	17.05	1913–14
5.58	1958–59	11.65	1945–46	17.56	1925–26
5.59	1898–99	11.72	1907–08	17.76	1926–27
6.67	1923–24	11.85	1891–92	17.86	1985–86
6.73	1893–94	11.88	1932–33	18.17	1942–43
7.06	1897–98	11.94	1954–55	18.65	1905–06
7.17	1971–72	11.99	1953–54	18.79	1961–62
7.22	1947–48	11.99	1990–91	19.18	1908.09
7.22	1975–76	12.07	1935–36	19.22	1943–44
7.35	1989–90	12.11	1882–83	19.22	1939–40
7.66	1986–87	12.31	1976–77	19.28	1888–89
7.77	1969–70	12.32	1970–71	19.30	1906–07
7.91	1899–00	12.48	1987–88	19.32	1902–03
7.93	1963–64	12.52	1919–20	19.52	1904–05
7.94	1924–25	12.53	1930–31	19.66	1921–22
7.99	1948–49	12.63	1909–10	19.67	1978–79
8.08	1988–89	12.66	1928–29	19.92	1915–16
8.14	1993–94	12.66	1946–47	30.34	1879–80
8.18	1959–60	12.68	1964–65	20.44	1965–66
8.21	1950–51	12.82	1984–85	20.96	1991–92
8.38	1962–63	13.07	1938–39	21.13	1957–58
8.51	1895–96	13.13	1880–81	21.26	1872–73
8.58	1918–19	13.36	1890–91	21.16	1877–78
8.72	1903–04	13.42	1912–13	21.66	1934–35
8.98	1980–81	13.65	1920–21	22.00	1966–67
9.21	1884–85	13.86	1917–18	22.31	1885–86
9.46	1952–53	13.87	1887–88	22.41	1936–37
9.54	1956–57	14.05	1886–87	23.43	1937–38
9.59	1922–23	14.35	1974–75	23.65	1913–14
9.77	1927–28	14.55	1933–34	26.21	1951–52
10.41	1881–82	14.92	1973–74	26.28	1892–93
10.43	1983–84	15.26	1916–17	26.98	1979–80
10.60	1901–02	16.00	1955–56	27.36	1992–93
10.60	1949–50	16.11	1894–95	27.47	1968–69
10.71	1981–82	16.18	1910–11	31.25	1982–83
11.18	1941–42	16.29	1900–01	32.76	1940–41
11.35	1878–79	16.58	1967–68	33.44	1977–78
11.52	1929–30	16.86	1896–97	34.84	1889–90
11.59	1944–45	16.95	1931–32	38.18	1883–84

say that “when present conditions are known and understood and when the history of the situation has been established, predictions can be made with some degree of confidence.” With regard to predicting landslides, successful subsurface exploration can establish the present conditions so that they are known and established to a reasonable degree. Geologists commonly describe potential hazards and refer to areas as potentially unstable. These areas contain materials in such a geometry that when subjected to sufficient internal or external forces (as described by Terzaghi, 1950), the slope will fail. The most common internal force that causes landslides is a rise in pore-water pressure (Terzaghi, 1950), due to infiltration of rain water. Thus, to predict a failure caused by an internal force—in this case pore-water pressure—the distribution of earth materials and their

properties must be established and the likelihood of occurrence of a triggering force must be assessed.

Soil slips were clearly recognized by Troxell and Peterson (1937) in their report on the 1934 flood in La Canada, California. They state: “A continuous heavy rain may saturate the soil mantle and induce such easy slippage that the whole soil cover of the canyon slopes moves into the stream practically in a mass” (p. 95). A photograph of this type of slide was included in the report (Plate 32-B) with the caption “Slides like this one were found in the unburned area from Topanga to Pomona.” Taylor (1934), in his report on the same storm, states “The continued rain so saturated the top soil that it slipped down the slopes at many points, forming great arrow-shaped scars on the hillside.” These statements, along with many other previous and

subsequent investigations, appear to establish "the history of the situation" needed to make a prediction concerning surficial slope stability with confidence. Many areas in southern California have a long history of susceptibility to deep-seated landslides as well.

Storms that have caused slope failures and flooding in areas of southern California have occurred in 1811, 1825, 1862, 1884, 1890, 1891, 1893, 1914, 1916, 1927, 1934, 1937, 1938, 1941, 1943, 1952, 1954, 1956, 1958, 1962, 1964, 1965, 1969, 1978, 1980, 1983, 1992, 1993, and 1995 (Jahns, 1969; Brown, 1984; and this paper). Storms with notably higher than normal precipitation or that caused flooding and may have caused slope failures that were not documented occurred in 1786, 1815, 1822, 1827, 1830, 1832, 1842, 1852, 1859, 1867, 1874, 1875, 1876, 1878, and 1880 (Reagan, 1915). These damaging storm years have not occurred in symmetrical and cyclic series but have occurred about twice every decade. A series of storm events that meet the criteria for triggering landslides and debris flows will occur several times during a typical 30-year mortgage period or the conventional 50-year design life of residential/commercial property (see Figure 1). Thus, the likelihood of a slide- or flood-triggering event certainly must be considered high.

Reliable prediction of slope failure requires a successful and sufficient subsurface exploration and materials testing program and the proper application of existing knowledge. Some geologists and engineers may argue that we cannot know that sufficient pore-water pressure will occur within a slope during a storm event and thus a prediction cannot be made. We believe that prudent geologists and engineers should assume that pore-water pressure will occur, with due regard to the details of the site geology.

Slosson and Krohn, at a symposium held at Caltech in 1980, observed that a series of storm events that meet the criteria for triggering landslides and debris flows will occur approximately once in every decade in the San Diego area, twice in every decade in the greater Los Angeles area, and three to four times every decade in the San Francisco Bay area. Knowing that the meteorological pattern of intense storms will repeat, recognizing the damage and losses caused by these storms, and knowing that the capability to recognize, predict, foresee, and prevent or avoid these losses is available, it seems unethical to allow these losses to continue—particularly inasmuch as they are generally foreseeable.

THE 1993 FAILURES

Some of the 1993 failures that the authors have studied occurred on properties developed before enactment of legislation requiring involvement of geologists and soil engineers in the land development process and

preparation of geologic and soil reports. There is often little that can be done to mitigate effectively the hazards to pre-developed sites. Limited remedial mitigative design will help in some instances. These property owners must be educated by government officials and private practitioners to the fact that potential hazards still exist on their sites and in their communities in order for them to make informed decisions about mitigation and loss reduction.

Initial studies indicate that properties developed since 1975 appear to have been impacted more severely by the 1993 storms than those properties developed between 1963 and 1975. This may be the result of a reduction, or at best, a lack of increase in the standard of practice in recent years (Slosson, et al., 1992; see Figure 3). Adequate requirements for engineering geology and geotechnical engineering studies have been in force since 1963 (Jahns, 1969; Slosson and Krohn, 1977); therefore, the majority of these failures should not have occurred.

We believe that at least 90 percent of these failures would not have occurred if a) proper attention and diligence had been paid to the geology analyses, b) appropriate recommendations had been incorporated into designs, c) construction had been maintained per Code, d) local government officials had performed or required permit application reviews, and e) property owners had maintained the drainage facilities (Shlemon et al., 1992; Slosson and Larson, 1993). Similarly, Sowers (1993, p. 254), after evaluating approximately 500 failures of civil and geotechnical engineering projects, stated that "88 percent of the failures have a human cause" and that "most of those [failures] could have been prevented." Many of the failures have partially or completely involved engineered fills which are within the purview of the geotechnical engineer. The news media unfortunately reports failures of engineered fills as geologic in nature, rather than geotechnical.

REASONS FOR FAILURES

The majority of landslides and ground deformation on developed properties studied by the authors can be attributed to the failure of geologic and/or engineering professionals to perform in a competent, diligent, and prudent manner with due regard to protecting the health, safety, and welfare of the public (original and future property owners). Petroski (1993) has made the following statement that should be the basis for methodology of investigation and mitigation of hazards: "Design is first and foremost failure anticipation, and it is only by the proper and complete anticipation of failure that it can be avoided." George Sowers (1993) indicated that the three most common causes of failures are absence of knowledge (12 percent of failures), ignorance (33

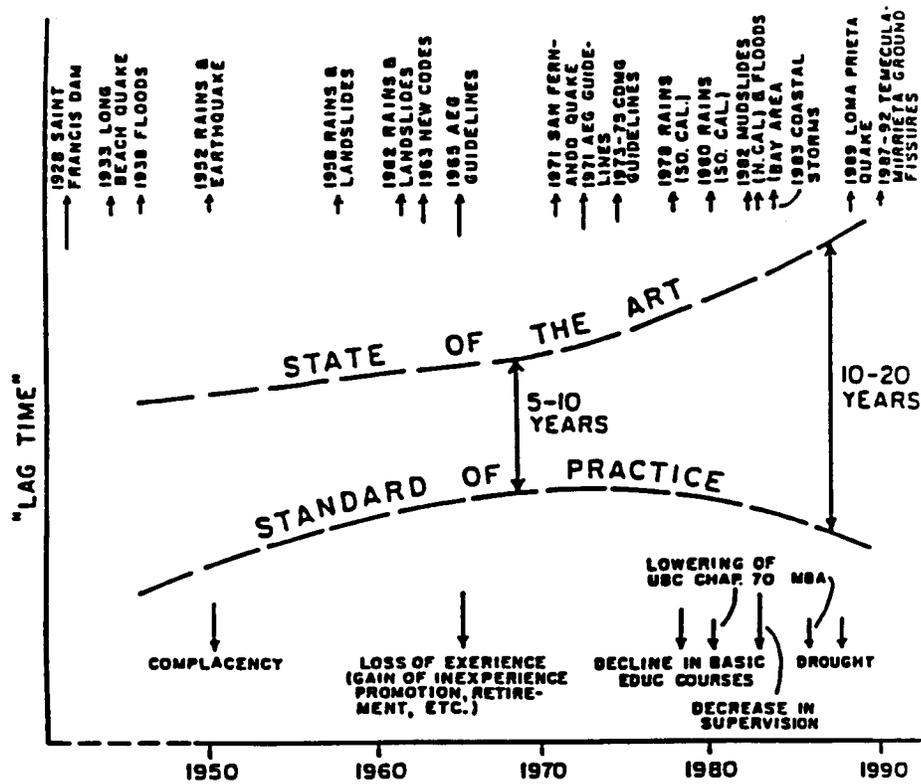


Figure 3. Estimated differential between Standard of Practice and State of the Art in California. Upward arrows show cumulative effect to the State-of-the-Art curve. The Standard of Practice curve had been affected by both upward and downward arrows. The greatest positive changes were brought about when AEG published Guidelines in 1965 and 1971.

percent of failures) and rejection of current technology (55 percent of failures).

With these observations in mind, the authors have prepared the following subjective list that represents the mistakes, misrepresentations, ignorance of physical processes, rejection of current technology, and faulty reasoning encountered in post-damage investigations during our careers which have, in our opinion, contributed to preventable failures in the past. It often takes several of these "actions" occurring sequentially to set up the situation in which failure may occur. The systems of checks and reviews does not catch all the problems. These problems are not limited to southern California. Initial investigations of 1993 storm damage indicate a repeat of many of these problems.

Failure to Perform a Competent, Diligent, and Prudent Field Investigation Due To:

1. Failure to use the method of multiple working hypotheses by limiting the thought process to only one hypothesis (Schumm, 1991).
2. Insufficient or inadequate geologic mapping or performing poor quality mapping.

3. Not utilizing proper subsurface exploration technology and/or methodology.
4. Not recognizing, collecting, interpreting, and reporting geologic data (e.g., not recognizing and/or mapping the slide plane in a shear key excavation prior to approval).
5. Filtering, "massaging," or skimming of geologic data to allow the design concept to appear to work.
6. Not collecting oriented, undisturbed samples of the weakest materials which may affect site stability.
7. Not recognizing areas of highly fractured bedrock in which the fracturing causes the rock to be weaker (lower rock mass shear strength) and increases potential for ground-water flow and storage (Deere and Patton, 1971).
8. Not recognizing and subsequently not completely removing, during grading, colluvial/alluvial/ weathered bedrock materials which act as a path for ground-water recharge and may be subject to hydroconsolidation.
9. The inability to recognize evidence of prior mudflow/debris flow activity or to understand that the evidence on geomorphically active slopes may not be recognizable after a few years.

10. Not utilizing published guidelines such as those prepared and released by the Association of Engineering Geologists (Slosson, 1984).

Failure to Use the Method of Multiple Working Hypotheses and Failure to Make Correct Assumptions

This includes limiting the thought process to only one hypothesis (Schumm, 1991; i.e., closed mind) and making erroneous assumptions such as:

1. That it will not rain again (or within the ten year limit of liability).
2. That there has been a climatic change and that it is not going to rain sufficiently to cause failures.
3. That an apparent lack of calcarious or other mineral deposits indicates that there is no ground-water flow and that a dry canyon or fault zone is going to be dry in periods of high rainfall.
4. That on-site private sewage disposal will not affect the stability of a landslide via percolation of effluent.
5. That fractured rock has no involvement in slope stability; and that, as long as the bedding or dip is favorable, there is no problem.
6. That a stabilization fill can be substituted for a buttress fill without the appropriate sampling, testing, and analysis.
7. That a project is safe and stable because it was approved by a County or City agency.
8. That a regulatory reviewer will catch any mistakes or deliberate omissions that a consultant has made.

Failure to Analyze Geomorphic Conditions of the Site and Vicinity Due To:

1. Not recognizing or acknowledging the existence of probable ancient landslides readily viewed in the aerial photos or in the field.
2. Not using aerial photos, and not learning or not being taught how to interpret aerial photographs.
3. Not reviewing early (older) photographs or the complete series of photographs readily available.
4. Not recognizing and recording geomorphic features observed in the field.
5. Not determining the cause of anomalous topography and other geomorphic features indicative of landslides or other geologic hazards.

Failure to Understand the Basic Fundamentals of Hydrogeology Due To:

1. Not understanding the relationship of ground water to slope failure (recognized in the last century by Cross, 1886).

2. Not understanding the processes of infiltration, throughflow, and development of pore-water pressure within the vadose zone.
3. Not recognizing that above-average rainfall can cause an apparently stable landslide to reactivate (Cronin, 1992).
4. Not recognizing that a fault zone may be a possible path of future ground-water flow.
5. Not anticipating flow from springs because field studies and grading were completed during time of drought.
6. Not recognizing that spring flow is often limited to times of above-average rainfall.
7. Not recognizing that effluent from dry wells, cess-pools, seepage pits, or leach lines will raise ground-water levels and often have an adverse effect/impact on slope stability.
8. Not realizing that a fill behind a crib wall may become saturated or assuming that the heel drain (one cubic foot of gravel with a pipe) will preclude saturation of the fill at a higher elevation.
9. Not recognizing that landscape irrigation will lead to an increase in local ground-water elevation due to infiltration (irrigation conveys water to the soil and is often equivalent to 40 in. to 80 in. of rainfall in one year).
10. Hydrogeologic misconceptions (e.g., water from the bedrock never enters the fill; therefore, drains are unnecessary or fills never become saturated).

Failure to Properly Mitigate the Adverse Effects of Ground Water Due To:

1. The inadequate design (often "cookbook") and construction or the elimination of subdrains, back-drains, and heeldrains from stabilization fills, buttress fills, and some sliver fills.
2. Lack of recognition of the need for subdrainage (i.e., field mapping and inspections are done during periods of drought).
3. Not requiring proper lot or building site drainage which is necessary to preclude ponding and infiltration of water or not correcting improper lot drainage.
4. Not recommending area drains where appropriate.
5. Not considering the development or future existence of pore-water pressure in the slope stability calculations (failure to understand hydrogeology).

Systemic Failures of Management and Supervision Due To:

1. Technically-incompetent administrative and staff personnel making technical decisions (see Site Investigation Steering Group, 1993, p. 31).

2. Approving design concepts proposed by others that are not in accord with one's professional opinion in order to get the job and meet payroll.
3. Field decisions made from the office.
4. Decisions based on opinions/observations made by inexperienced personnel.
5. Lack of apprenticeship under experienced personnel and lack of supervision of inexperienced personnel.
6. Following company policy that dictates standard procedures that are not always appropriate for the situation.
7. The selling of one's professional signature without taking "responsible charge" of the project.
8. Not seeking expert advice when the problem is outside the limits of one's knowledge and experience.
9. Failure to properly scope a property during the initial site visit to determine extent of investigation needed to identify geologic hazards.
10. Relegating the scoping and cost estimate to someone concerned solely with marketing.

Failure of the Government Regulatory Review Process to Function in a Responsible Manner Such As:

1. Governmental reviewers just looking for the signature of a registered professional as a basis for approval and not at the adequacy of the report.
2. Political pressure forcing the approval of projects that should not be approved due to a lack of technical merit.
3. Governmental employees not completing a site inspection or visit as part of review and not referencing or reviewing past documents, aerial photos, and other materials/documents on file as part of the review process.
4. Reviews completed by unqualified/unregistered personnel.
5. Management concerned with budgetary factors and abandoning the homeowner/taxpayer.

CONCLUDING REMARKS

Developers, and society as a whole, often make demands of our profession which force engineering geologists to make difficult professional-practice decisions. However attractive some options may seem, competent and ethical professionals must resist the easy path and must strive to provide accurate interpretations and reasonable recommendations. Latent defects may remain as residual defects on some properties no matter how thorough the site analysis. The presence of such defects may explain why the loss reduction appears to be limited to about 90 to 95 percent. However, the fact that not all failures will be avoided must not dissuade geologists from performing hazard identification and mitigation in a diligent and prudent manner.

We would like to encourage all professionals to get out of the office and observe failures when they occur. Petroski (1993) has stated that "The single most important source of judgment lies in learning from one's mistakes and those of others." We hope that the "mistakes" highlighted in this paper will provide an opportunity for geologists to develop and enhance professional judgment that will result in reducing the number of failures.

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PRESERVING THE VALUES OF NATIONAL PARKS: MITIGATING THE IMPACT OF OIL AND GAS EXPLORATION AND DEVELOPMENT

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The National Park Service (NPS) is charged with preserving the natural, cultural, and historic resource of parks for the enjoyment of present visitors and future generations of Americans. However, due to private mineral ownership in parks or leasing on adjacent lands, mineral development occurs in and around parks that has the potential to adversely affect park resources. The challenge for the NPS is to protect park resources while allowing the reasonable development of private mineral rights. To manage in-park development, the NPS has established an operation permitting system that requires the use of the most environmentally friendly techniques and advance consideration of restoration of the affected lands. The NPS requires industry to consider not only the immediate environmental consequences of its operations, but the long-term effects on the surrounding ecosystem and viewshed as well.

Recently, technological advances in the oil industry, including three dimensional seismic data, downhole mud motors, and extended reach or horizontal drilling, have made the reevaluation of old hydrocarbon provinces and exploration of new areas more feasible geologically and attractive economically than ever before. These technology advances have increased the pressure for mineral development on parks and other public lands. Experience has shown that much of the environmental impact from oil and gas operations results from surface disturbance associated with geophysical acquisition, exploratory drilling, and production facilities. Additionally, studies have shown that surface disturbance on public lands heavily influences the public's perception of oil industry operations.

As the industry strives to minimize its impact, meet increasingly strict regulatory requirements, and enhance its public image, new and environmentally sensitive techniques have been developed to reduce impacts on sensitive lands.

Examples include remote acquisition of seismic data, vehicle modifications, containerized mud systems or zero-discharge drilling, use of existing vegetation and topography to diminish viewshed degradation, and an extensive array of secondary containment techniques. Advance planning and facility design incorporating reclamation considerations can effectively and economically provide for restoration of abandoned well sites and production facilities to near natural appearance and minimize reclamation requirements.

Creation of new roads in particular is a contentious issue on public lands. Studies have shown environmental impacts from oil and gas operations per se are not nearly as detrimental as the long-term effect of unrestricted access into previously roadless areas that results from road construction. Sensitive management methods include closing or limiting access on rig roads, maximizing use of existing roads and pads, multiple wells drilled from a single pad, using non-traditional vehicles, and reclaiming roads upon completing operations.

Ensuring wealth and standard of living for future generations

**John C. Steinmetz
Indiana Geological Survey**

The wealth of nations derives from their natural resources. A high standard of living largely results from a nation's wealth and its care for the environment. In the United States, environmental laws and regulations have been established to help secure the standard of living for present and future generations, yet the present wealth of the nation is, for the most part, supported by its rapid production of non-renewable minerals. (Minerals here refers to metallic and non-metallic, fuel and nonfuel minerals, and water.) There are few incentives in place to ensure a basis of natural resource wealth for future generations.

Current rates of mineral resource extraction are driven by demand; therefore, aside from the law of supply-and-demand, there are no limits placed on the quantities of minerals produced. While providing for immediate wealth for the producers and the nation, such practices are shortsighted in the context of continued or prolonged economic wealth and well being beyond the immediate present. By establishing a balance between short- and long-term extractive practices, the mineral wealth of the nation can be preserved for future generations.

The prospect of a national mineral bank should be explored. The nonrenewable resources would be treated as assets in the bank. Withdrawals would be paced to meet current needs, while reserving some remaining balance for future generations. At present, conservation measures slow withdrawals from the nation's mineral reserves, but despite being well-intentioned, they are meager efforts and do not amount to a concerted or national effort.

How would a natural resource mineral bank function? Using objectively collected data amassed by federal and state geological surveys, mineral assets would be catalogued. The known reserves of each mineral would serve to establish a balance. Based on the balance, rates of withdrawal (extraction) would be projected, ensuring a moderate rate of growth balanced against projections of population growth. "Deposits" to the mineral bank could be made with each new discovery of an economic deposit. Tax or production incentives could be granted to mineral developers who contributed to an increase of the national balance for a particular mineral commodity. Similarly, premature withdrawals would be conducted at a substantial "early withdrawal penalty rate."

A national mineral bank board, having powers similar to those of the federal reserve bank, would determine or declare the mineral balance in the bank, forecast the total life of a mineral reserve (namely, in terms of centuries), set frequency and rate of withdrawals (for example, units per decade), and set

interest rates. The board would regularly reassess the balances. Depending on demands placed on the availability (supply) of a particular mineral commodity, a natural incentive to establish alternative technologies may be built into the program. Shifts in the demands for a particular mineral would be expected as new technologies develop. New practices developed in refining or reclamation might also markedly increase an available balance. Such activities would be richly rewarded, again with tax incentives. Minerals not native to this country or in short supply would continue to be imported to fill the demand and maintain a balance, thereby securing a steady supply and reserving balances in the mineral bank for future use.

An ancillary benefit to limits placed on the extraction of minerals in the bank might be the incentive to conserve or recycle minerals which are in greater demand. Landfills could be better planned and "mined" by requiring (also through incentives) the sorting of refuse into simple, gross categories such as metals, glass, synthetics, inert or bulk materials, and organics.

An extensive awareness and education program would be necessary to ensure the success of a national mineral bank. The first elements of such a program would stress the fact that unfettered extraction of all minerals is not in the long-term best interest of sustained high standards of living for our progeny or for the security of the nation. A major change in the national perspective would be required, one that would mean some degree of sacrifice for the sake of unknown, future generations. Finally, the concept of a national mineral bank may fail for two very important and simple reasons: selfishness and shortsightedness.

This paper is Issue #2 in a Series of Studies
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ENCIRCLING THE PEAK OF WORLD OIL PRODUCTION

Richard C. Duncan¹ and Walter Youngquist²

Abstract

We assume that the peak of world oil production will be a watershed in human history. Our goal is to predict the world peak. To accomplish this goal, we have developed (to our knowledge) a unique new procedure based on oil production data, data analysis, conventional formulas, and heuristic knowledge. It comprises (1) a program, and (2) a strategy.

The program models the historic production and predicted future production for the world's 42 top oil-producing nations (each modeled separately), grouped into 7 regions, and the world.

The strategy is to build up a series of forecasts which, taken together, will inevitably converge on the peak. This paper presents the second in this series -- designated "Issue #2." It predicts the peak production year and the expected ultimate recovery for each nation (Table 1). Similar information is given for each region (Table 2).

Figure 1 depicts the world oil production life-cycle with the peak in 2007. Likewise, Figures 2-8 show the life-cycle for each of the seven regions, with peaks ranging from 1984 for North America to 2010 for the Middle East. Important aspects are discussed in the text.

We believe, so to say, that a series of "base-camps" are necessary before climbing to the summit. "Encircling" we call it, as illustrated by the three forecasts we've made so far. Specifically, the 1996 Issue #1 put the peak in 2005 (Duncan, 1997); the 1997 Issue #2 put it in 2007 (Duncan & Youngquist, 1998, this paper); the 1998 Issue #3 put it in 2006 (future paper). Of course the peak could occur before 2005 or after 2007. Perhaps 10 base-camps will be required. Maybe more.

We've minimized technical details in this paper because, happily, all the models (and the application program to run them) are available on the Internet. Free. Page 15 gives the site address.

Further: We believe the new forecasting method can successfully predict the production life-cycle of any nonrenewable resource, including oil, gas, coal, uranium, lithium, tungsten, etc.

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ENCIRCLING THE PEAK OF WORLD OIL PRODUCTION

Richard C. Duncan and Walter Youngquist

The coming of oil. In all human history no substance has so changed economies, social structures, and lifestyles so rapidly, so profoundly, and affected so many people as has oil. Oil brought personal motor transport, intercontinental air travel creating worldwide economic and cultural interchanges, revolutionized agriculture and manufacturing, and lifted much work from the backs of many people.

Oil converted muddy trails into millions of miles of paved roads, and continues to maintain them. Oil powers vehicles to transport goods cheaply across great distances. Oil is high density energy in a most convenient form which can be taken to remote areas for use, and it can be easily stored for long periods of time. Oil's versatility in end use has no equal. Oil is also a cause of war.

Oil more than energy. Very importantly, oil is also raw material for myriad products including medicines, paints, and plastics. Oil and its close companion, natural gas, are the bases for thousands of other petrochemical products, especially chemicals to promote crop growth, and to defend crops against insects and diseases. Bartlett (1986) correctly states that modern agriculture is simply a way of converting petroleum into food.

The going of oil. The coming of oil has changed the world, presumably much for the better. But oil is finite, and its

inevitable eventual decline and departure will be a signal event in human history. Anticipating the time when this trend begins is the subject of this paper. It appears to be sooner than most people expect. The very critical related matter of what alternatives may exist to replace oil is also briefly examined.

A 550 million year inheritance. Oil has formed in the upper approximately 16,000 feet of the Earth's crust since at least as far back as the Cambrian Period, some 550 million years ago. It is a rich inheritance of highly concentrated solar-derived energy captured by myriad organisms, chiefly algae, and then distilled by geological processes into an energy form that is unequaled by any other energy source in versatility of end use, and convenience in handling. Now, within one human lifetime, half this unique 550 million year inheritance will have been spent. The remainder will go very fast.

The oil interval. We are not in the Age of oil--the term "Age" is for things of longer duration. We are living in a brief oil interval. The average citizen pulling into a service station and saying "Fill 'er up" gives little or no thought to where the oil came from, or how long that stream of gasoline will continue to be available to flow into the car's tank. There were two brief times in the 1970s when the American public was made acutely aware of what the lack of oil might mean. But those long gas lines are now a faded memory, and for the youngest third of the U.S. population there is no such memory at all.

The wrong question, and the peak. If the public does think

briefly about future oil supplies, the question commonly asked is, "How long will oil last?" This is the wrong question. Oil will be produced in some insignificant quantity perhaps 200 years from now. The critical question is: "When does the peak of world oil production occur?"

Importance of world peak. The importance of the "peak of world oil production" is generally not grasped. But it is the peak time which is critical. Hubbert (1967) emphasized its significance stating: "Because gas and oil are exhaustible resources, the discovery history of these fuels in any particular area must be characterized by a beginning, a period of increase, a period of decline, and ultimately, an end. In this sequence, the most significant dates are neither those of the beginning or of the end, but that of the transition between the period of increase and the period of decline." In other words, the peak.

The United States has already briefly felt the importance of peak. Precisely as forecast by Hubbert in 1956 (either ignored, or regarded in gross error by most people at the time), U. S. oil production peaked in 1970. The U. S. actually had to begin to import oil about 15 years before the peak was reached, as demand had already outstripped production capacity by peak production time. But the fact that U. S. production had peaked in 1970, and then began to decline further assured the success of the Arab oil embargo against the U. S. in 1973, and altered U. S. Middle East foreign policy.

The U. S., well past its peak of oil production, now imports

more oil than it produces. But when world oil production peaks, there will be nowhere else for the world to go for more oil. The problem then will become the harsh reality of distribution of an irreversibly declining resource, rather than dividing more and more oil as has been the pleasant experience to the present. This is when final competition begins for the last half of world oil reserves. It will be a global struggle. All countries will be involved--the industrialized countries more so than the less developed countries. For the first time the entire world will be locked in one massive contest for a single resource. This may be the most important event in human history. In terms of lifestyles, our relatively cheap and abundant food supplies, the manufacture of many things which depend on the energy of oil, and the distribution of these products, the beginning of the decline of oil production will be momentous event.

This study. We have forecasted the peak of oil production in each of 42 countries accounting for 98 percent of 1996 world oil production. These and related statistics are shown in Table 1.

— Table 1 is on page 22a —

From production data, together with a judgmental amalgam of the possible production variables in the 42 countries, we have produced a composite world oil production profile from 1960 to 2040, shown in Figure 1. The Figure also shows the profile and production peaks of the OPEC and non-OPEC nations, and the significant final cross-over point when OPEC nations (by that time chiefly those of the Persian Gulf region) will be producing half,

and from then on, more and more of the world's remaining oil.

— Figure 1 is on page 22b —

This graph forecasts that the peak of world oil production will occur about the year 2007--only nine years away! After this time, with the world production peak at 30.6 Gb a year, world production drops rapidly to 24.6 Gb a year in 2020 and to 11.5 Gb per year in 2040--a total decline of 62 percent in just 33 years. Note also the important date when OPEC production becomes the dominant world oil source. This is also at the time of world oil production peak, 2007. This may have significant implications, because at that time the world's remaining oil reserves and production will be largely under control of the Muslim Persian Gulf nations.

Present world oil production is about 25 Gb a year. The 2040 production will be less than half the present oil consumption, and will face a demand from a world population which is estimated to be 50 to 70 percent greater than a present. Compounding world energy demands will be the increasingly industrialized nations (particularly SE Asia, China, and India) wanting more energy per capita. China, Southeast Asia, and India now with some 60% of the world population are getting motorized wheels. If China used oil on a per capita basis as does the United States, China alone would account for approximately 14 million barrels a day more than the present entire world oil production.

Insignificant production beyond 2040. Although some oil will be produced well beyond 2040, we have not plotted the "tail" of the

production curves of individual countries or of the world beyond the year 2040. Production then will be insignificant compared with potential world demand. The happy oil interval will have come to an end for all practical purposes. This is why the common question "How long will oil be produced?" is of little consequence.

Production peaks by region. Graphic illustration of the oil production history since 1960, and projected future production of seven major oil producing areas of the world are shown, respectively, in Figures 2-8. This provides a view of the relative abilities of each of these regions to provide for its own oil. Notably, the region with the greatest population, Asia-Pacific (Figure 8), is the least capable region for providing its own oil.

— Figures 2-8 are on pages 22c-22i —

The basic information shown graphically by Figures 2-8 is tabulated in Table 2.

— Table 2 is on page 22j —

Forecasts of oil peak. In earlier years a number of forecasts have been made about the peak time of world oil production. With few data points and many of the potential world oil basins only poorly explored at that time, most of these estimates have already proved to be wrong. Thus by implication it is sometimes assumed current projections will (hopefully) also be wrong. However, the world's potential oil provinces are now well known. (Campbell, 1997b). Recently, based on more and better data, further forecasts have been made, and, although each estimate is slightly different than the others, most now cluster remarkably, one might say

alarminglly close together on that critical time. These include forecasts by Campbell (1991, 1997b), Campbell and Laherrere (1998), Duncan (1997), Fleay (1995), Hatfield (1997), Ivanhoe (1995,1997) and MacKenzie (1996). All estimate the peak at the year 2013, or earlier except for the most optimistic forecasts by Edwards (1997) of the year 2020. There are, however, some divergent views on the time of world oil production peak as noted by Brown (1998), but those cited here are the most recent, and we believe the most nearly correct.

Our forecast methodology. How our figures and estimates are derived is briefly described here.

The oil production profile (all figures include natural gas liquids) from 1960 to 2040 for each country in this study is modeled separately by use of a special program (the World Oil Forecasting Program, outlined in later paragraphs). These 42 production profiles have been melded into a single projected world oil production profile (curve 3, Figure 1).

We owe much to the great pioneer theoretical work by Hubbert that defined the oil production life-cycle in terms of discovery, production, and reserves, and which he used so successfully in predicting the peak of U. S. oil production. However, the oil forecasting program and procedure used in this study departs from and goes beyond his forecasting method to try to anticipate and encompass numerous variables related to future oil production, particularly technological advances in exploration and production, not known in Hubbert's time.

The World Oil Forecasting Program. The software ("tool") used for the conclusions expressed in this paper we have called the "World Oil Forecasting Program" which consists of two distinct, stand-alone models for each nation.

The Numeric Forecasting Model. The first model ("N-model") is quantitative, using production data and mathematics on a translated coordinate system to produce an intermediate "helper" forecast for each nation. This, the so-called "guide" forecast ("G-forecast"), is a purely mechanical prediction of future production. In some cases the G-forecast can provide useful information about the shape of future oil production, by providing a lower boundary on the estimated ultimate recovery (EUR), and the probable shape of the future production curve. But in other circumstances it is not very useful as in the case of the OPEC production quota-limited countries. The N-model produces the G-forecast, the best forecast we are able to make based solely on historic production data, and mathematics. Data are from British Petroleum (1968-1997), and Campbell (1991). Details are in Duncan (1996).

The Guide Forecast is just one of many items of information that may be used in the second model portion of the World Oil Forecasting Program.

The Heuristic Forecasting Model. By definition 'heuristic' denotes a method of solving a problem for which no algorithm exists. It involves trial and error, as in iteration. In this discussion 'heuristic knowledge' means 'soft,' 'qualitative,' or

'judgmental' knowledge. Although judgmental knowledge is lacking in the Numeric model, it is crucial for oil forecasting in the heuristic model ("H-model"). The H-model provides the user with a powerful interface for oil forecasting, chief of which is a 3-curve graph for each nation with years 1960 to 2040 on the x-axis, and production on the y-axis. Curve 1 shows the historic data from 1960 through 1996--a crucial reference for forecasting. Curve 2 shows the Guide forecast (previously discussed) and is very useful as the lower bound curve. Curves 1 and 2 are important forecasting aids, but they are only the beginning.

Curve 3 also displays the historic data from 1960 through 1996, but this time the data serve as a base for a new and better forecast 1997 through 2040. A so-called graphical input device (GID) makes it easy to enter and run different trial forecasts. After each trial run, a different estimated ultimate recovery (EUR) value is displayed so, after making several runs, the user can choose an upper-bound curve for each nation. Thus, now confined by lower and upper curves, and further modified by judgmental input, the user extends the most recent production trend seamlessly into the curve extending through the year 2040, providing what we call the "judgmental" forecast (J-forecast) of future oil production, one nation at a time. Details of the heuristic model are in Duncan (1997).

In our 42 nation study, we have also grouped the nations into seven regions (Figures 2-8 and Table 2), and made a world summary (Figure 1 and Table 1) which are the output of the heuristic model.

The judgmental forecast. This step is qualitative and involves judgmental factors. We recognize that predicting either a nation's or the world's oil production peak is not an exact science. Hennessy (1997) states: "Although qualitative factors are generally more prone to measurement error than quantitative variables, we should not exclude them on that basis alone. How well a model recreates the system's performance--and thereby the model's usefulness--depends on much more than measurement precision." In our model, we have, on a judgmental basis, incorporated the important variables which we visualize might affect the conclusions.

In general, we have not used reserve estimates in our forecast as we believe these to be less reliable than are the actual production figures. Reserve estimates are subject to political and economic factors. Basing production quotas on reserve estimates, as is done by the OPEC nations, may cause reserves to be overstated. Using oil reserves as collateral for loans as was done by Mexico, may also lead to inflated figures. Government owned oil companies like to show a gain in reserves each year, and this factor may distort the reserve picture. Laherrere (1995), Campbell (1997a,b), Campbell and Laherrere (1998), Riva (1995) and others have pointed out the risks in using stated reserves by countries, designating some as "political reserves."

Although production figures are also subject to some error or deliberate misstatement, we believe that production can be more easily verified than can reserves--unseen oil in the ground. Also,

production generally represents the true ability of oil fields to produce, except in instances where production may from time to time be restrained artificially (e.g. OPEC quotas). For these reasons the first part of our world oil forecasting is based chiefly on production history, which was also the basis of Hubbert's successful 1956 forecast of the U. S. 1970 oil peak. However, in this second part of the model, we do employ some reserve figures, which, on a judgmental basis, may differ considerably from those reported by a given country.

Other judgmental elements include ultimate recovery volumes based on what is known about reservoir characteristics, and the effect on production of new technologies (e.g., 3-D and 4-D seismic, directional drilling, CO₂ and air injection, deeper water and subsalt drilling capabilities, etc.) (Anderson, 1998) These are already to some extent factored into present production curves. But we have also given these some weight in the judgmental part of our model as we project the curves into the future.

Also considered are the most recent leasing, exploration, and discovery trends, current and probable national policies and restraints (such as OPEC's production quotas which, however, are frequently violated, and Norway's intent to limit production so as to make their production peak flat and as long-lasting as possible). Some substantial discoveries may be made, although it should be noted that no major oil field in the world as large as Prudhoe Bay has been discovered since the Prudhoe Bay find in 1967. Previously, some 15 super-giants (fields with five Gb or more of

economically recoverable oil) had been found at irregular intervals. We now know the location, size, and shape of almost all of the potential world oil basins, and there are not likely to be many if any large surprises. The world has been rather thoroughly explored. Much of this information is proprietary. However, Masters (1985) and his associates (Masters, et al., 1994) with the U. S. Geological Survey have, over the years, provided excellent public reviews of world petroleum resources.

Judgmental element summary. The judgmental elements applied to the historic production curves are an important part of the world oil forecasting program. Purely on the basis of extrapolating production data into the future (the Guide curve), we arrived at a figure of 1303 Gb for the estimated ultimate recovery (EUR) of oil in the 42 nations. But when the judgmental element is applied we have a figure of 1996 Gb for the EUR, the figure we believe to be the more nearly correct. Other variables on which we have briefly commented upon in the following paragraphs may move the peak back. With the judgmental element we have resolved these into the final world production curve.

Unconventional oil. There are oil deposits which are sometimes termed unconventional, as they can be made to produce oil using special technologies beyond those employed in usual oil recovery by flowing or pumping, which also includes gas repressuring and water flooding. These resources include oil sands/tar sands, and oil from wells by various enhancing methods including use of detergents, hot water injection (Cold Lake area,

Alberta), and steam flooding. These resources will increasingly be brought into production as economic and environmental factors permit. We have factored these into our forecast on a judgmental basis, but they appear to change very little the curve derived from a projection of conventional crude oil production. They simply give a modestly extended life to the low far end of the curve of world oil production.

The problem of bringing on sufficient quantities of unconventional oil resources to appreciably move the peak of world oil production is illustrated by the calculation by Bartlett (1998) that each additional Gb of oil added to present projected world supply, would move the peak of oil production just 5 1/2 days further away.

Fouda (1998), and George (1998) have recently suggested a significant extension of the available volumes of oil from unconventional sources. However, whereas these sources will help to extend the far end of the oil production, one problem with these sources is their generally low net energy recovery, a fact brought out by Spreng (1988). To bring on production from unconventional oil resources in sufficient quantity in time to alter the projected peak of 2007 even just one year, is quite unlikely.

Alternative energy sources. Another consideration is the amount of displacement of oil by other alternative energy supplies which could limit demand and therefore production, thus delaying the time of peak production. These include solar, wind, hydro, nuclear, and geothermal energy sources. However, an evaluation of

how soon and to what degree alternative energy sources could fill the gap created by the declining oil production indicate that such sources, neither individually nor in total will significantly replace oil within the next 15 to 20 years and perhaps not even beyond that time, given the many ways and especially the volumes in which we use oil today. (Youngquist, 1997). In any case, neither unconventional oil nor other alternative sources can be brought into production soon enough and in sufficient quantity to significantly affect the time of the peak of world oil production.

Economics. We also recognize that economics plays a part in oil production. However, there is a difference between the attractive oil economics by which oil displaced coal, still leaving large quantities of coal in the ground, with the situation now with oil. Alternative energy sources to possibly displace oil do not have the great versatility of end use and the energy/profit ratio that oil had over coal. The favorable economics and the much greater versatility in end use that oil has compared with coal, which caused the switch to oil, generally do not exist for alternative energy sources over oil. In spite of eventual rising prices, we believe the much preferred and used energy source will remain oil as long as reasonable quantities exist.

Eventually, price will move oil into its higher and higher end use values. Transportation may be one such higher value. The more than 600 million gasoline and diesel powered cars and trucks in use today cannot be quickly or easily replaced with other types of vehicles. And there is no alternative energy system in sight that

can replace kerosene as a fuel for use in jet aircraft. Oil for simply burning in the low end use of space heating is likely to become prohibitive in cost. In spite of price, oil will remain in strong demand. For these reasons we believe that the curves, both regional and worldwide, have considerable validity, and economics will not materially change them.

On the Internet. The World Oil Forecasting Program is available at Website: www.halcyon.com/duncanrc/. All programs are free (both Macintosh and Windows versions), including the latest run-time version of Stella 5.0. Users can study our forecasts, or make their own forecasts for 42 nations, seven regions, and the world. All historical data and the guide forecast are automatic. No programming is needed.

No total oil substitutes apparent. There is a general citizen confidence that alternative energy sources exist or will be found to replace oil. "The scientists will think of something" is a widely expressed pleasant public placebo. However, there is no alternative energy source or combination thereof now known that can completely replace oil in all its many and varied uses, particularly with regard to the concentration of such a large amount of energy in such a convenient, easy to handle form for use in mobile machines (cars, trucks, tractors, airplanes, etc.). The energy source that can compare with five gallons of gasoline which may be conveniently carried for hundreds of miles to where it may be put in a car to propel it for 150 miles or more at 60 miles an hour is nowhere in sight. Nor has an alternative energy system

been identified which can propel an airplane non-stop for 14 hours at 600 miles per hour (the present New York to Capetown flight).

The distinguished British scientist and statesman, Sir Crispin Tickell (1993), has expressed the same opinion regarding oil alternatives and the future stating, "...we have done remarkably little to reduce our dependence on a fuel [oil] which is a limited resource, and for which there is no comprehensive substitute in prospect."

Encircling the peak. We do not presume to have the precise date of the peak of world oil production. Campbell (1997a), in discussing oil reserve estimates, stated, "All numbers are wrong: that much we know. The question is: how wrong?" The same thought can be applied to the peak time of world oil production. Our estimate may be wrong, but we do not believe it is very far wrong, and that the critical date of peak world oil production is in sight. Even allowing for the highly unlikely event of the discovery of 15 more "super-giant" fields, our happy but very brief oil "interval" we have had the good fortune to enjoy, a bright almost instant flash even in human terms, will shortly become history.

We use a special map, called a "scatter diagram," to track our progress in establishing the peak. Each forecast pinpoints a milestone along the route. The first forecast put the peak in year 2005, with production at 28.50 Gb (Duncan, 1997). The second forecast, the subject of this paper, puts the peak at 2007 with that year's production at 30.64 Gb. Successive points are marked

on the map and connected by lines, each line on average reaching closer to the peak. By repeating this effort annually, we expect to correctly forecast the time of the peak within the next few years.

However, the exact date will not be known for certain until some time after that year arrives, when it can be viewed in retrospect with the downward trend well established. We expect that the peak at the time will not be easily recognized and rather than a sharp peak, there will be a gradual leveling out of production, and the peak will be obscured in a fairly flat, plateau-like curve. Our figures portray this shape of the peak in our prediction of annual Gb of oil production for the year 2001 at 29.75; 2003, 30.41; 2005, 30.59; 2007, 30.64; 2009, 30.40; 2011, 29.52; and 2013, 28.32. The peak may be more evident by a sharp rise in price as demand begins to exceed supply at prior price levels.

Estimated ultimate world oil recovery (EUR). An outgrowth of our study has been an estimate of the amount of world oil which will ultimately be recovered. The most recent discussion of the future of world oil production is an outstanding article by Campbell and Laherrere (1998) with which we are in substantial agreement. These authors estimate the probable ultimate world oil recovery at about 1.80 trillion barrels. By using a somewhat different approach, our estimate is 2.04 trillion barrels. However, Campbell and Laherrere do not include natural gas liquids in their estimate. We do. If one assumes eight percent additional

oil from natural gas liquids, then the Campbell/Laherrere figure is about 1.94 trillion barrels compared with our figure of 2.04 trillion--in remarkably close agreement. Both studies show, as Ivanhoe (1995) has also noted, that there is a now-visible limit to world oil supply and we are approaching the halfway point of its consumption.

The circle narrows around people living today. As already described, we propose to steadily close in on the time of peak world oil production by an on-going study as new data are available. But the important point is that by all reasonable estimates, within the lifetimes of most people living today, the peak of world oil production will be reached. We should be concerned now.

The declining oil supply paradigm. Policy makers worldwide must face the reality of soon beginning to move into a post-petroleum economy which will be markedly different from our present circumstances. Achieving an orderly social, economic, and non-military transition to the post-petroleum global paradigm beginning within the next decade, with its probable much changed personal lifestyles, and the far reaching implications for both the agricultural and industrial economies, may be the largest and most critical challenge the world has ever faced. The implications of the peak of world oil production, and of the beginning of the irreversible decline in oil supplies, cannot be overstated.

Striking, basic facts. It is difficult to get the attention of either policy makers or the public in general concerning

something which will happen 10 or 15 years hence. However, here are simple facts which should surely gain attention. The world now consumes about 25 Gb of oil a year. But we are finding, the world around, less than 5.5 Gb annually. (Campbell, 1997c). Campbell and Laherrere (1998) state, "In the 1990s oil companies have discovered an average of seven Gb a year; last year they drained more than three times as much." These authors also note that the world oil discovery rate peaked in the early 1960s and they add, "About 80 percent of the oil produced today flows from fields that were found before 1973, and the great majority of them are declining."

World going out of the oil business. Any company which is selling its product faster than it is being replaced is going out of business. The world is going out of the oil business. Political leaders, business planners, and social policy makers take note. Heed the words of Aldous Huxley: "Facts do not cease to exist because they are ignored."

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#	Nation	Peak Year	Oil Production			Cumulative Production			Yet-to- Produce		Decline:	
			Peak Gb/yr	1996 Gb/yr	2040 Gb/yr	1996 Gb	2040 Gb	EUR Gb	Produce Gb	Produce %	Pk-2040 %	
1	Canada	2005	1.00	0.91	0.33	22.7	56.9	59.6	36.9	61.9	67	
2	Mexico	1998	1.24	1.21	0.11	25.3	51.0	51.6	26.2	50.9	91	
3	USA	1970	4.12	3.03	0.42	197.4	267.0	271.2	73.8	27.2	90	
4	Argentina	2001	0.33	0.30	0.05	6.7	14.6	14.6	6.1	54.7	85	
5	Brazil	2011	0.33	0.27	0.13	4.3	16.9	18.0	13.7	76.1	61	
6	Colombia	2012	0.32	0.24	0.09	4.2	15.1	15.9	11.7	73.6	72	
7	Ecuador	2002	0.15	0.14	0.04	2.4	6.7	6.9	4.5	65.2	73	
8	Peru	1981	0.07	0.04	0.02	2.1	3.5	3.5	1.4	40.0	71	
9	Trinidad	1977	0.08	0.05	0.02	2.9	4.6	4.7	1.8	38.3	75	
10	Venezuela*	2005	1.47	1.17	0.78	49.5	106.0	113.2	63.7	56.3	47	
11	Denmark	2001	0.09	0.08	0.02	0.6	3.0	3.1	2.5	80.6	78	
12	Italy	2001	0.09	0.08	0.01	0.6	2.6	2.7	2.1	77.8	89	
13	Norway	2001	1.40	1.24	0.17	9.3	42.1	43.1	33.8	78.4	88	
14	Romania	1976	0.11	0.05	0.01	5.1	6.3	6.3	1.2	19.0	91	
15	UK	2001	1.05	1.00	0.25	15.0	43.8	44.8	29.8	66.5	76	
16	FSU	1987	4.62	2.61	1.65	130.7	244.0	263.8	133.1	50.5	64	
17	Iran*	1973	2.17	1.36	0.75	46.5	116.0	130.7	84.2	64.4	65	
18	Iraq*	2010	1.95	0.24	1.08	23.5	94.0	110.0	86.5	78.6	45	
19	Kuwait*	2018	1.74	0.80	1.08	28.2	94.1	110.6	82.4	74.5	38	
20	Oman	2002	0.38	0.33	0.06	4.9	14.8	15.0	10.1	67.3	84	
21	Qatar*	1973	0.20	0.18	0.04	5.4	10.7	10.8	5.4	50.0	80	
22	Saudi Arabia*	2011	3.92	3.28	1.76	80.5	228.0	273.0	192.5	70.5	55	
23	Syria	1999	0.23	0.23	0.04	2.5	8.4	8.5	6.0	70.6	83	
24	UAE*	2017	1.77	0.97	0.57	17.8	82.2	89.4	71.6	80.1	68	
25	Yemen	2002	0.15	0.14	0.05	0.7	5.4	5.5	4.8	87.3	67	
26	Algeria*	1999	0.53	0.51	0.10	13.4	27.0	27.6	14.2	51.4	81	
27	Angola	2002	0.30	0.27	0.05	2.7	10.3	10.6	7.9	74.5	83	
28	Cameroon	1985	0.07	0.04	0.00	0.8	1.6	1.6	0.8	50.0	100	
29	Congo	2004	0.11	0.09	0.01	0.9	3.4	3.5	2.6	74.3	91	
30	Egypt	1993	0.34	0.33	0.06	7.2	15.5	15.6	8.4	53.8	82	
31	Gabon	2000	0.14	0.13	0.03	2.2	5.4	5.5	3.3	60.0	79	
32	Libya*	1969	1.16	0.54	0.28	19.8	46.5	48.4	28.6	59.1	76	
33	Nigeria*	2005	0.95	0.80	0.30	17.6	46.9	49.6	32.0	64.5	68	
34	Tunisia	2009	0.05	0.03	0.04	1.0	3.0	3.2	2.2	68.8	20	
35	Australia	2002	0.25	0.22	0.06	4.8	11.6	11.8	7.0	59.3	76	
36	Brunei	1979	0.09	0.06	0.02	2.9	4.6	4.6	1.7	37.0	78	
37	China	2003	1.31	1.16	0.46	21.3	64.2	66.3	47.0	68.8	65	
38	India	2003	0.31	0.27	0.08	4.6	12.8	13.1	8.5	64.9	74	
39	Indonesia*	2003	0.67	0.60	0.18	18.3	39.8	40.5	22.2	54.8	73	
40	Malaysia	2001	0.30	0.27	0.06	3.5	11.2	11.4	7.9	69.3	80	
41	P.N Guinea	2005	0.04	0.04	0.01	0.2	1.5	1.5	1.3	86.7	75	
42	Vietnam	2004	0.08	0.06	0.01	0.3	2.5	2.6	2.3	88.5	88	
	42 Nations	2007	30.0	25.4	11.3	810.3	1846	1996	1186	59	62	
	TOTAL WORLD +	2007	30.8	25.9	11.5	830.0	1884	2042	1212	59	62	

Table 1. Oil production peaks, some already established, others forecasted for 42 countries, representing 98 percent of total world oil production. Production for 1996, and forecasted 2040. Cumulative production through 1996, forecasted cumulative production to 2040, and forecasted ultimate recovery (EUR). Amount yet to produce, and percentage of forecasted ultimate recovery yet to produce. Far right column: The percentage fall from peak production to year 2040. Notes: The International System (SI) term "Gb" is used in this study, and is equivalent to the U. S. use of the term billion. "*" Designates OPEC member. "+" Indicates that production and cumulative production figures were increased to account for nations omitted from this list.

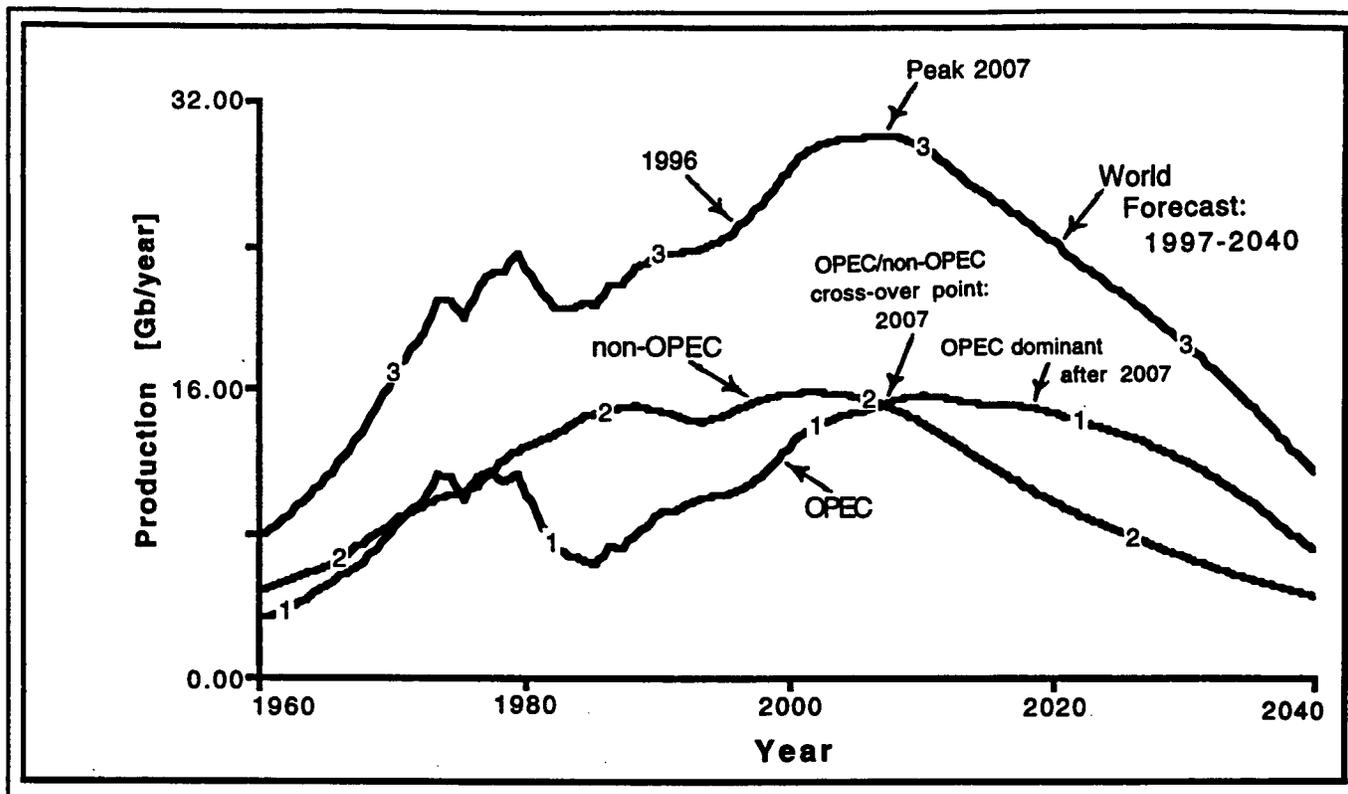


Figure 1. World, OPEC, and non-OPEC Oil Production Life-Cycles. Years 1960-2040 curves and peaks of the world (curve 3, peak 2007), non-OPEC (curve 2, peak 2001), and OPEC (curve 1, peak 2010). The cross-over point when OPEC production exceeds non-OPEC production (year 2007). In 2007 almost all OPEC production will be in the Persian Gulf region. OPEC nations outside the Gulf will have minor production, except for Venezuela. Some countries may have dropped out of OPEC when domestic demand exceeded production, with no surplus to export.

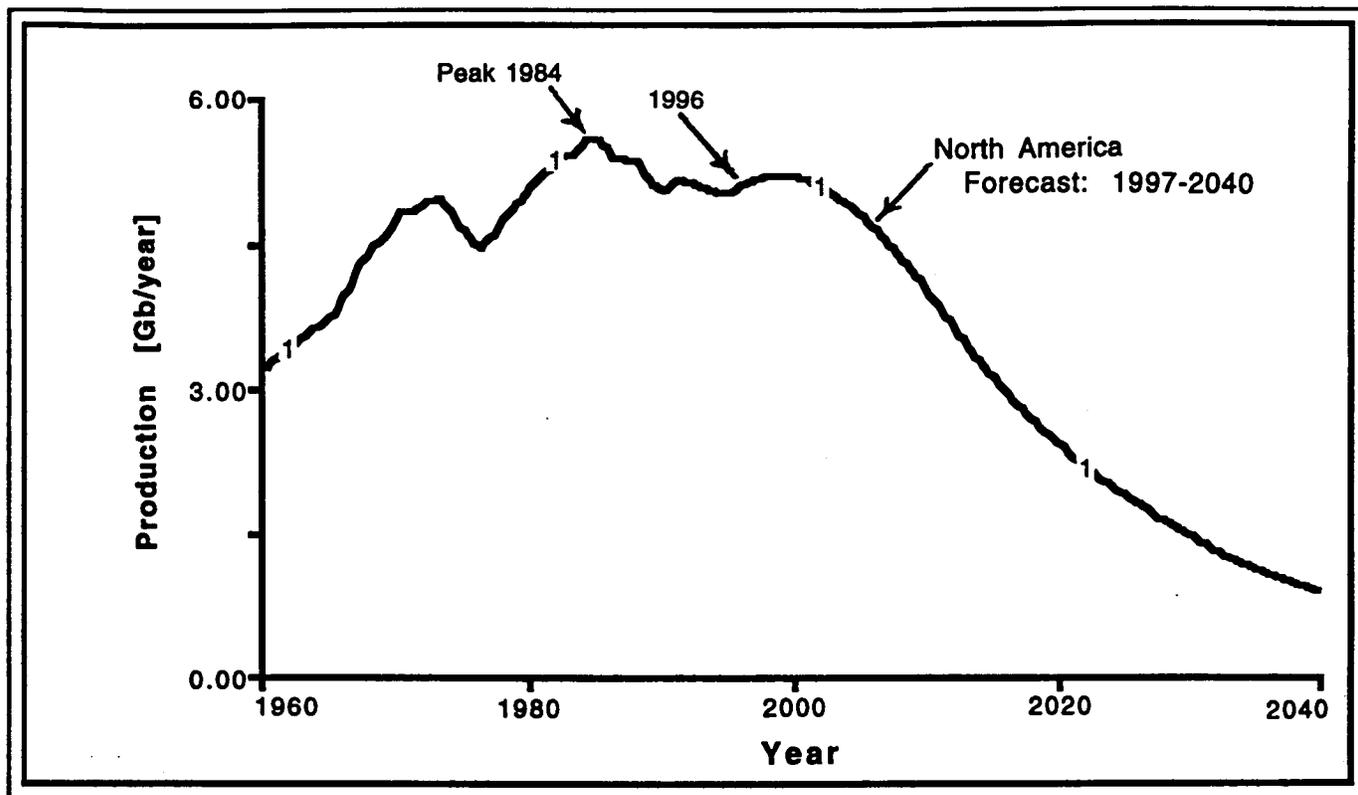


Figure 2. North America. This includes Canada, United States, and Mexico. United States passed its peak in 1970, but the later development of the offshore Mexican fields along with Canadian exploration successes moved the regional peak to 1984. This region, dominated by the United States, reached its peak the earliest of the seven regions. The United States was the first nation to substantially exploit its oil resources, and reach its production peak. This early exploited abundant and cheap oil helped to rapidly propel the United States to its high "oil standard" of living enjoyed today, but maintained now only by increasing oil imports.

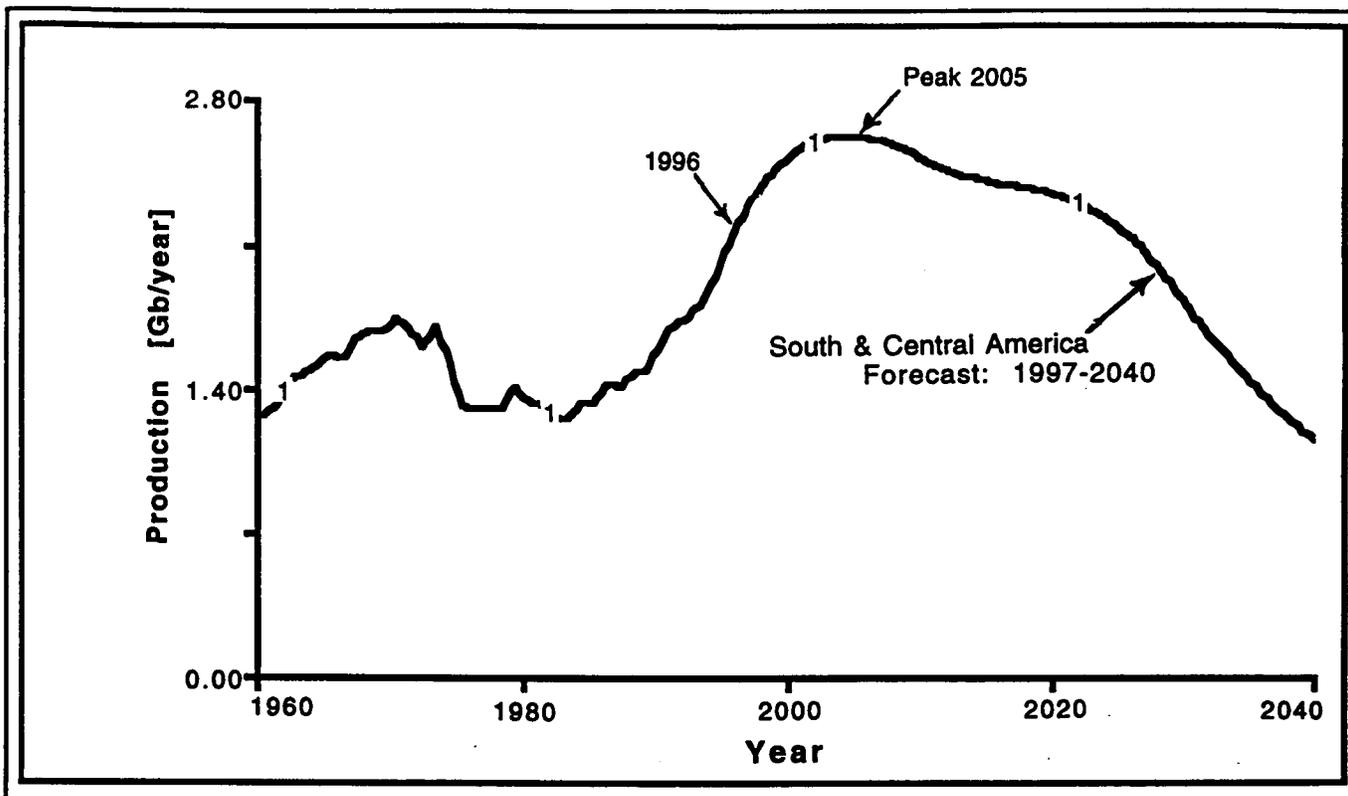


Figure 3. South and Central America. This includes all countries south of Mexico. We project the previous peak in 1996 will be replaced by the all-time peak in 2005, due to recent successes and developments along the eastern margin of the Andean fold belt, the privatization and increased activity in the Argentine oil industry, and more aggressive development programs in Venezuela, which country now accounts for about 51% of this region's production.

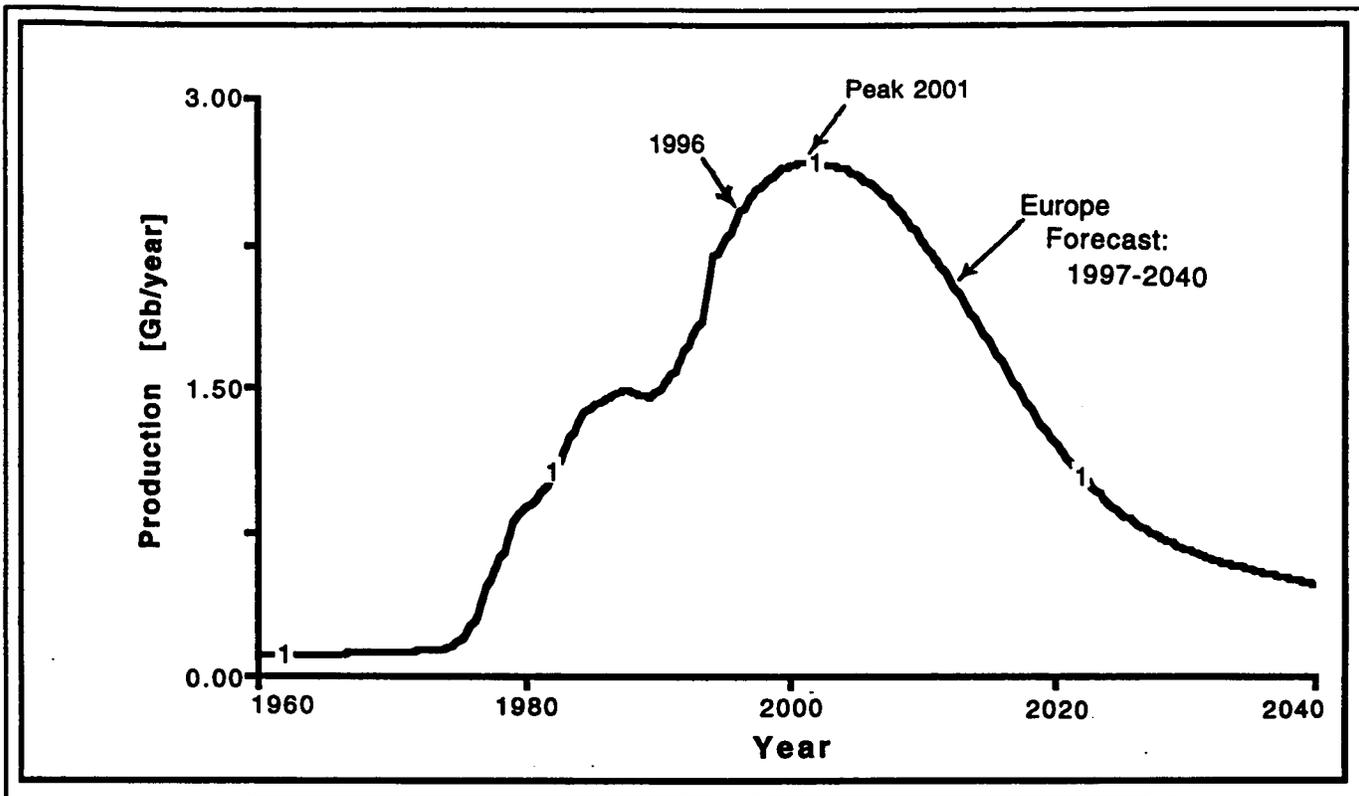


Figure 4. Europe. This region's production is now chiefly from the North Sea, where Norway and Great Britain are dominant. Other European oil production is minor. The curve reflects a steady, orderly growth, and then a decline, with the peak at 2001. Decision by the Norwegian Government to limit production in order to flatten and lengthen their production peak, may move the 2001 peak to slightly later.

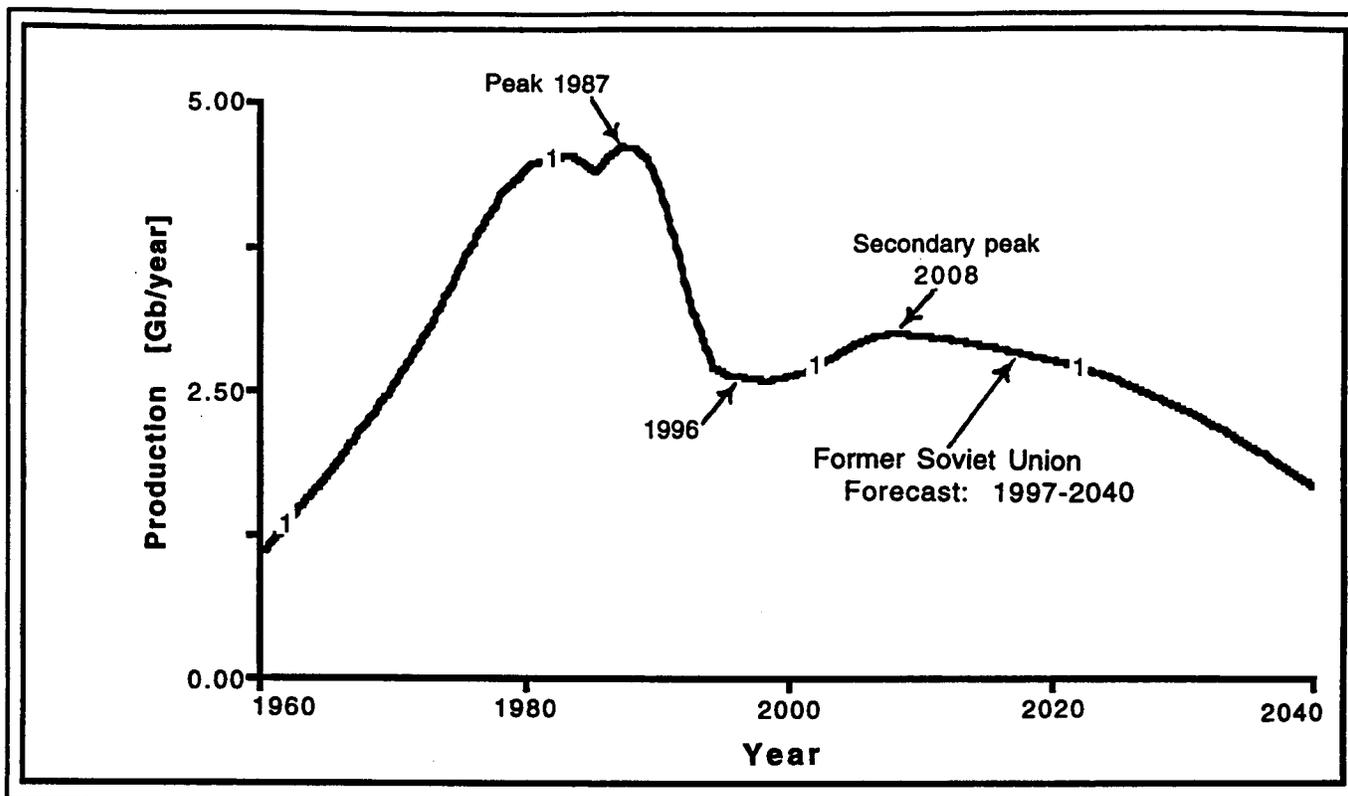


Figure 5. Former Soviet Union (FSU). Since the break-up of the USSR, this region now has diverse political and economic agendas. The previous production peak reached by the unified USSR in the 1980s seems unlikely to be surpassed. The Russian oil regions are in an aging phase. The now independent republics are not coordinated in their efforts to secure needed financing and technology for oil development, and will not achieve a unified peak production time. We do project a secondary peak the year 2008, but it will not reach the earlier 1987 USSR peak.

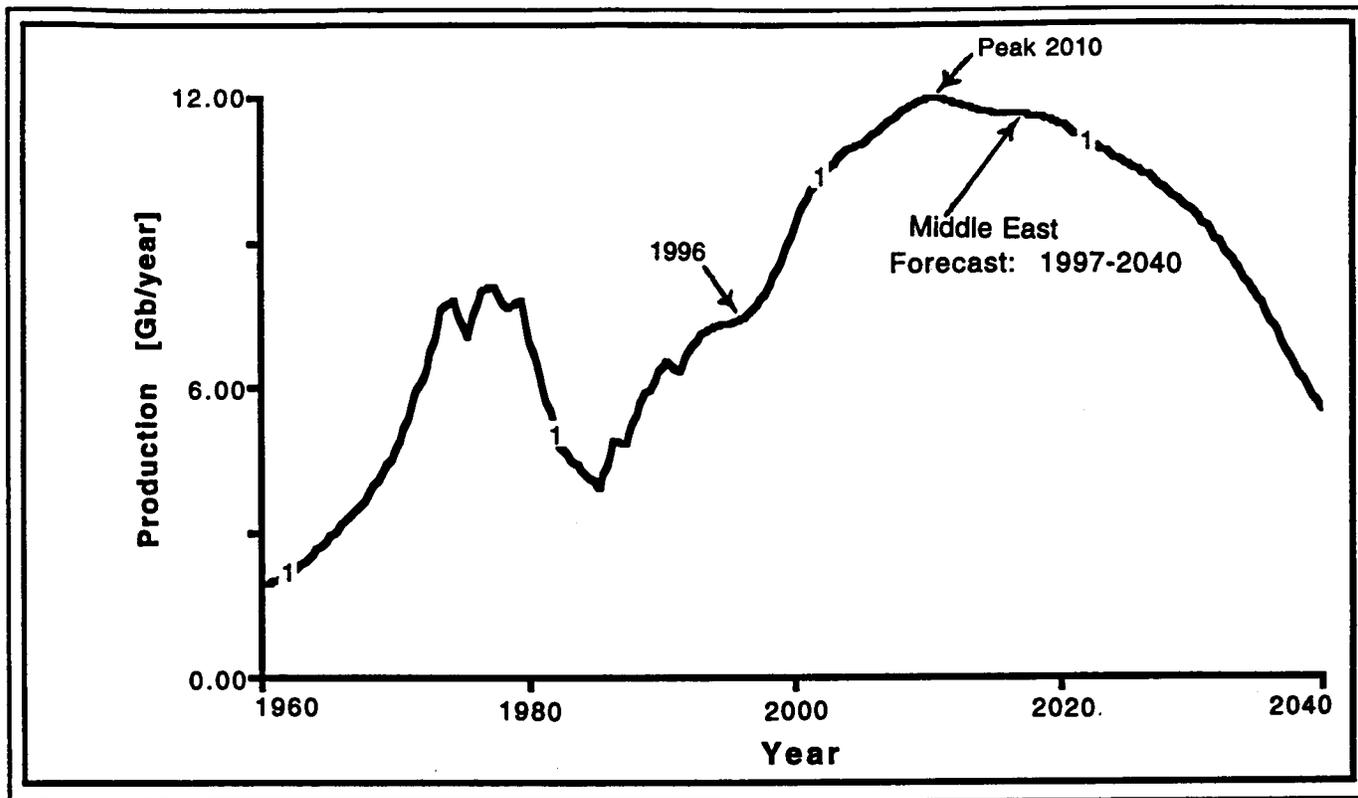


Figure 6. Middle East. This region holds the bulk of remaining world oil reserves. Because of political and religious considerations, and the production quota system which is met with intermittent and uneven success, production here is the most difficult of the seven regions to forecast. However, the practical political necessity for these governments to continue to finance their variety of social programs, combined with the rapidly growing population, suggest that production will continue to approach the classic bell-shaped production curve of a finite resource. Even allowing for some intermittent production distortions, such as the U. N. oil sale curtailment imposed on Iraq, the curve seems established long enough to be projected with some confidence to 2040. It is clear this region will be the last to reach peak production, in 2010. By 2007 the region will account for half the world's production, and will dominate world oil production thereafter. In the year 2020, when oil prices will be much higher relative to today's prices, this region will have the bulk of the world's oil yet to sell--a large international economic and political advantage.

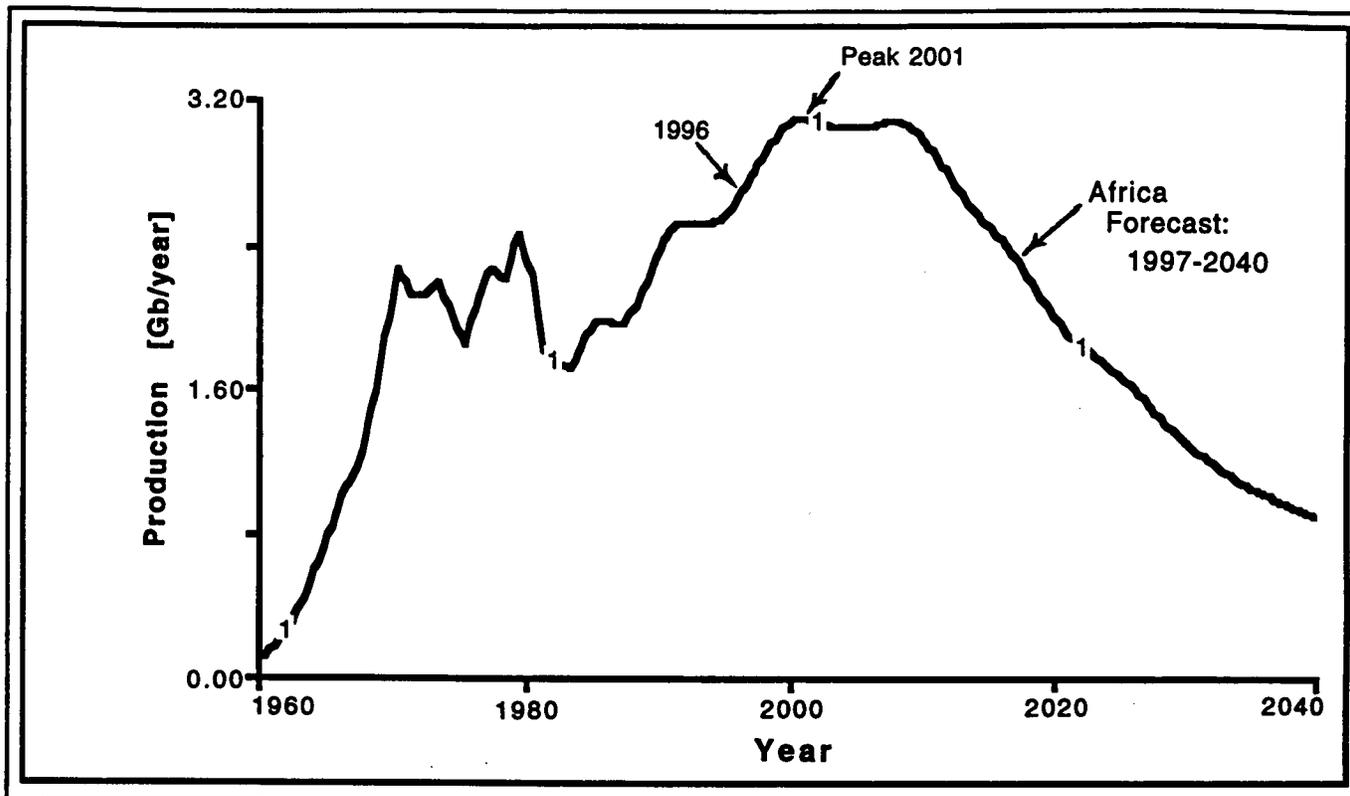


Figure 7. Africa. Production importance order in this region is Nigeria, Libya, Algeria, Egypt, and Angola. Other production is minor. This rank of importance is not likely to change, except that Angola could move up ahead of Egypt. Therefore, the production curve data controls already in place probably will not be significantly altered. With the peak year very near at 2001, the curve is already well established.

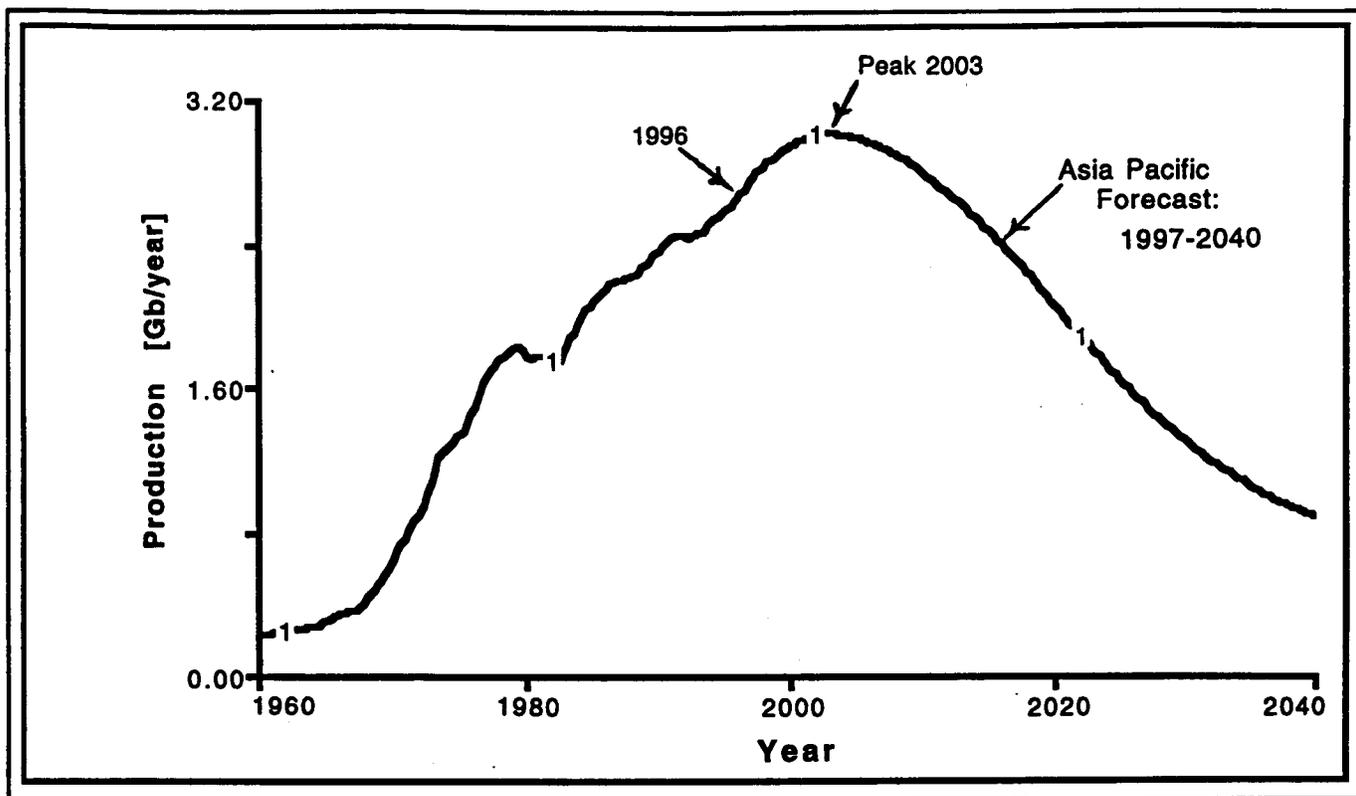
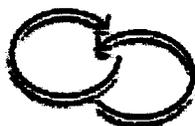


Figure 8. Asia Pacific. This includes Indonesia, Brunei, Australia, China, and also India as the principal oil producers. It produces about 11% of present world oil supplies. With 60% of the world's population, this region has been endowed with only 7.6% of the world's oil. As Asian nations become more motorized, as is their plan, their oil demands will add significant strain to the world's production capacity. China is seeking joint ventures with Caspian Sea region oil operations, and has already bought into some U. S. oil production in the Gulf of Mexico.

#	Region	Peak	Oil Production			Cumulative Production			Yet-to-	Yet-to-	Decline:
		Year	Peak	1996	2040	1996	2040	EUR	Produce	Produce	Pk-2040
			Gb/yr	Gb/yr	Gb/yr	Gb	Gb	Gb	Gb	%	%
I	North America	1984	5.6	5.2	0.9	245.4	375	382	136.9	35.8	85
II	So. & Cent. America	2005	2.6	2.2	1.1	72.1	167	177	104.9	59.3	57
III	Europe	2001	2.7	2.5	0.5	30.6	98	100	69.4	69.4	83
IV	Former Soviet Union	1987	4.6	2.6	1.7	130.7	244	264	133.3	50.5	64
V	Middle East	2010	12.0	7.5	5.4	210.0	654	754	543.5	72.1	55
VI	Africa	2001	3.1	2.7	0.9	65.6	160	166	100.0	60.4	72
VII	Asia Pacific	2003	3.0	2.7	0.9	55.9	148	154	97.9	63.7	71
Regions Total		2007	30.0	25.4	11.3	810.3	1846	1996	1186	59	62

Table 2. Summary of seven major world oil producing regions: Peak production year and volume. Production in 1996 and forecasted production in 2040. Cumulative production 1996, forecasted cumulative production 2040, and forecasted ultimate recovery (EUR). Amount yet-to-produce in Gb, and percent left from original oil endowment. Decline from peak production to 2040, in percent.



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MEMORANDUM

DATE: September 2, 1998

TO: Lee C. Gerhard, Director and State Geologist,
Kansas Geological Survey

FROM: James H. Williams, Director and State Geologist, DGLS

SUBJECT: Science and Public Policy

Hope we can have someone at the conference. What you have proposed is a most worthwhile intent. I have a few thoughts on this topic as well. These in part stem from my position on Missouri's Land Reclamation Commission with coal and industrial mineral permitting responsibilities. Also, with our environmental work for the last several decades we have seen these matters swell into torrents of emotional rhetoric. Currently, with reference to landfills, if the proposed site fails the hydrogeologic environmental protection needs site characterization investigation as defined in our statute and rules, it goes no further. That has markedly reduced the costs, displeasures, antagonisms and other adverse occurrences concerning landfills. Here, an early based science decision can make a big savings in time and money plus reduces the confrontation levels, markedly. Public policy made this possible.

With specific reference to resources and the public policy, all the science in the world (regardless of credibility) has no chance against a public who lacks even the basics of natural resource-geology knowledge. Until we can provide a semblance of that learning, especially in the school environment, we can count on a continuance of present difficulties. Knowledge means communication is possible. This knowledge is vital for those persons who become county commissioners, planning and zoning board members, city councils and mayors and others participating in local government decisions and policies.

Even when these folks have knowledge of science and resources, they are in an extremely difficult position. There has to be a balance of responsibilities between both state government and local government. For some decisions, citizens can make life so miserable for local government, no decision is possible. CAFO's are an excellent example. In order to stave off the militants, local authorities, and some counties created ordinances that would have halted work of the ordinary small farmer not realizing what they were doing. The anti's could care less. For these highly volatile and

at times physically dangerous situations, only state level decisions are feasible. At some hearings and related actions, we will have state highway patrol present. Also, there are some sites that need to be elevated to the federal government. What and at what level natural resource and competitive land use decisions are made are matters of public policy. I hope that is discussed. However, to do so in a meaningful manner means local government people need to be present as well as those at state levels.

Our industrial mineral site permitting decisions are at the state level and under the umbrella of the Missouri Land Reclamation Commission. They act through the staff support of the Division of Environmental Quality, one of the five divisions in Missouri's DNR. However, if county planning and zoning has created ordinances that prohibit an industrial mineral site, there is nothing we can do about that. I fear that will be the increasing trend. Citizens near a proposed mineral extraction site are seldom pleased with our decisions. Elected officials get into the act. Threats are made relative to our statutes. As long as it is in some one else's back yard, or constituency, then by all means permit the site and reduce downstream product costs. If in my backyard, not only no, but hell no. The ultimate costs to others or loss of the resources is of no matter. Regardless of how well the operation of the quarry or other natural resource activity is conducted, there are generally hard feelings. Some operators have the compassion and knowledge to solve that, most do not or cannot due to the work demands, their operation costs and so on. Here also lies some public policy considerations, specifically compensation for adjoining property owners and other matters besides just pollution prevention.

For state surveys, the illustration you gave concerning sand and gravel resources on the Kansas River is of paramount significance. We as state surveys must maintain credibility in our work relative to providing science based knowledge. However, unless we do that with a continuous means of communication with those persons in the area under study, then our work becomes a surprise at the end. If that happens, it will not be well received. Team building is an important theme to emphasize in any permitting process. Only by the applicant, public, scientist, and regulator joining to address all issues and concerns from a team perspective, can the process be successful. Making sure we can operate so that state surveys can provide such information and in close concert with those affected is definitely public policy. Only our statutes can assure at least some degree of protection from external public and political pressures. I hope that can be discussed.

c: Mimi Garstang
Ira Satterfield
Ardel Rueff

A chapter in "Geology's Gaze: Looking Toward a Livable Future", J.S. Schneiderman, editor. W.H. Freeman Co. Early 1999(?)

STAKES, OPTIONS, AND SOME NATURAL LIMITS TO A SUSTAINABLE WORLD

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INTRODUCTION: A COMMON CHALLENGE

Let me set the stage for this essay with a metaphor. Suppose I am guardian for someone who may soon need long term nursing care that is beyond my means to pay. As a prudent person, should I count on a medical miracle or on winning in a lottery? Would I not want to forego that luxury car and instead buy a long term care insurance policy?

The Earth as a habitat too needs a long term care policy, a safety net; and we humans, so sure of our sagacity that we call ourselves *Homo sapiens*, are its only capable guardians.

Concern about the future of the Earth as a place for civil habitation, of course, has a long history. For example, Garrett Hardin (1968), in his seminal essay "The tragedy of the commons", suggested that a community threatened by over-crowding and diminishing resources might yet salvage sustainably civil social arrangements by adopting a code of rewards and penalties so designed that self-interest propels communal responsibility; he called this "mutual coercion mutually agreed upon." A tragedy would result, however, if, absent such a code of ethics, short-sighted self-interest is free to trample on the common good. During the thirty years since Hardin's paper, world population

has nearly doubled, consumerism is on the rise globally and is being applauded by politicians and economists as a sign of an improved world, and the tragedy depicted by Hardin seems to be racing, unstoppable, toward its fatal conclusion.

In addition to the desire to leave a civilized society for our descendants, another cause for concern is a recognition that those who benefit from living in rich and powerful nations and societies should do their share to ensure social justice on a global scale. This means that the future we envision should include amelioration of the exploitation of the environment and resources of the poor societies by the rich.

Considerations such as these have led to the notion of "sustainable development", an idea widely circulated through the book, Our Common Future (World Commission on Environment and Development, 1987), and defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition is at once canny and cunning, but what do the words mean? How do we translate good intentions into action that may be politically unpopular (Ashby, 1993)? How do we arrive at international and intercultural compacts that can effectively implement Hardin's "mutual coercion" that is at the heart of a sustainable world?

Presumably to try to get away from semantic quagmires and conflicts of perspective, some scholars have shifted their focus onto "sustainability transition" which, according to the National Research Council's Board on Sustainable Development (Robert W.

Kates, 1997, written communication), is "to encourage a successful transition in the early decades of the next century in which people meet their wants and needs in sustainable ways that move away from ones that degrade the planet's life support systems toward ones that sustain or restore them, and that move away from widening disparities in human welfare towards ones that reduce or eliminate hunger or poverty."

This description is much more specific than the definition of "sustainable development" and displays a commendable purpose. However, translation of these good intentions to effective global action is likely no less challenging than to attain a sustainable world itself.

To begin this process of transition, the developed and developing nations must establish a shared view both of what constitutes fair and equitable distribution of resources, including the environment, and of what can be done to bring about that end. Although it is by no means clear that all nations will agree on the criteria for a fair and just human society (see Huntington, 1996), a point central to global sustainability, yet when seen as in their self interest to pitch in - that essential ingredient to successful mutual coercion - national leaders have on occasions at least shown verbal statesmanship. Examples are the Law of the Sea Regime for that global commons, the Montreal Protocol on CFC for stratospheric ozone depletion, the Rio Treaty on the global environment, and the Kyoto compact to reduce carbon dioxide emission. These agreements do not add up to a program

for sustainability, but they are notable first steps.

WHAT DO WE WANT TO SUSTAIN, AND WHAT'S AT STAKE

The term "sustainable" must mean a state in which first-order factors such as population size, resource stock, food supply, and environmental quality are in balance, for a period that is long compared to what it would take to get us there, for otherwise that state would be just a blip on the growth curve not worth worrying about.

A viable state of sustainability must be global. Thus, it must be established in a materially closed system, through re-ordering of priorities and habit change, aided by human ingenuity. What conditions are necessary for it to work, and what may be our safety nets if it should fail? What constraints might be imposed by nature and by our concept of our relation to nature? What can earth science do to help inform us about the prospects and limits of such a social transformation? And, very important, what role would political and cultural factors that embody the communities' value systems play in our striving for sustainability? Might these factors form a landmine of social strife and resistance, triggered by fear of scarcity and of change, even before the actual depletion of natural resources?

We need to be explicit about what we seek to sustain. I hold that we must not sustain the current rates of resource consumption and waste production, and we must not sustain the current rate of population growth and the disparity in wealth among nations. I further hold that we cannot seek sustainable

development, which is arguably an oxymoron (Lachenbruch, 1997; hereafter I will speak of a sustainable world, society, or future). Instead, we should examine the lifestyle of the vast economical middle-class of the world, which might provide clues on productive approaches to global sustainability (Durning, 1992; Conca, 1998, written communication).

We need to know what is possible as well. Some major questions we might ask are: (1) are there configurations of society that are unacceptable to all civilizations and must be excluded from the roster of potential goals? (2) what would be the burden imposed on the Earth and its resources, including the biosphere and the Earth's physical environment, if the goals of a global society were pegged to the level of material subsistence that the developed world deems desirable, as evidenced by our lifestyles and by the exhortations of our entrepreneurs and economic and political leaders? Finally, (3), what are the options that must be treasured and preserved by a society that promotes decent life for its inhabitants, and what are the material bases essential for assuring that these options will be available at a future time and will survive the process of sustainability transition?

The scale and complexity of the global future defies accurate prediction, and well-intentioned efforts to forestall potential problems could backfire because the world isn't simple or adequately understood, and because nature's processes are commonly nonlinear. Forecasts of global warming have often been

challenged (e.g. Mahlman, 1997; Singer, 1997); past forecasts that the world will run out of earth-based resources or food have been confronted by the bountiful and continued supply of fossil fuel and metals at least in the more affluent societies, and by successes in plant breeding that have provided rich harvests of rice, wheat and corn.

Despite these numerous past successes that are seen by some as giving the lie to Cassandra's dire predictions (for example, Simon, 1995, Introduction and Conclusion), it seems nevertheless overwhelmingly likely that the combination of population growth and consumerism cannot go on forever (Cohen, 1998, commented on some of the fallacies in such optimism). This is so despite the claim by some, including scientists, that science will fix problems in resource and environment through ingenuity: the problems go beyond technical knowledge and fixes; they place demands on the Earth that push the limits posed by laws of thermodynamics. Further, even though human ingenuity and the elasticity in the natural system have allowed the through-put of the global economy to increase up to now, the Earth is a closed system except for the input of solar energy. Sooner or later, it will run out of room for growth (see Daly and Cobb, 1994; Youngquist, 1997). Reliance on future inventiveness is the metaphorical equivalent of a timely medical miracle.

We do not know when that moment of saturation will arrive: it may be already here, only waiting to be recognized. Perhaps the oil embargo of the early 1970's, or the Gulf War, triggered by the oil-consuming nations' perceived need to protect their

supply, or the collapse of the world's fisheries, are harbingers of the day of reckoning. Yet few national leaders seem to face these threats to the habitability of the Earth with much sense of urgency: which U.S. leader can expect to be re-elected if he/she advocates a no-growth national economy? Yet, if we seriously care about the well-being of our descendants, then we must not assume that human ingenuity will provide the panacea. The affluent societies will have to change their lifestyles, and all of us will have to work together to effect drastic reductions in global procreational fecundity.

Some simple calculations will illustrate what is at stake here. Using data compiled by the World Resources Institute (1992, 1996), I employ seven "tracers" to measure material consumption and pollution, as proxies to material load on the Earth by the world's five most populous nations (as of 1995, China, India, U.S.A., Indonesia, and Brazil; see Table 1). The tracers include three earth-based metals (crude steel, copper, and aluminum), industrial use of electric energy, and three greenhouse gasses, CO₂, methane, and CFC (Table 2; for practical reasons, I am excluding water vapour here).
{Tables 1 and 2 near here}

Imperfect though the tracers are as proxies to consumption and waste generation, they do highlight the fact that the United States leads numerically in every category. On a per capita basis (Table 3), our preeminence here is even more striking - our per capita consumption and waste generation is 10 to 15 times

those of the other four nations. Put in another way, in terms of consumption and waste generation, every child born and brought up in the United States will, at the 1995 level, have an impact equivalent of 10 to 15 children in the other nations. If we deplore societies that have 10 children per family, how then can we accept with equanimity two-children families here with their projected life-time consumption?

{Table 3 near here}

Most of us probably share a feeling that people of the less developed nations deserve better quality of life. Decency and equity demand that we help them to improve their lot. Better life, to many, especially those who hitherto have done without, means more creature comfort, material accretion, and improved social services; for better or for worse, this will mean more demand on resources, and more generation of pollutants.

Suppose the per capita standard of living for China, India, Indonesia and Brazil, as measured by the tracers, is raised to some fraction, m , of the U.S. value. Their national consumption relative to that of the U.S. can then be expressed by a factor f :

$$f = m \times (\text{national population size}) / (\text{U.S. population size})$$

Table 4 gives the results for $m = 0.25$, i.e., if the per capita standard of living for the four nations rises to one quarter of the U.S. level for the same time period. The *net load increase*, i.e., the total increased consumption of a commodity minus the pre-improvement value, would be between 1.5 and 2 times the load produced by the United States (Table 4, Column "D").

Because the four nations plus the U.S. account for about one half of the total world population for 1995 (Table 1), one might infer that a global improvement of per capita standard of living by the same fraction would lead to a net load increase 2-3 times the current value. Table 4 also gives (right hand column) the ratios of the total projected load increase between the two reference dates, 1996/7 and 1992/3; these figures show that on the whole the prospect has not improved over the time period.

{Table 4 near here}

If the U.S. share of the load were reduced, doubtless too optimistically, to half of the current values, the total load for the five nations would roughly double; for the world as a whole that might mean a tripled total load. These estimates do not include growth in the world population, which is projected to continue for many decades (Cohen, 1995).

Human beings are estimated (Vitousek and others, 1986) to consume now between one-quarter and one-third of the net primary production (NPP), i.e., the amount of energy captured by plants through photosynthesis less the energy consumed for their own growth. Increased human consumption would leave little NPP for that part of the ecosystem not directly feeding into the chain of human consumption. Rough though the figures are, they raise grave concerns for a sustainable future.

In a study of the ecological footprints of the average U.S. citizen, Palmer (1998) showed that, per capita, we need about twice as much land to support our lifestyle as is our share of

the global commons, even if we ignore the needs of the rest of the ecosystem. Palmer's study uses a different approach and different database than my own estimates, nevertheless his conclusions convey the same message.

Despite our imperfect understanding of all the interactions that affect sustainability, we can be reasonably sure that the following conditions are necessary for its realization: (1) the world population be stabilized; (2) the per capita consumption of materials and generation of pollutants be drastically reduced; and (3) the disparity between the developed nations, symbolized by the United States, and the developing nations be reduced.

A tall order, perhaps unattainable, but the consequence of taking no precautionary measures and relying on the hope that things will somehow work out, would be the equivalent of hoping to win in lottery to pay the medical bill. We in the United States have decided that we should not bequeath to future generations the unsequestered radioactive waste; should we not accept as much social responsibility for the protection of the future habitability of the Earth? Both are insurance policies, hedges against a situation that must not be allowed to happen if the human society is to have a viable future.

RELEVANCE OF THE GEOLOGICAL RECORD

The Earth is not a static place; the geological record shows that the physical and ecological environments of the Earth have always been changing (e.g. Pielou, 1992; Dickinson, 1995; Singer, 1997, p. 5). Some changes are slow on a human time-scale;

others, not necessarily minor, are rapid. The slow rates inferred from the geological record may in part result from the fact that our chronological mileposts are commonly far apart, so the average rates thus deduced may poorly reflect reality.

Changes, both natural and anthropogenic, that may affect the future of the Earth as a habitat include increases in greenhouse gasses, climate change, sealevel changes, and ecosystem changes including large-scale migration or extinction of fauna and flora. Such geological changes are indeed ever-present and inevitable; they provide the needed context to view the future. A runaway growth in human population at the expense of the rest of the ecosystem might be just another geologically insignificant natural event. This, however, does not address a purely human-centered concern: are we destroying our own future by our profligate ways? Can humans adapt to changing natural environment fast enough to ensure a viable future for our children? In the geological past, fertile land may have been reduced to desert, sealevel rise may have inundated lowland areas, and the air temperature may have risen to a point destructive of animal and plant life. Nobody was there to protect the threatened life species; they died out, evolved, or were forced to adapt to different ways of living. As members of the "civilized" human society, however, we seek to control and manage our land and its utility to us. We want to maintain the Earth as a stable living space consistent with our idea of a "comfort zone", modifying the Earth to suit our desires rather than adapting ourselves to it - witness the channelization of the

Mississippi River on its delta, or the efforts to "shore up" the beaches on the mid-Atlantic seaboard so that vacation houses may be rebuilt on shifting sand.

This is a different proposition than acknowledging that the geological record tells us that changes are to be expected. Moreover, aside from the fact that we deem natural changes beyond certain limits unacceptable, we also do not know how large-scale human-induced changes would interact with natural processes, and on what kind of time scale. Broecker (1996, 1997), for example, discussed how anthropogenic carbon dioxide could cause major mode shifts in ocean circulation that would drastically affect the productivity of the agricultural land in the circum-Atlantic region. The record of the Holocene Period shows that such mode changes happened numerous times and that the rate of change could be fast even by human standards (years to decades; see Broecker, 1997, and Bond and others, 1997, for data and primary sources). Even if we ignore the rest of our ecosystem and focus only on the well being of *Homo sapiens*, we would be irresponsible if we do not address how changes in natural conditions, whatever their causes, could affect the future viability of the world.

OPTIONS AS NONRENEWABLE RESOURCES

I take it for granted that we want to leave for our descendants a sustainable opportunity to lead decent, civil lives. Such lives surely must include the possibility to make real choices among alternative ways of living. Thus, a prime objective for a sustainable world must be to preserve and if

possible to enhance future options. Options are resources some of which are nonrenewable but are being rapidly depleted by human activities (Zen, 1993). Options change with human perception of the possible and with the availability of goods and services; they are both material and intangible and are anchored to both material and cultural foundations.

What options are essential to assure that a future society will provide a decent life for all, while treading gently on the ecosystem? Every choice has its consequences. For example, if we choose to use up our petroleum resources, then future societies would have to do without this source of energy and important petrochemicals, including plastic and medicine. If we do not take steps to protect the soil of the arable lands, we would be hurting people's dietary habits and health. Converting nonrenewable resources in the ground into capital, lauded as "value added" in conventional economics, would reduce options. Our land-use plans, especially for sensitive niches such as tropical forests, wetlands, riparian systems, and ocean islands, should opt for conditions favourable to ecological diversity. We should consider *how* to sequence our land use so as to maximize options (Zen, 1983), and *whether* to set aside certain earth resources so that future societies may deal with civilization's emergencies. We should bequeath to our descendants both the opportunity and the wherewithal to review *their* future options in a meaningful way, and this bequest must include a margin of safety for surprises and miscalculations. Lastly, respect for human dignity, that *sine qua non* for our self-designation as *Homo*

sapiens, is also a social option, and a fragile one at that. The sidewalks of Calcutta, the shantytowns of Rio, and the slums of our own inner cities, not to mention the recent global record of governance by mass terror, are testaments to that fragility. If we want to preserve future options to choose forms of social organization that respect human dignity and human rights, then we must preserve the material base for it.

What material goods are required to underpin a given option? What is the relative importance of using the available goods now versus preserving them for future exercise of options? How should we allocate alternative ways to use a given resource, both geopolitically and in terms of the nature of the commodity? These issues need to be addressed, and the sooner the better.

GETTING THERE FROM HERE

Let me change my metaphor. Instead of looking over a long-term care insurance policy, we are now a group of Lilliputians traveling down a rapids-filled river in a bulky and unwieldy raft. Our diminutive size relative to the river prevents us from an overview of the channels in the river. Although we know that different passages lead to different strands, some of which provide quieter water and safety from disastrous overturning, we are unsure of the locations of these desirable strands, or the passages leading to them. Indeed, we have not yet fully defined the configuration of the desired quiet strand. So not only must we make decisions on the run, not only must we make decisions soon because delays will cause the loss of some passages and quiet strands, but we have to be able to steer the unwieldy raft

into the passage and the quiet water without major mishap. How, then, should we proceed?

It seems prudent that we have some clear idea of what kinds of sustainable society, i.e., which quiet water strands, are acceptable, and that we should study the nature of the river currents so as to steer the raft safely. Even though we do not want to preempt the ability of our descendants to make their own choices, including their preferred form of social organization, we must recognize that our decisions and actions, or lack thereof, will affect their choices, and so we need to make allowance in our own choices for that fact. We must also allow for our miscalculations.

A conceivable sustainable society is one in which the majority of people live in hovels, barely surviving at the subsistence level: would that be an acceptable goal? Would a habitat that is fully polluted and teeming with sick people be acceptable? Should we tolerate arrangements in which terror and intimidation are the normal way to rule and be ruled? Should we insist that all nation-societies enjoy equitable and equal access to human amenities, or should we accept social and economical disparities across and within national boundaries, as they exist now? How important is it for us to insist that the sustainable society includes respect for human dignity and human rights?

Assuming that we can answer these questions and can choose our goal, we next need to consider how to preserve the options that accompany this choice. The list of options must be

complemented and supported by a full appreciation of the required underpinning of material bases.

CHOICES WE NEED TO MAKE

It seems reasonable to suppose that we base our planning on a realistic size of the future world population - for instance, 12 billion a century from now. We need to anticipate how the population will be distributed, economically and geographically. I believe we already have a reasonable grip on the available nonrenewable earth resources at least to an order of magnitude (see, e.g., Barton, this volume; Craig, Vaughan and Skinner, 1988; Youngquist, 1997). I think we also have a pretty good idea of the pattern whereby these nonrenewable resources tend to diminish, and some idea of the difficulties in extracting the inaccessible remainders.

Suppose we make the most parsimonious projection as a start, and assume that civil society can be sustained, on the average, with little or no amenity - say 2000 kilocalories of daily per capita food intake (in terms of food derived mainly from Net Primary Production, about 1-1/4 lbs of rice or wheat and nothing else; see Cohen, 1995, especially Appendix 5), hovels for shelter, polluted air and water, and no ecosystem save what is absolutely essential for human survival at this crude level. What would be the demands of this projection on material resource and the environment? This level of survival is perhaps unacceptable for most of us living in the developed world, but it is close to or better than the daily reality for some of our

fellow dwellers on this globe. Sad to say, but even this rock-bottom state of subsistence would be unsustainable if population growth continues unabated.

Paddock and Paddock (1967) asked how an affluent society should respond when it encounters dire poverty in societies where basic human needs such as food are in short supply and require donation from outside. They suggested a triage approach, with the donor societies deciding the assignments of recipients to different aid categories. Despite Simon's (1995, p. 22) offhand dismissal, this deeply troubling issue of balancing national interest, capability, and needs with fairness and justice remains unresolved, and could seriously impede an equitable and peaceful sustainability transition.

The planners - social scientists, philosophers, economists, lawyers, natural scientists (especially ecologists and geologists), political leaders, along with the media, will need to get together and consider how to establish a process by which mutual coercion can be defined and accepted. The discussion must include not only natural resources and environment, but also the social and cultural adjustments that accompany the transition. The planet is small not just in ecological terms, but also in human terms (Sachs, 1998); the connectivity of human and natural constraints should play a major role in our planning for a sustainable future.

The scope of planning may be global, or it may be a mosaic of regional compacts; it could even be based on "civilizations"

(Huntington, 1996). However it is done, the resolution will no doubt be dictated in part by the realities of today's national powers and resource distribution and in part by demographical projections; but, I hope, also in part by a robust sense of social and environmental justice and idealism. Every one of the conceivable improvements would require added material resources, some of which may be impossible for certain demographic projections. Decisions on these choices will lead us to different strands of quiet water, and they are ineluctably governed by the availability of earth resources.

These earth resources are often grouped as "renewable" and "nonrenewable", depending on whether their time-scales for replenishment are human or geologic. Examples of the former are clean water and air, timber, soil, fishstock; examples of the latter are fossil fuels, ores of metals, hydroelectric dam sites. For any sustainable future, we demand that either the time-scales of replenishment be short, or we keep to a very low rate of consumption. However, if the rate of replenishment is long compared to the rate of consumption, then even "renewable" resources become effectively nonrenewable.

Clean water and air, fertile soil, healthy and multicultural stands of timber, robust and sustainable fisheries - these are surely essential for a healthy society; yet all are now under siege because short-term gains have taken precedence over long-term conservation. A high-priority item in planning for a successful sustainability transition, then, must be to point out how to use the renewable resources so that they stay renewable.

Nonrenewable resources, by definition, cannot be extracted in any sustainable way within the lifespan of human institutions. How to provide future generations with such resources, then, depends on the time-scale we want to consider. It seems that a minimum duration worthy of our effort should be 8 to 10 human generations - say two centuries. Some of our nonrenewable resources may be effectively exhausted by then, in the sense that the remaining material can be put into usable form only by processes that are energetically not profitable (i.e. "energy return on investment" or "energy profit ratio" less than one; Cleveland and others, 1984; Youngquist, 1997). To achieve a sustainable future, we must circumvent this major barrier.

Recycling and substitution, using material and methods that perhaps we have not even thought of, may alleviate this upcoming shortfall. For example, the use of aluminum and titanium as manufacturing materials, and the use of nuclear reactions to generate electric energy, were inconceivable options merely a century ago. However, the efficacy of recycling is ultimately limited by the Second Law of Thermodynamics; every instance of recycling loses some material and requires more energy input, so sooner or later the process too will run into the brick wall of "energy return on investment." Likewise, reliance on the conjectured future emergence of new options, such as new forms of substitution, is based on faith; even if it should ultimately prove true, such reliance is akin to counting on a medical miracle for a sick person.

EPILOGUE: WORKING FOR OUR COMMON FUTURE

As our Lilliputian travelers brave the rapids, they do have some notion that there may be more than one strand of safe water, and that though no strand has all the desirable attributes, some strands are better than others. Choices must be made: one strand may be "equitable, egalitarian, limited affluence for all", one may be "a world with creature comfort but without human dignity; reign by terror"; yet another may be "subsistence for most, opulence for a few." The rafters know that every strand is accessible from one or more of the anastomosing channels of the river, even if they are not sure which passage is connected to which strand. They also know that the manner of approach to any strand could determine the outcome.

As responsible citizens, should we not urgently discuss where we want to go, and agree on the groundrules for decision making? Can sustainable societies and sustainability transition be implemented in the face of social inertia and ignorance, and in the face of geological and biological realities? The four apocalyptic horses and riders of sustainability are not conquest, slaughter, famine, and death; they are crowding, loss of options, marginal subsistence, and loss of human dignity. The horses and riders are reared and fed on unbridled population growth, resource depletion, habitat fouling, and social inertia and selfish intransigence. These factors interact in ways we do not yet fully understand; yet the task of sustainability transition hinges on knowing how to quantitatively counter their effects.

Happily, some leaders now recognize the need to act while there is still time (e.g., Gore, 1992). The international agreements of recent years to conserve the Earth's habitat, even if only partially effective, do signal us to pause and think. These are hopeful signs that Hardin's vision for a social ethic, his "mutual coercion mutually agreed upon", might yet be put into practice. But the grandest of all pacts of mutual coercion, that of coordinated, civilized, and effective planning on population, is not yet within sight. Social custom, religious scruples, value system, and other factors have so far collectively prevented the world from dealing sensibly and effectively with this leading and fateful horseman.

Even blind inaction and indecision on our part will affect available choices for our descendants. Prudence and good stewardship for the living world dictates that we start to chart our future soon, and in rather specific terms. We may or may not yet have the knowledge or wisdom to make all the right choices, but do we at least have the sense of purpose to begin?

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Table 1. World population, in millions

	1990	Percentage of world total	1995	Percentage of world total
U.S.A.	249.2	4.7	263.3	4.6
China	1139.1	21.5	1221.5	21.4
India	853.1	16.1	935.7	16.4
Indonesia	184.3	3.5	197.6	3.5
Brazil	150.4	2.8	161.8	2.8
Total	2576.1	48.7	2779.9	48.6
World total	5292.2		5716.4	

Sources: World Resources Institute, 1992, Table 16-1; 1996, Table 8-1.

Table 2

Total Resource Consumption and Waste Generation of Key Materials

	U.S.A.	China	India	Indonesia	Brazil	Sum, CIIB [#]
Commercial energy	81.75	29.68	9.34	2.66	3.80	45.48
Giga-Gj	<i>73.37</i>	<i>26.16</i>	<i>7.53</i>	<i>1.45</i>	<i>3.45</i>	<i>38.59</i>
Aluminum	5.41	1.32	0.48	n.d.	n.d.	1.80*
Mt	<i>4.35</i>	<i>0.65</i>	<i>0.42</i>	<i>n.d.</i>	<i>n.d.</i>	<i>1.07*</i>
Copper	2.67	0.75	n.d.	n.d.	n.d.	0.75*
Mt	<i>2.14</i>	<i>0.51</i>	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>	<i>0.51*</i>
Crude	93.33	71.04	20.30	n.d.	n.d.	91.34*
Steel, Mt	<i>102.35</i>	<i>69.50</i>	<i>20.04</i>	<i>n.d.</i>	<i>n.d.</i>	<i>89.54*</i>
Industrial CO ₂ , Gt	4.88	2.67	0.77	0.19	0.22	3.85
	<i>4.87</i>	<i>2.39</i>	<i>0.65</i>	<i>0.14</i>	<i>0.21</i>	<i>3.39</i>
Anthrop. CH ₄ , Mt	27.0	47.0	33.0	10.0	9.9	99.9
	<i>37.0</i>	<i>40.0</i>	<i>36.0</i>	<i>6.5</i>	<i>8.8</i>	<i>91.3</i>
CFC	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Kt	<i>130</i>	<i>12</i>	<i>4</i>	<i>1</i>	<i>6</i>	<i>23</i>

Sources: World Resource Institute, 1992, Tables 21 and 24; 1996, Tables 12 and 14.

Upper entries, 1995. Lower entries (in *italics*), 1990. See World Resources Institute, 1992, 1996 for slight variations in the year of data entry.

CIIB, sum of figures for China, India, Indonesia, and Brazil

* Sum for only those nations having data, as shown.

Table 3

Per Capita Consumption and Waste Generation of Key Materials

	U.S.A.	China	India	Indonesia	Brazil
Commercial energy, Gj	310 <i>294</i>	24 <i>23</i>	10 <i>8.8</i>	13.5 <i>7.9</i>	23.5 <i>22.9</i>
Aluminum Kg	20.5 <i>17.5</i>	1.1 <i>0.57</i>	0.51 <i>0.49</i>	n.d. <i>n.d.</i>	n.d. <i>n.d.</i>
Copper Kg	10.1 <i>8.6</i>	0.61 <i>0.45</i>	n.d. <i>n.d.</i>	n.d. <i>n.d.</i>	n.d. <i>n.d.</i>
Crude Steel, Kg	355 <i>411</i>	58.2 <i>61.0</i>	21.7 <i>23.5</i>	n.d. <i>n.d.</i>	n.d. <i>n.d.</i>
Industrial CO ₂ , t	18.5 <i>19.5</i>	2.2 <i>2.1</i>	0.82 <i>0.76</i>	0.96 <i>0.76</i>	1.36 <i>1.40</i>
Anthrop. CH ₄ , Kg	102.5 <i>148.5</i>	38.5 <i>35.1</i>	35.3 <i>42.2</i>	50.6 <i>35.3</i>	61.2 <i>58.5</i>
CFC Kg	n.d. <i>0.522</i>	n.d. <i>0.011</i>	n.d. <i>0.005</i>	n.d. <i>0.005</i>	n.d. <i>0.040</i>

Sources: see Tables 1 and 2.

Table 4

Projected Total Resource Consumption and Waste Generation
for China (C), India (I), Indonesia (D) and Brazil (B)

Formula: $f = (\text{Population of nation}) / (4 \times \text{population of U.S.A.})$

	U.S.A.	China	India	Indonesia	Brazil	CIDB Sum, Projected (D)	Sum Less Actual	D ₁₉₉₅ ----- D ₁₉₉₀ #
<i>f</i> for 1995		1.160	0.888	0.188	0.154			
<i>f</i> for 1990		1.143	0.856	0.185	0.151			
<hr/>								
Commercial energy Giga-Gj	81.75 73.37	94.8 83.8	72.6 62.8	15.3 13.6	12.6 11.1	195.3 171.3	149.8 132.7	1.14
Aluminum Mt	5.41 4.35	6.28 4.97	4.81 3.72	1.02 0.80	0.83 0.66	12.94 10.15	11.14 9.08	1.27
Copper Mt	2.67 2.14	3.10 2.45	2.38 1.83	0.50 0.40	0.41 0.32	6.39 5.00	5.64 4.49	1.28
Crude Steel, Mt	93.33 102.35	108.24 116.95	82.92 87.59	17.51 18.92	14.34 15.44	223.01 238.90	131.67 149.36	0.93
Industrial CO ₂ , Gt	4.88 4.87	5.66 5.57	4.34 4.17	0.91 0.90	0.75 0.74	11.66 11.38	7.81 7.99	0.98
Anthrop. CH ₄ , Mt	27.0 37.0	31.4 42.3	24.0 31.7	5.07 6.8	4.15 5.6	64.52 86.40	-35.38 - 4.90	7.22*
CFC Kt	n.d. 130	n.d. 149	n.d. 111	n.d. 24	n.d. 20	n.d. 304	n.d. 281	n.d.

* This ratio represents a larger decrease. The negative values for both reference dates represent improvements.

This ratio does not depend on *m* as long as the same value of *m* is used.

Sources: See Tables 1 and 2.