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U.S. ECONOMIC GROWTH FROM 1976 TO 1986: PROSPECTS, PROBLEMS, AND PATTERNS

Volume 4—Resources and Energy

STUDIES

PREPARED FOR THE USE OF THE

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JOINT ECONOMIC COMMITTEE

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LETTERS OF TRANSMITTAL

NOVEMBER 12, 1976.

To the Members of the Joint Economic Committee:

Transmitted herewith is the fourth volume of the Joint Economic Committee study series entitled "U.S. Economic Growth From 1976 to 1986: Prospects, Problems, and Patterns." This series of over 40 studies forms an important part of the Joint Economic Committee's 30th anniversary study series, which was undertaken to provide insight to the Members of Congress and to the public at large on the important subject of full employment and economic growth. The Employment Act of 1946, which established the Joint Economic Committee, requires that the Committee make reports and recommendations to the Congress on the subject of maximizing employment, production and purchasing power.

This volume comprises five studies on the relationship of resources and energy to future economic growth. Four of the papers focus on the issues of resource and energy scarcity and also substitution. The other is on the Federal Government's role in the resource and energy sectors of our economy. These studies have been done by Dr. John McHale, Dr. Preston Cloud, Prof. William Vogely, Profs. Lee Schipper and Thomas Long, and Prof. Allen Kneese. The Committee is indebted to these authors for their fine contributions which we hope will serve to stimulate interest and discussion among economists, policymakers and the general public, and thereby to improvement in public policy formulation.

The views expressed are those of the authors and do not necessarily represent the views of the Committee Members or Committee staff.

Sincerely,

HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee.

NOVEMBER 8, 1976.

Hon. HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee,
U.S. Congress, Washington, D.C.

DEAR MR. CHAIRMAN: Transmitted herewith are five studies entitled "Resource Availability and Growth" by Dr. John McHale, "Mineral Raw Materials and the National Welfare" by Dr. Preston Cloud, "Resource Substitution" by Prof. William Vogley, "Resources and Energy Substitution" by Profs. Thomas Long and Lee Schipper, and "Natural Resources Policy, 1976–86" by Prof. Allen Kneese. These five studies comprise volume 4 of the Joint Economic Committee's study series "U.S. Economic Growth From 1976 to 1986: Prospects, Problems, and Patterns." This series forms a substantial part of the Joint Economic Committee's 30th anniversary study series.

Taken together, these five papers present an excellent synopsis of current thinking on the questions of resource and energy scarcity and substitution possibilities. What is made quite clear is that there is still a wide divergence of opinion on these issues and how economic growth will be affected by the availability of resources and energy in the future.

Professor McHale concludes that in overall terms, there are no foreseeable absolute scarcities which might constrain economic growth in the next 10 years. Though the U.S. industrial materials outlook is good, the main problems are likely to come from economic availability rather than physical shortage. Various factors discussed in the papers suggest that as higher living standards are met for more people, material demands peak out below maximal satiation, and satisfaction is sought through less material means. The paper emphasizes that many of these changes towards alternative growth patterns cannot be taken care of by conventional market forces but will require a restructuring of incentives and regulatory practices to reward the kinds of new public and private initiatives which will be required.

After examining the various types of resources, Dr. Cloud concludes that only a few geochemically abundant substances are both so far from the energy barrier and so widely distributed that there is little danger that they will cease to be available. For many others, however, recurrent shortages and for some economic depletion can be predicted within the first half of the 21st century. Based on this, he argues that we need to generate a less materials-consuming set of demands while striving to satisfy genuine needs. He gives 10 suggestions for minimizing or avoiding shortages of mineral supplies. He stresses that the only kind of growth that is both beneficial and capable of being sustained by national and world resources is growth in enhancement of the human condition. Two suggestions are offered for attaining this: (1) Establish a program of sabbatical, educational and advanced training leaves for all members of the working force and (2) establish an array of new urban grant universities.

Professor Vogely's analysis led to three basic conclusions. The first is that within the time frame of 1975 to 1985, and with only slightly diminished certainty within the time frame 1975 to 2025, the physical characteristics of materials availability will not cause any increase in the real cost of materials to the world economy. Thus, physical constraints on production of materials are not a threat to continued economic growth. The second conclusion is that the process of material substitution is extremely complex, and the traditional economic theorem that it is a function of relative prices is inappropriate to understand the process. Finally, there are serious emerging institutional problems surrounding the production and use of materials and these issues should be subject to intensive research and evaluation to develop proper governmental policies.

Professors Long and Schipper derived 10 principle conclusions, among which were the following. The crucial issues regarding resource scarcities concern the rates and prices at which resources will be available and the political constraints to using them in ever increasing amounts. They also assert that we need to increase the flexibility of the economic system to respond to sudden resource supply disruptions through broadening our understanding of and technical potential for resource substitution. On a macroeconomic level, the authors assert that the substitution of productive factors should be viewed in a unified framework that permits exploration of the interdependencies of capital, labor, and material and energy resources, rather than solely within a value added formulation that focusses on the tradeoffs between capital and labor. Finally, they convey data which supports the conclusion that international comparisons of energy requirements in industrial production show that many opportunities exist for energy conservation in the U.S. through the introduction of more advanced technologies.

Professor Kneese's basic thesis is that our natural resources policy is a matter for deep concern. He feels that it is inconsistent, often outdated, and grossly over dependent on direct regulation vis-a-vis modifications in our defective system of economic incentives. What results from the marketing imperfections and defective public policy is an excessively rapid rate of resource extraction, too much discharge of residual materials to the environment, and an over dependence on foreign sources of supply of some natural resources. He stresses that a coherent policy program is needed, one which recognizes the interrelated nature of, the economic sources of, and economic remedies for, our resource problems.

The Committee is deeply grateful to these authors for their insightful papers. Dr. McHale is with the Center for Integrative Studies, SUNY at Binghamton, Dr. Cloud is with the U.S. Geological Survey and the Department of Geological Sciences, University of California at Santa Barbara, Professor Vogely is in the Mineral Economics Department at Pennsylvania State University, Prof. Thomas Long is with the Resource Analysis Group at the University of Chicago while Professor Schipper is with the Energy and Resources Program, University of California at Berkeley, and Prof. Allen Kneese is on the economics faculty at the University of New Mexico.

Dr. Robert D. Hamrin of the Committee staff is responsible for the planning and compilation of this study series with suggestions from other members of the staff. The administrative assistance of Beverly Mitchell of the Committee staff is also appreciated.

The views expressed are those of the authors and do not necessarily represent the views of the Members of the Committee or the Committee staff.

Sincerely,

JOHN R. STARK,
Executive Director,
Joint Economic Committee.

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NATURAL RESOURCES POLICY, 1976–86

By Allen V. Kneese

RESOURCE AVAILABILITY AND GROWTH

By John McHale*

Summary

The central question in the U.S. resources and growth debate is not whether we can sustain traditional growth in view of apparent resource depletion and scarcity—but how growth directions themselves are changing in society and where emerging patterns of resource supply and use now qualify the conventional depletion and scarcity arguments.

1. *The Challenge of Change*

(*a*) In general terms:

Overall resource availability will continue to expand with regard to reserves expansion, recovery, substitution and efficiencies of use.

Growth demands will shift through changes in social attitudes and values—probably with less emphasis on wider consumer product ranges: more on human systems and services needs. With a stabilising population, growth may be less dependent upon increased resource demands but more on human resource development.

Greater requirement for more rapid social and organisational innovation to cope with new socio-economic challenges of increased complexity and interdependency, both domestic and international.

U.S. society appears to be moving from a short range, autonomous and "means" outlook towards a longer range, interdependent, "ends" orientation—thus may not only be receptive to different growth patterns but more willing to accept longer-term costs and benefits of alternative growth policies.

(*b*) Resource use and technological change:

The leading edge in industrial growth and development has shifted to electronics, telecommunications, computers and new material ranges and processes. These tend to be less labor intensive, use less energy and other resources per unit output and have lower environmental impacts.

This coincides with the *post-industrial shift* hypothesis where industrial productivity is maintained with less manpower, decreasing energy and materials inputs whilst labor force and eco-

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nomic emphasis moves towards a services oriented economy. This implies changes in growth areas, institutions and resource needs which are essentially different from traditional directions and require new configurations of public and private enterprise with shifts in capital, tax and R. & D. investment.

A new dimension of resource range emerges with *information as resource* which has profound systemic implications for the structure of the economy and society.

2. *The Energy Outlook*

In next decade terms, the most critical element will be the degree of external dependence for oil and natural gas. Domestic reserve estimates range between 10–20 years at current consumption rates. Coal's potential is greater with a very much longer time horizon. Nuclear power is unlikely to add significantly within the decade and requires a "second look" in view of potential long term hazards. Alternative energy sources need higher priority by investment and development to augment supplies:

Constraints on growth are cost and time dependent rather than being based on actual scarcity. Exploration and exploitation of new fields could improve the supply picture in five to ten years: Given time and increased R&D, higher recovery rates of submarginal oil could add considerably to domestic reserves. Both will require increased energy pricing and changes in taxing structures to provide the necessary capital—but higher pricing should contain tax revenue components earmarked for direct investment in R. & D. and low energy growth areas.

Estimates of demand and supply are policy contingent. Consumption can be reduced significantly, (i) through increased industrial efficiencies and encouragement of higher energy intensivity-of-use. (ii) by more rigorous energy accounting and efficiency incentives. (iii) by disincentives towards over-stimulation of consumer demands, e.g. by taxing advertising, automobiles power/size/energy consumption etc. and diverting revenues into R. & D. (iv) by better conservation techniques in construction and transportation uses, and more "systemic" design of residential uses.

In overall terms, it is estimated that the U.S. energy budget could be reduced significantly—without appreciable effects on living standards and economic growth. This would require consumption restraints as above with more comprehensive review of producer/consumer practices and a rigorous overhaul of direct and indirect Federal subsidy programs in the energy area.

The role of the market. There is no "free" energy market in the classical sense. Given its hybrid private/public structure the market per se is particularly unwieldy in its ability to provide swift and equitable "across-the-board" adjustment to strains and shortages in supplies. The private sector is necessarily too short-range and proprietary interest oriented to give anticipatory guidance on longer-term energy policy. *No system of incentives or re-*

straints, applied piecemeal, is likely to aid the market's capacities in these respects—in the absence of a more coherent and comprehensive federal energy policy. The development of such a policy should include wider consumer interests and contain specific elements for monitoring, on a more continuous basis, the effects past and present of legislative action.

3. *The Materials Outlook*

In overall terms, there are no foreseeable absolute scarcities which might constrain growth in the next ten years. World and domestic reserves are ample, in most cases, and the supply picture does not indicate any severe price constraints other than those which may emerge in market collusion or commodity price adjustments arising from political factors in the world economy:

As with energy, one of the key policy needs is more adequate and reliable information on reserves, supply and materials usage.

Where some reserve margins, expressed in years of supply seem slender, rates of economic recovery, growing intensivity-of-use, substitution and recycling capacities extend them considerably. The "in-use reserve" pool is also a neglected factor in estimation.

Increased prices may increase manufacturing costs but in most cases, raw materials now constitute a relatively small fraction of such costs.

Growth in the capacity to "do more with less" is quite marked in U.S. materials use per function. This coincides again, with the post-industrial shift and paces the comparative decline in energy and materials components in GNP growth.

Though the U.S. industrial materials outlook is good, the main problems are likely to come therefore from economic availability rather than physical shortage. Healthier directions for U.S. materials policy—in terms of reducing social, economic and environmental costs—should be sought in policies which emphasize:

Alternative process paths should be sought which optimize materials use and indicate specific reductions in energy and environmental costs.

Increased R&D in material use technologies and substitutions at each stage in the materials cycle—with more rigorous energy input accounting.

The role of the market. Again not a free market, but differing from energy in the wider raw materials, processes and products. It is also a complex and hybrid structure in which government intervenes to a considerable degree via taxing, regulatory and subsidy procedures. In critical areas of supply it is unlikely that the commercial market *alone* could be relied upon to provide sufficiently swift adjustments to strains and scarcities. More systematic sets of materials policies will probably require more lateral integration of various industrial sectors and a closer working relationship between government and consumer interests.

4. *Towards a Regenerative Resource System*

In terms of more adequate energy and materials' policy we need to move, in the next decade, towards a system which operates on a *metabolic* model. This would be one which treats the overall flows of energy and materials in society so as to account for all agri-industrial and other uses and devise ways to optimise at larger systems' levels, linking up wastes and byproduct effluents so that they feed back regeneratively into the system—instead of being discarded at great socio-economic and environmental costs.

Many of the policies for organizing such a system are under consideration:

> Policy components for approaching such a system are already extant in the many hearings which have examined the structure of the energy and materials industries and are also present, for example, in the 1973 National Commission Materials Policy report and other documents. In general, they would comprise a set of incentives for the re-use of materials, for wastes utilisation and by-product rationalisation to encourage optimal resource use.
>
> One specific measure may be to set up annual or biennial "growth" reviews which, paralleling various Presidential reports, would give overall energy, materials, socio-economic and environmental balance sheets for continuous growth direction appraisal—as well as evaluating the impact of ongoing policies.

5. *Concluding Remarks*

These counter the prevailing view that growth in advanced societies is predicated on continuation of high energy and material demands and consumption—leading inevitably to resource scarcity and high environmental deterioration:

> Various factors are advanced to suggest that as higher living standards are met for more people, material demands peak out below maximal satiation and satisfaction is sought through less material means.
>
> Overall, the kinds of social and value changes ongoing within U.S. society, accompanied by various technological and resource-use shifts, suggest not only that growth directions will change but that growth requirements in the next decade and beyond could be satisfied with less per capita resource use, lower environmental impacts and expanded productivity.

It is emphasised that many of these changes towards alternative growth patterns cannot be taken care of by conventional market forces but will require a restructuring of incentives and regulatory practices to reward the kinds of new public and private initiatives which will be required.

Introduction

The assessment of resources available in relation to growth in the next decade, and beyond, calls into question many of our orthodox assumptions both with regard to resources themselves and the kinds of growth which they may subtend.

Our sets of working premises and assumptions pre-select the kinds of problems addressed, the data which is available and the end conclusions reached. A central aspect of the resources and growth discussion is, therefore, conceptual. Resource scarcity or abundance is dependent upon the state of our knowledge and the perception of our needs. Only a short time ago, nuclear energy was a laboratory phenomenon, aluminum a scarce metallic curiosity and many of today's materials were regarded as waste impurities in other ores. As may be expected in a period of rapid change, our conceptual frames of reference have often not kept pace with the changes themselves.

This is particularly important when we discuss U.S. economic growth using the relatively short term horizon of the next ten years. Several points should be borne in mind:

The time scale of a decade, past or present, may be inadequate given the kinds of changes which have perturbed that economy and will continue to perturb it in the more distant future. Many of our present crises stem from habitual resort to short term perspectives on what are essentially long term problems.

Decisions made for practicality and expediency in the next year or in five to ten years can commit us to large scale energy and materials usage patterns whose full consequences may not be felt for another ten or twenty years. Our current dependence on oil as major fuel is an example of this kind. Urgent decisions required in relation to nuclear energy generation have already exposed problems of radioactive waste accumulations whose disposal and storage problems extend over several generations.

Federal and local governments are already actively encouraging technology assessment. The need for similar assessments in the long term planning of resource uses is now urgent and should deal with the whole spectrum of consequences—economic, social, political and environmental, both locally and internationally.

Resources assessment does not fit easily into the conventional economic frame. With specific regard to energy and materials assessment, economic valuation and pricing are not reliable guides as the market is not "free" in the classical sense but subject to constraints and distortions through subsidies, taxes, and other regulatory practices.

The growth debate itself cannot be confined to considerations of physical resource availability, even when these take account of market mechanisms and fiscal structures. The debate extends to questions of shifting values and attitudes, changes in life styles, social expectations and environmental concerns that indicate alternative patterns of growth which may or may not be met within our present institutional frameworks.

The shock waves of recent upheavals in energy and materials supply, environmental pollution, urban problems, inflation and unemployment, which give rise to the need for this kind of decade assessment, are not singular and isolated physical crises per se. They are evidence rather of an institutional crisis. Their discontinuous impacts derive from particular sets of institutional arrangements, of piecemeal modes of economic, industrial and fiscal operation, which have been encouraged as expedient in the short range. It is only when their dysfunctional effects become apparent in the longer term that they emerge at crisis levels—and are then displaced into separate compartments such as the "energy crisis," the "urban crisis" and so forth.

Serious consideration of the prospects, problems and patterns of U.S. economic growth cannot be limited therefore, even in this chapter, to the more immediate aspects of resource scarcity or abundance, pricing mechanisms, market constraints and regulatory procedures. These questions need to be subsumed within a brief review of some of the changes affecting long term growth.

1. The Context of Change

The key dimensions to be considered here are the changes in energy and materials usage, the technologies through which these are effected, their environmental consequenses and the perception of socioeconomic needs, demands and requirements which vary according to growth and change in population.

The latter third of the twentieth century has been particularly characterised as the period of abrupt change and discontinuity with the past.

Change itself has changed. Where previously discrete, relatively separated in time and limited in the numbers of people affected, today's changes are increasingly interlinked in multiple feedback relationships. Within living memory, series of sicentific, technological, social and economic changes have impacted one upon the other. It is unlikely that the pace, frequency, range and scale of such changes will alter significantly in the next decade. Just as in the past, it is highly likely that many abrupt changes will occur unanticipated.

Increased frequency and narrowing intervals between scientific discoveries, technological development and large scale use have become particularly apparent in many sectors of resource use in the past decade. Where it used to take five or ten years for a product to move from research to production and widespread distribution this process is now often dramatically shortened.

Many consumer products have also moved into more rapid obsolescence cycles and degrees of expendability, e.g. from buildings and cars to refrigerators, Kleenex, clothes and food packaging. Where this may be defensible in terms of innovation and economic prosperity it may be acutely dysfunctional in environmental impact and socially efficient resource usage unless accompanied by more long term anticipatory planning.

Growth in human numbers and concentration on the world level will continue. In the U.S. case, however, demographic figures show that population is relatively stabilised. Population increase in the coming decade will not draw down significantly on resource use. However, attitudinal changes within the population could change resource availability ad consumption patterns in important ways, e.g. through continued environmental concern, increase in consumerism and changes in quality of life perception.

Population pressures and rising demands for equity in the lesser developed countries could still impact considerably on the world flow of resources critical to the U.S. as more OPEC type resource coalitions and market blocks emerge in the changing international economic order. As standards of living improve in other countries we may assume greater competition for physical resource access and control. The effect of this may be offset in the U.S. by virtue of the size of its own resource base, by stabilisation of population and by saturation and increased efficiency in resource usage.

The increases in scale, complexity and interdependency of human support systems and services is an important resource change factor. In terms of technological systems scale, the Wright brothers, in 1903, could introduce a new technology, the aeroplane, at a level where it could be designed, built and tested by two men. A comparable technological development in the past decade could be the Appollo project requiring approximately 300,000 people, thousands of parts, sub-assembly operations and well over one million times the cost.

The scale of many of our globally operative technological systems in production, distribution, transportation and communications now require and are dependent upon the resource range of the entire earth for the metals and minerals fom which they are built and the energies which they need to run. Many single industrial products draw similarly on a range of globally distributed resources for their manufacture. No single nation is, therefore, now wholly self-sufficient in industrial resources.

Large economies of scale in technological undertakings have, in many cases, gone beyond the capacity of individual nations to build, maintain and develop further, e.g. the Anglo-French Concorde. Similarly, at the local level, many of the socio-physical maintenance services in society such as health, housing, transportation, energy supply begin to go beyond the point of "economical" provision and control by private enterprise and increasingly require government support and intervention.

It is not surprising that the most swiftly growing and powerful sectors of the world economy are no longer national undertakings but multinational corporate entities. These organisations are unprecedented in size, in their globally interlocked operations and their autonomy from national control. More important decisions regarding resources availability and usage are probably made in such organisations than in national governments.

The local growth and complexity of our technological support systems also has been accompanied by critically interactive relationships. Relative minor malfunctions, such as an electrical "brownout", a transportation strike or a material shortage can cascade swiftly through a whole industry, a city or affect international trade relations.

Our investment in large scale systems is further complicated by its effect on innovation and change. We already find ourselves committed to out-moded systems in production, transportation and other areas where necessary changes may be hampered by the inertia of the system and the relatively enormous costs of change.

The new magnitudes of these systemic ramifications and interdependencies from the local to the global level are but imperfectly understood and urgently require more research, anticipatory assessment and long range planning.

Summary Note.—Some salient implications of such changes for future growth patterns may be noted as follows:

The pace of technological change, with regard to resource recovery, reserves expansion, substitutions and efficiencies of use and re-use, will increase with more visible pressures of pricing, competition and interdependence. Longer range coordinate federal policies of incentives and controls will be required to aid beneficial changes and conserve resource options. Whilst technical innovation advances there is an accompanying requirement for more rapid social and organisational innovations to cope with the new economic challenges of increased complexity and interdependency both domestic and international.

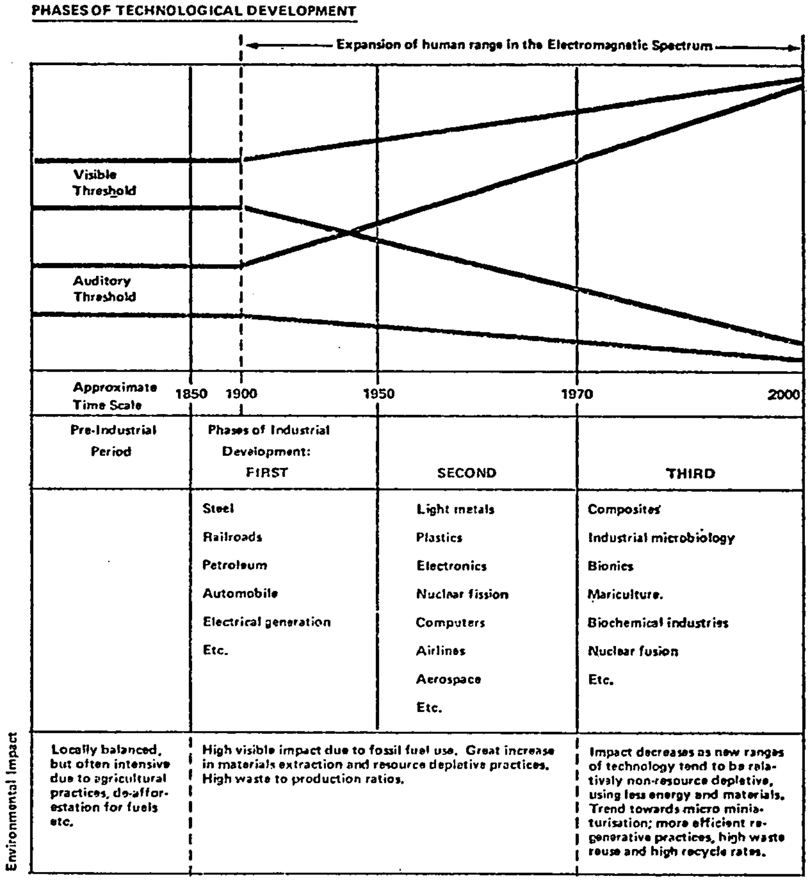
Shifts in growth demands may be expected through changes in social attitudes, standards and values. These appear to place less emphasis on wider consumer product ranges but more on improvements in the quality of socio-physical maintenance systems e.g. housing, health and environmental services, transportation and social services. Meeting such changed demands will shift the balance of public and private provision of goods and services—and will require different managerial, regulatory and administrative systems.

The overall orientation of U.S. society may move more rapidly from being short range, autonomous and "means" oriented towards a longer range, interdependent, "ends" oriented outlook. This has implications for growth policies which go beyond our immediate questions of available resources to support conventional growth patterns as the society may not only opt for different kinds of growth but be more willing to assume the longer range costs and benefits of alternative growth options.

2. Resource Use and Technological Change

The relative abundance or scarcity of resources is crucially related to technological development. We may distinguish, for present purposes, three major phases of this development with their different sets of typical resource use patterns, environmental impacts and related socio-economic changes. (See figure 1.)

FIGURE 1



Source: McHale, John and Magda Cordell McHale, Human Requirements, Supply Levels and Outer Bounds: A Framework for Thinking About the Planetary Bargain. A Policy Paper prepared for the Aspen Institute for Humanistic Studies, Program in International Affairs, 1975.

The first phase encompases the heavy industry developments incident on the later stages of the Industrial Revolution. These were typically steelmaking, railroads, automobiles, centralised electric generation, etc., and were based on the fossil fuels: coal, oil and natural gas. This type of industrial practice is highly resource depletive, with relatively low efficiency of performance per input of energy and materials and has gross environmental impacts through its effluents and other by-products. As developed historically in terms of large centralised facilities to exploit economies of scale, this area of industrial development is heavily invested in large plant, established market patterns and tends to be less flexible in its capacity to adapt and change.

The second phase of industrial development emerges most clearly after World War II, accompanying the development of computers, large scale air transport and the emerging set of new electromagnetic spectrum industries, i.e. electronics, tele-communications and nuclear energy generation. The materials base expands more in the direction of the light metals—aluminum, titanium, magnesium, etc., and their alloys—the rare earths and plastics. The materials supply base becomes not only more expanded but more complex with a much wider variety of basic elements being used. This phase typically uses less energy and less material by weight per function or product with successive micro-miniaturisation of components. It tends, by comparison with heavy industry, to be more economical in energy use and to have a much lower impact on the environment.

The third phase appears to move towards the increased fusion of biological and technological capabilities, e.g. biomics, industrial microbiology applications in the more efficient use of microbial populations to produce energy, food and process materials. There is increased attention to the genetic tailoring of food stocks and modes of "organic" technical growth using renewable resource stocks like forest and agricultural by-products. Its materials base tends towards new ranges of metallic and non-metallic composites and other hybrid materials coupled with more sophisticated electronic and electro-chemical processing. The energy directions move towards less centralised non-fossil fuel alternatives such as those associated with solar power, fuel cells, hydrogen and other synthetic fuel sources with the longer term possibility of nuclear fusion techniques for larger scale power generation.

In practice, the three phases overlap considerably with different rates of growth.

The overall profile of materials entering into volume production over time gives another dimension to these phases of development as industrial usage expands towards fuller use of the whole table of elements. (See figure 2.)

These developmental phases have been linked to structural changes in society from industrial to post-industrial forms. This does not mean that the society is less technologically or industrially based, but that there is a shift in the economic wealth generatng sectors in terms of manpower, investment and productivity.

> The United States, to some extent is the first post-industrial nation in which the majority of the labor force is not engaged in either agriculture and extractive industries, or manufacturing, or a combination of both, but essentially in services—that is trade, finance, real estate, education, research, administration and government. . . . It is a change equally in the character of the societies themselves.[1]

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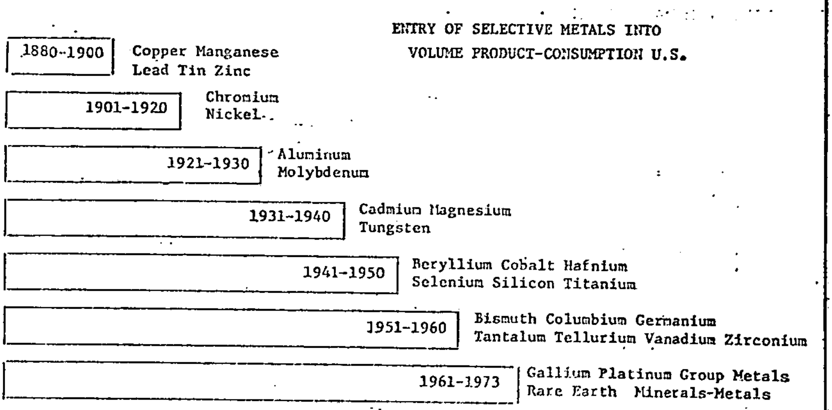
[1] *The Management of Information and Technology:* paper prepared for 11th meeting of the Panel on Science and Technology, Committee on Science and Astronautics, U.S. House of Representatives, 1970, Moderator's Remarks, Daniel Bell, p. 14.

FIGURE 2



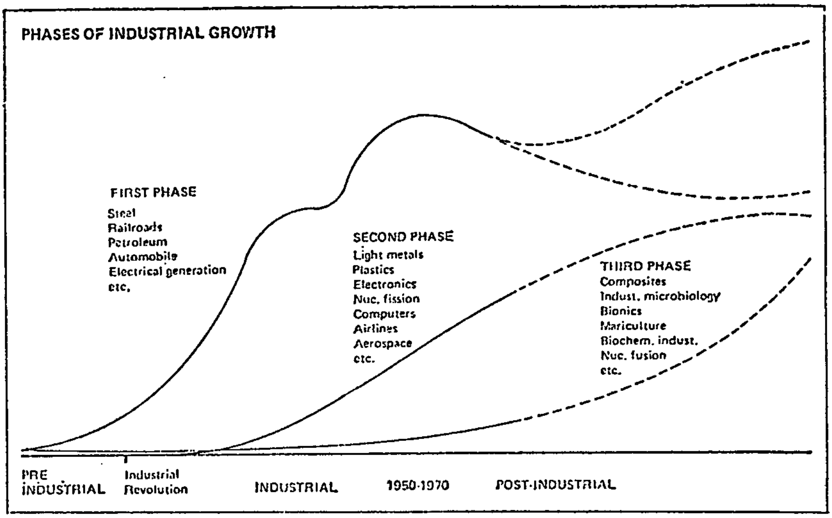
PERIOD	QUANTITY (TONS)	PERIOD	QUANTITY (TONS)
A. 1880-1900:		E. 1941-1950:	
Copper	100,000	Silicon	500,000
Lead	100,000	Titanium	250,000
Manganese	100,000	Cobalt	2,500
Zinc	100,000	Beryllium	1,000
Tin	10,000	Selenium	250
		Hafnium	2
B. 1901-1920:			
Chromium	10,000	F. 1951-1960:	
Nickel	5,000	Zirconium	30,000
		Vanadium	1,300
C. 1921-1930:		Bismuth	750
Aluminum	100,000	Columbium	500
Molybdenum	500	Tantalum	250
		Tellurium	100
D. 1931-1940:		Germanium	10
Cadmium	3,000		
Magnesium	1,000	G. 1961-1973:	
Tungsten	1,000	Rare Earth Minerals	10,000
		Platinum Group Metals	50
		Gallium	5

Source: Center for Integrative Sttudies.

As with agriculture, the extractive and production sectors become less labor intensive whilst maintaining and increasing productivity and, in some cases, less energy and materials intensive. The transition, however, is not merely a change in the economic and industrial base towards a service economy but implies as massive an institutional shift as that from an agriculturally based to an industrially based society.

In the Fig. 3 describing these waves of development, we have extended the "third generation" schematic line, back historically as many of these "alternative technology" paths have quite ancient pre-industrial origins (e.g. bee keeping, silkworm cultivation, etc.). These alternate tracks have been accorded little recent attention due to the emphasis on "machine" industries. We might also introduce in this third generation development many other ranges of emerging "soft" technologies modeled on natural processes, e.g., behavioral technologies, various "mixes" of man/machine systems, etc.

FIGURE 3



Source: Center for Integrative Studies.

We may note one single distinction between the old and new forms. The new patterns of industrial development tend to be relatively non-resource depletive, with lower environmental impact, compared with the older highly resource depletive and environmentally impactive forms.

This shift is still difficult to assess in resource and economic growth terms. Many service sectors are still energy and materials intensive, and have a different tax and subsidy relationship to the economy than the heavy industrial base. Some require high technology inputs with high capital costs where such technologies also change with greater frequency, e.g., in medical equipment computers and the diffusion of electronic systems.

Many of our anxieties and crises regarding possible energy and material shortages, changes in employment investment and fiscal structures, however, may result from a failure to understand these fundamental changes and to continue to regard the society as essentially industrial and production oriented in terms of economic wealth generation.

Summary Note.—The implications for future growth with regard to the outlined shifts in industrial technology are:

> The leading edge in industrial growth, productivity and wealth generation is no longer held by the older heavy industries but already shifted over into the "second phase" developments in electronics, telecommunication, computers and new material ranges. To retain its initiative in this phase, the U.S. will have to invest more in capital and R. & D. intensivity in these areas.

Third generation technological developments noted suggest possible growth breakthroughs in advanced applications and fusions of biological, agri-industry and materials design components which may constitute as large a market base as electronics, plastics and computers.

The third challenge obviously lies in devising new institutional mixes of public and private enterprise to meet increased human services demands which have been typically low technology, labor intensive areas but represent growth markets both for new technical applications and entrepreneurial functions. These would depend less on physical resource demands but draw more on human resource development and managerial expertise.

Information as Resource

Information treated as basic resource has certain unusual properties:

(i) All other resources are ultimately dependent upon information and organised knowledge for their recognition, evaluation and utilisation.

(ii) As resource, information is not reduced or lessened by wider use distribution or sharing, like other resources—it tends rather to gain in the process.

Where other resource bases such as raw materials and energy are, by comparison, potentially depletive, information and knowledge are inexhaustible.

> . . . A preindustrial society is essentially one based upon raw materials, as a game against nature, and in which there is diminishing return. An industrial society is organised primarily around energy and the use of energy for the productivity of goods. A post-industrial society is organised around information and utilization of information . . . as a way of guiding the society.[2]

The properties of this new dimension of the resource range have profound implications for the structure of our economies and our societies.

The range of such implications extends beyond our present discussion with its emphasis on physical resources. It may be worth noting, however, some areas in which the fusion of information and communications technologies imparts upon resource evaluation questions:

Broadening the resources range as more data accrues on given materials or substitutive practices and on increasing energy and resource usage efficiencies and manufacturing processes.

Increasing the reserves base through earth satellite monitoring, aerial and land survey technics whose basis ties in new information and communications technologies.

Computer modelling and control of resource utilisation in industry and agriculture can lead to greater economy in energy

[2] Ibid., Daniel Bell, *The Management of Information and Knowledge*, p. 14.

and materials use, with enhanced capacities to monitor and predict economic and environmental impacts.

In more general terms, changes in the information environment have already had considerable unanticipated impacts on both the polity and the structure of the economy. From the Pentagon papers to the Watergate affair, debate now reverberates through rights to consumer and other information, questions on proprietary ownership of vital resource data and political contributions disclosure. The structure of the business economy itself has tightened up as new information and communications systems change the flow and immediacy of impact of market data. Industrial organisation and productivity has been strongly influenced by automated procedures, new instrumentation, new products and processes. The overall *systemic* effect of these changes has not yet been adequately assessed in comprehensive policy terms to gauge their specific points of advantage for future growth directions.

We have already drawn attention, for example, to the emergence of the new *electromagnetic spectrum industries*—electronics, telecommunications, computers, automated central process equipment, etc. These are prime growth sectors in the economy but with comparatively little drawdown on extractive resources and increasing energy efficiency. As one analyst notes here:

> Insofar as it is free from depletion upon use, the spectrum has characteristics of a sustained yield (flow) resource of a unique sort, perhaps most similar to solar or water power . . . In the spectrum, if equipment is maintained intact, then the same flow of information is possible, indefinitely, with no depletion of the resource itself.[3]

The wider impacts of the changing information environment on specific sectors of society will have their effects on work and organisational modes, on individual productivity, life and political participation. Some of these are considered in the accompanying chart of their centralisation and decentralisation tendencies. (See figure 4.)

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[3] *The Invisible Resource: Use and Regulation of the Radio Spectrum,* Harvey L. Levin, Johns Hopkins Press, 1971, p. 28.

Figure 4

THE INFORMATION ENVIRONMENT:
CENTRALISING AND DECENTRALISING FACTORS

INFORMATION PROCESS	Information industry transformed, in part, into centrally administered public utility. Economies of scale and operation favor necessary centralized development of certain aspects of new technologies. Convergence of information and communications technologies produces tendencies towards greater decentralization in certain modalities, e.g. terminal use, dataphone links. Continuing tendencies towards monopolies in control structure of communications, e.g., radio, TV, newspapers. Systems networks develop which by their nature are too highly diffused and complex to be centrally "controlled." Proliferation of remote access systems and other interactive modes encourage decentralization of access and general usage.
BUSINESS	Scale of investment required by new technologies requires large centralized enterprises. Large scale social demands will accelerate creation of larger business clusters — so centralize economic power. Rise of more individually oriented, and specialized, group markets increases company diversification and market management decentralization. Rapid information flow will give functional decentralization — more locally autonomous decision making. Trend towards "social services" enterprises encourages growth of small service-oriented entities.
EDUCATION	Scale of investment for certain types of research will require its location in centralized facilities. Policy setting, long term planning, funding, purchasing, etc., particularly in the multi-versity, will probably remain more centralized Expansion of multiple educational options makes selection of central or decentralized mode a matter of personal choice. Functions such as short range planning, projects, programs, local coordination, etc., will be decentralized. Ability to communicate cheaply and conveniently may tend to weaken identification with particular central institutions. Development of home communications a decentralizing factor for specific types of educational experience.
POLITICAL PROCESS	Tighter rather than looser organisational structure via use of technologies used for specific purpose of greater social control. The use of "manipulated consensus" as a form of social control. Two general but contradictory tendencies: A re-integration of national parties — with tighter political structure and more centralized economic structure. Opinion fragmentation is likely to increase the number of party factions and coalitions — due to increase of "social movements politics." Increase in number of sources of information will increase the number of separately identifiable opinion aggregates in society. Two-way communication will help people similarly situated, but in assorted places and strata to find each other, and to organise without first coming together, without having to work out a preliminary system of representation.
INDIVIDUAL GROUP	Increase in stratification and conflict between information "haves" and "have nots" may lead to stronger centralized political control to dampen conflicts. Centralised control of media accompanied by monopolistic structure homogenizes society, encourages center consensus. Expansion of individual options via use of new technologies designed for this end gives more choices in all sectors. Inadequacy in, inequality of access to education may lead to less active participation in large society: individual and group withdrawal.

COUNTERBALANCING FORCES

← Centralising	Policies in "national interest" seek greater central data storage control with corollary trends towards more social surveillance, etc. Monopolistic structure of business trends towards central control lodged in various industrial complexes.
	Functional balance of society and deliberate planning calls for centralization of those functions requiring it, and decentralization of those operating best in this mode. Social pressures for both tendencies equalize out towards median distribution.
Decentralising →	Larger systems tend to be "leaky" and inefficient for certain purposes. Antitrust legislation. Decentralized autonomous systems market grows as technology develops smaller, cheaper instrumentation.

The possibilities of growth diversification through the "spectrum" industries and the ways on which new developments in the information environment can be tailored to meet social demands are very great. Realizing these possibilities both for domestic growth markets and for retaining favorable U.S. position in the world economy will require more specific attention to this sector by policy makers in business and government—and accompanying changes in attitudes to growth objectives.

There is great demand for attention to critical problems in environment, health and auxiliary services, mass transportation, education and urbanisation which are all critically interrelated. The allocation of attention and resources to meet such demands could create a diversity of new product and market opportunities on the same scale as federal attention to national security needs and aerospace have in the past decade or so. The balance of market growth may not, however, be so much in new single products but in new services and systems to meet interrelated demand clusters.

3. The Energy Outlook

The separation of energy supply considerations from materials is for convenience only. In principle all materials are energy in temporally stable forms. We can then, to a certain extent, define the materials supply available to us in terms of the energy at our disposal for its extraction and processing.

For present purposes we will concentrate on the U.S. energy position in the next decade with obvious regard for the longer term implications of supply and demand.

The basic data on energy production, consumption and end uses varies considerably according to source and bias. The immediate and foreseeable critical elements are:

(i) The acute dependence which has been developed on certain preferred sources of energy. In this regard, the crisis as it originally emerged was not so much an energy crisis but an oil supply one. Though it has since broadened to include natural gas, it is still not a crisis in terms of actual world shortage but in terms of price, *external availability* and declining domestic supplies. It is a crisis which also occurs within a relative abundance of other domestic energy reserves. It is estimated that we have well over 500 years in coal reserves at current rates of use, and though domestic oil exploration had declined in recent years there are still considerable field (and oil shale) reserves of varying estimates of magnitude.

In terms of U.S. growth in the next decade, one of the most critical elements will be the degree of dependence on foreign sources for oil and natural gas. The bill for foreign oil has risen from $3.7 billion in 1971 to an expected $35 billion in 1976. How far this will rise by 1985 critically depends on the kinds of energy policies which the U.S. adopts in the very near future, both for short term solutions and larger term shifts to alternative full sources and use patterns.

(ii) The level of energy consumption which is unique to the U.S. in terms of its population size. The U.S., with 215 million people, uses more energy in total than the combined use of four major industrial countries, United Kingdom, Japan, USSR, and the West Germany, totalling 500 million people. This may be defensible in terms of the comparable amount of energy which the U.S. produces but it still requires questioning.

(iii) The ways in which energy is used—at what rates, for which purposes and at what degree of efficiency.

Energy sources are divisible into "capital" and "income" types which are roughly equivalent to non-renewable fuel deposits, which can be used up, and renewable energy flows which are part of the recurrent and regenerative processes in the environment.

The accompanying table of energy systems illustrates these various sources with their advantages and disadvantages. (See figure 5.):

Figure 5

ENERGY SYSTEMS

INCOME ENERGY — Continuous or renewable energy receipts of light, heat, gravity, cosmic rays, etc.

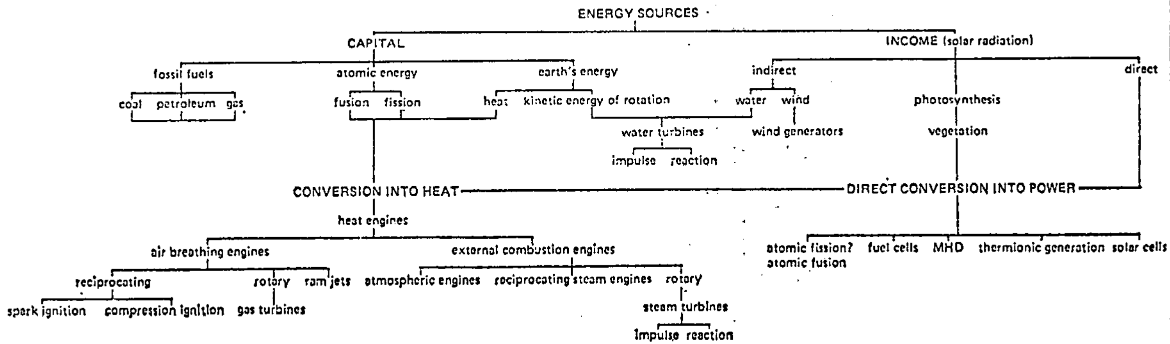
Stellar Energy Sources Chiefly Solar

CAPITAL ENERGY — Exhaustible or unrenewable energy sources stored over extended periods of time.

Energy Conversion (naturally occurring)	Energy Conversion (human agencies)	Merits	Demerits
Indirect Inanimate — Molecular movement (temperature differences between atmosphere, earth & ocean), geothermal heat & tidal forces.	Sails, waterwheels, wind generators, hydroelectric generators, dryi g processes, geothermal steam & tidal power conversion facilities	Winds, temperature differences geothermal heat,etc. are continuous & have few inherent pollutants	Difficulty of controls, periodic surges, geographic disproportion etc.
Indirect Animate — Photosynthesis, microbial energy conversion.	Food, human labor, draft animals, fermentation & alcohol extraction from vegetation, wood fuels, dung, etc. controlled microbial action in agri-industrial processes.	Self regenerating systems. Microbial action may be used in waste reclamation cycle.	Large volumes of heat energy dissipated in direct metabolic processes.
Direct — Photo Chemical, Photo-electrical, Thermo-electrical.	Heat and electrical energy yielded through electro-chemical reactions & optical concentrations of lights, etc.	Direct energy transfer, may be stored bio-chemically or electro-chemically but on a relatively small scale.	Presently not capable of economic application on wide scale or large volume range.
Fossil Fuels — Coal, petroleum, natural gas, shale oil, tar sands, etc.	Heat and electrical energy yielded through combustion in various chemical processes and mechanisms	May be stored, transported and controlled with ease and in large volumes.	Excess waste heat, gasses, & pollutents effect biogeochemical processes.
Fissile Fuels — Radioactive fissionable elements.	Heat and electrical energy yielded through acceleration of atoms in combination with electro-mechanical systems.	Independent of geography, minimal upkeep, by-product wastes may be used as other fuels.	Large investment in shielding and fuel refinement, disposal of radioactive waste is a present key problem.
Bio-geochemical — Cycling minerals such as nitrates, phosphates, etc.	Heat yielded through chemical reactions, etc.	May be stored, controlled, and used as fertilizers in other food energy processes etc.	Used in explosives etc. Primarily destructive energy use.

Human Utilization: Cooling food, preserving food, cooking food, space heating, space cooling, pumping water, air & gasses, motive power, lighting, communications, industrial heating, conversion and forming of materials, etc.

"The Nature and Sources of Energy", Zimmerman, Introduction to World Resources, Frederick A. Praeger, Inc., New York, 1966, p. 68.



Energy Into Power, E. G. Sterland, National History Press, Garden City, 1967, pp.120–121.

(i) *Fossil fuels:* coal, natural gas, oil (including shale and oil sands.) These have been built up over a 500 million years of geological time and are "non renewable" other than on that time scale.

(ii) *Nuclear fuels:* those elements yielding energy through nuclear fission and fusion processes. Though relatively finite in terms of their earth crust sources, when we include their extension to the ocean elements and the development of "breeder" and fusion technologies they are almost "infinite" energy sources. Though in potential use since the early 1940's nuclear energy is developing more recently at a faster rate.

Income energy sources are those which are recurrent and regenerative processes in the environmental system:

(i) *Solar energy:* this is mainly used indirectly, for example, through photosynthesis in the food energy cycle—using plants and animals as converters. We also tap into this cycle by extracting fuels from wood and other vegetation sources, by using microbial action in biological fuel cells, etc., and so on. Most recently we have begun to develop the use of solar energy more directly through collecting and converting devices for heating and cooling purposes, photo-electrical and photo-chemical cells.[4]

For most current uses, and in terms of projected technological developments for the next decade we are almost entirely dependent on *capital* energies derived from the non-renewable fossil fuels—coal, natural gas and oil (possibly augmented by shale and oil sands).

Given this dependence, however, the most immediate question is whether we will have access to enough fuel in the next ten or twenty years without undue economic distortion, environmental and other impacts.

In terms of overall potential supply, both domestic and foreign, the answer is a qualified yes. The main qualifications are those of domestic reserves available and the balance of internal and external supply. Both of these are a function of the rates of use, types of consumption, interchangability of fuels, and the relative economic and socio-environmental costs which may be entailed.

The reserves and supply question is extremely tangled. Data available varies according to source, and the major sources are from the energy industry and, therefore, hardly unbiased.

Reserves, themselves, are classified as recoverable and submarginal. A recoverable reserve is that which can be extracted profitably in terms of investment and production of usable fuel at current costs of recovery and processing. This is the kind of reserve figure which is given in terms of "reserve-to-annual-production ratio" or how many years our reserves will last if present rates of production and consumption are maintained.

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[4] The energy the earth receives annually from solar radiation is about 35,000 times the present yearly energy consumption. If it were possible to transform one ten thousandths of the sun's radiation directly into power the world's energy production would be increased by 250 percent. *World Patterns of Energy Consumption*, E. Willard Miller, The Journal of Geography, vol. LVIII, No. 6, September 1959, p. 227.

Estimates of reserves fluctuate, therefore, according to demand and pricing structures. This is particularly important in relation to submarginal, or known undeveloped deposits, which are not used as they are unprofitable to extract with present technology, costs and prices.

. . . as the economy of scale reduces costs, and as new technology reduces costs, submarginal deposits tend progressively to be developed and are transformed into reserves. As an oilfield, it flows easily at first, then less easily, then the cost of getting it out exceeds the price it will bring. The inventory of recoverable oil has been exhausted. The reserves are gone. Yet 70 percent or so of the original oil in place in the field still remains there as a submarginal resource.[5]

Fowler's intensive analysis of the same question from a wide variety of sources gives roughly the same answers. Noting that it is estimated that half of the U.S. coal and oil is still to be discovered, he also points out that:

The actual recovery efficiency—for oil-in-place—has risen from about 26 percent in 1955 to a present 31 percent. It is projected to rise to 36 or 37 percent by 1985. Thus 2 barrels of oil remain underground for each barrel removed, 186 billion barrels for the 93 billion barrels produced to date.[6]

On "total estimated resources", and using 1973 consumption growing at 4.5 percent per year, Fowler suggests that these would last 17.5 years.

FIGURE 6

Energy resources	World production (millions)	Reserves: World (millions)	Reserves: United States as percent of world	U.S. years supply (projected)
Coal:				
Bituminous and lignite	2,982t			
Anthracite	174t (1973, preliminary)	805,787.9t (Jan. 1, 1974)	49.2	512
Helium	26.04m³ (1973, estimate)	4,358.2m³ (Jan. 1, 1975)	99.4	132
Natural gas	1,358,400m³ (1975, estimate/preliminary).	60,731,800m³ (Dec. 31, 1974).	20.4	11
Crude petroleum	2,853.9t (1974, estimate)	99,532.4t (Jan. 1, 1975)	4.9	12
Shale oil	53.9t (1975, estimate)	983,880t (1973)	9.3	1,080
Thorium	0.0119t (1973, preliminary)	0.893t (1973)	4.7	663
Uranium	0.0186t (1974, estimate)	0.967t (January 1974)	25.04	13

Note: The above figures are approximate and may be qualified in many ways. U.S. years oil supply forecast is based on 1973 production: Coal years supply excludes anthracite.

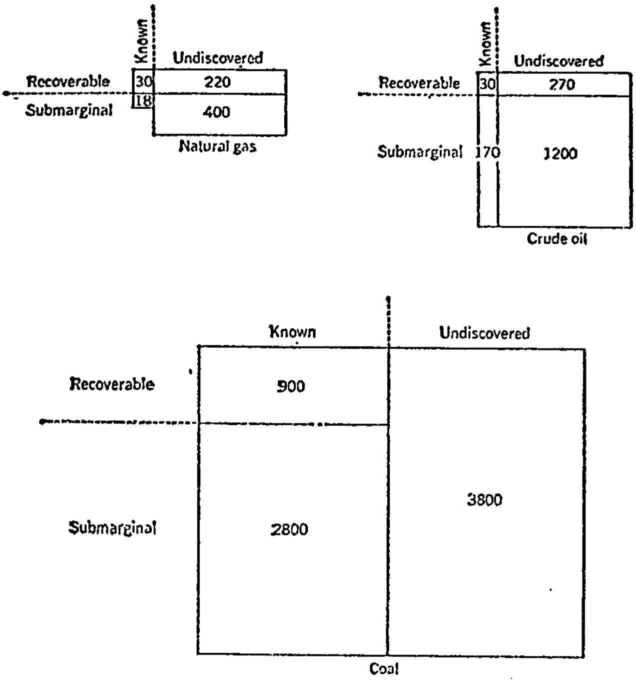
Data: Various sources; mainly Bureau of Mines, mineral facts and problems, 1975.

For a more graphic picture than is usually presented we may refer to Fisher's "same scale" diagram. (See figure 7.) Though using 1970 consumption data, this gives a succinct overview of the recoverable, submarginal and undiscovered reserve estimates.

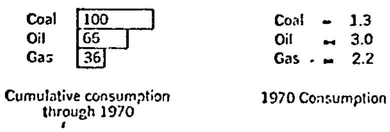
[5] Fisher, John C., *Energy Crisis in Perspective*, published by John Wiley and Sons, New York, 1974, p. 29.
[6] Fowler, John M., *Energy and the Environment*, published by McGraw Hill Co., 1975, p. 277.

Figure 7

ENERGY RESOURCES



United States reserves and resources of natural gas, crude oil, and coal, in units of $C = 10^{16}$ Btu.



Consumption of fossil fuels in the United States, cumulative through 1970 and for the year 1970, in units of $C = 10^{16}$ Btu.

Source: Energy Crises in Perspective, by John C. Fisher, John Wiley & Sons, New York, 1974.

Overall the domestic position seems to be—about 10–15 years of easily recoverable oil supply, natural gas on a similar basis but probably with a shorter supply horizon due to increased use, and enough coal for several centuries.

The domestic reserve could be expanded (hence "years of supply") if submarginal oil and gas are added plus offshore and Alaskan fields in development. To these we may add Bureau of Mines estimates of virtually untapped "heavy" oil deposits, potentially doubling the domestic proven oil reserves. Again, this additional reserve has been considered uneconomic to exploit in terms of costs but rises in the price of petroleum and new extraction techniques may bring it into the more easily recoverable category.

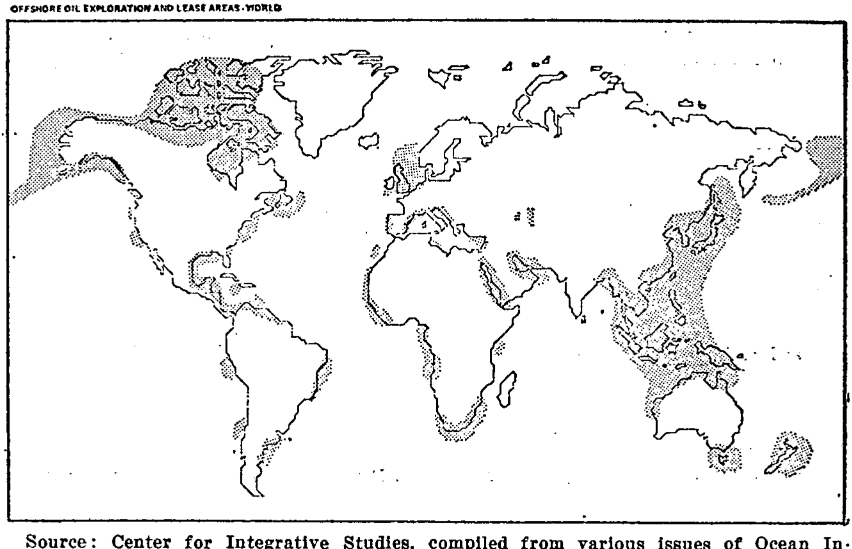
One would stress, however, that all such estimates of "years of supply" are usually based on continuing patterns of consumption in terms of current technologies, use efficiencies and costs. Each of these factors is a policy contingent variable—consumption can be reduced, technologies and efficiencies improves more rapidly and costs rationalized according with appropriate incentive policies—and "years of domestic supply" extended to a more secure margin.

In terms of shortage vs. growth for the next ten years, again the constraints are cost dependent rather than being based on actual scarcity. Obviously it would be unwise to deplete even known domestic reserve supplies too rapidly but more effort might be made to encourage: (*a*) submarginal exploration of present fields, (*b*) stock piling of oil fuel as an economic hedge similar to the strategic reserves.

If we include the estimates of external reserves then, in addition to the reserves of the OPEC bloc, the rate of exportation and exploitation of new oil and gas sources around the world threatens no real scarcity for some time. (See figure 8.)

FIGURE 8

OFFSHORE OIL EXPLORATION AND LEASE AREAS-WORLD



Source: Center for Integrative Studies, compiled from various issues of Ocean Industry, 1969–1974, plus additional sources.

The oil lease mapping alone of the South China seas looks like a multinational subdivision! There is still a possibility, therefore, that the real crisis of the next decade or so could be a return to oil "surplus" with a lowering of prices—thus encouraging more profligate use, with gross environmental impacts, of a resource that is potentially more valuable as a source for petrochemicals, medicinals, plastics, and even food, than as a material to be wantonly burnt up. The opportunities for energy conservation and of more diverse growth in oil, gas and coal derived products might thereby be lost.

The so-called energy crunch of recent years, therefore, is basically a price problem arising from the encouraged dependence on cheap foreign oil to augment local supply. This dependence[7] running to about one sixth of overall energy supply, was relatively well known before the OPEC upward pricing began in the late 1960's but little action was taken other than setting oil import quotas and other measures to protect higher cost domestic production against low priced foreign costs. Middle East oil wellhead costs range as low as 20 or 30 cents a barrel which is more than triple the cost for U.S. oil. Historically, therefore, it was more profitable to buy foreign than to invest more in domestic exploration and recovery. Part of the case for cheap energy was also made by the energy industry itself in encouraging high oil dependence and electrical consumption through its various marketing practices. The industry alone however cannot be expected to cut demands for its products. It could, however, be encouraged to rationalize its internal policies, where at present one sector may be operating at very high standards of efficiency in energy economy but another may be encouraging higher consumption through demand stimulation for its products.

The present situation is, therefore, not one of absolute scarcity—but of increased costs of imported energy and of domestic production. This begs the question of *real* costs as the ratio or profitability to production and processing costs is probably higher than it might be, in an industry relatively well insulated from so-called free market practice.

Natural gas has many similar critical domestic supply features to oil. One of the main problems appears to realistic estimation of reserves as, until very recently, the only annual national estimate was that provided by the American Gas Association itself.[8]

The use of natural gas has increased greatly as a versatile "clean" fuel of high heat value, free of many of the pollutants associated with other fossil fuels and delivered by pipeline from source almost directly to consumer. Federal law price regulation certainly contributed to its increased use but recent deregulation has not as yet had time to effect larger exploration and recovery rates to augment domestic supply shortages.

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[7] Dependence varies, i.e., up to 33 percent before the onset of the Mid East embargo and continuing to about 40 percent of today's U.S. consumption.

[8] This problem of acute dependence on proprietary AGA data is closely questioned in the Jan. 1976, Hearings on Natural Gas Supplies of the Subcommittee on Oversight and Investigations of the Committee on Interstate and Foreign Commerce, House of Representatives 94th Congress, Serial No. 94-88, pp. 14-29.

The gas transmission and distributing utilities have therefore committed resources to synthetic gas manufacture from naptha, no doubt to be augmented later by coal gasification.

Large gas supplies are believed to exist on U.S. public lands and offshore and in Canadian fields and these issues are being vigorously pursued to offset increasing dependence on imports of liquefied gas.

As the world reserve and supply level problems are much the same in terms of known reserves and supply estimation except that in many nonuser producing countries large amounts are vented and flared off in the course of associated oil production.

Given the increased importance of gas, however, overseas sources, both associated and nonassociated with oil fields, are now being more intensively pursued and many supplies may be forthcoming in the next few years outside the OPEC bloc. Though prices will be high they may be less dependent, therefore, on political factors. The overall situation for the next decade is, therefore, one not of absolute scarcity but of *economic* availability.

As domestic gas shortages have occurred, users have, in many cases, switched back to oil and electricity hence exacerbating the overall energy situation. As price deregulation may not ease this for some time in terms of new on-line gas supplies, many of the recommendations made for oil would apply to the gas situation. Conservation policies are more limited than for oil, however, as the efficiency of use is relatively high and the use sectors are less elastic in this regard.

Energy use and consumption. At present the comparative use of various energy sources used in the U.S. is approximately: See figures 9 and 10.

FIGURE 9

1975 U.S. energy sources—used

	Percent
Coal[1]	18.5
Natural gas (dry)	28.2
Petroleum	46.3
Hydroelectric[2]	4.5
Nuclear[3]	2.5

[1] Anthracite, bituminous and lignite.
[2] Includes hydroelectric power produced.
[3] Nuclear power production.

Source: Federal Energy Administration, Energy Information report to Congress, Quarterly Report—First Quarter 1976 (National Energy Information Center, Washington, D.C., 1976), p. 104, Table 7-11 and, Federal Energy Administration, Monthly Energy Review, July 1976 (National Energy Information Center, Washington, D.C., 1976), pp. 2, 41, 70, 46. Various sources cited.

FIGURE 10.—*1975 U.S. energy consumption by sector*

	Percent
Industrial	25.8
Production of electricity[1]	28.5
Transportation	25.7
Residential and commercial	20.1

[1] Electric utilities.

Source: Federal Energy Administration, Energy Information report to Congress, Quarterly Report—First Quarter 1976 (National Energy Information Center, Washington, D.C., 1976), p. 104, Table 7-11 and, Federal Energy Administration, Monthly Energy Review, July 1976 (National Energy Information Center, Washington, D.C., 1976), pp. 2, 41, 70, 46. Various sources cited.

Given this comparison of energy source usage with consumption what are the prospective implications for economic growth in the next decade? The first problem may be the relationship between energy growth rates, need and demand.

The problem of "sustainable" energy growth seems weakest in assuming aggregate past demands as the basis for linear projection, e.g., at the rate of 4.8 percent of energy growth of 1974, for example, our energy consumption would double in 15 years. Needs are not the same as demands. Much of the apparent demand is artifically stimulated, sustained by inefficiency in use systems and end products and has a high waste factor. Our actual energy needs are thus overstated.

Could we sustain traditional economic growth with less energy consumption? This may be answered in several ways.

(i) *Energy consumption and GNP.* Here again, our standard assumption has been that energy use paced GNP growth. Whilst this may be true for developing societies and those in the heavy industry phase, it need not be so in the U.S. where economic development has shifted into post-industrial forms of growth which are less energy and material intensive in terms of performance per unit input of resources.

> . . . the changing composition of the GNP. Demand forces have (already) moved our economy towards more service output relative to a more goods output. This has, on the whole, resulted in a shift to a less energy intensive sector, especially where comparison is made between energy use over decades.[9]

Other aspects of this post industrial shift have already been noted with reference to:

"Resource Use and Technology Change", where the table of metals entering into volume production and the charts of technological development phases show the decline from central importance of the older heavy industrial processes requiring large extensive resource and energy inputs.

[9] *Mineral Resources and the Environment,* National Academy of Sciences, 1975, pp. 276-277.

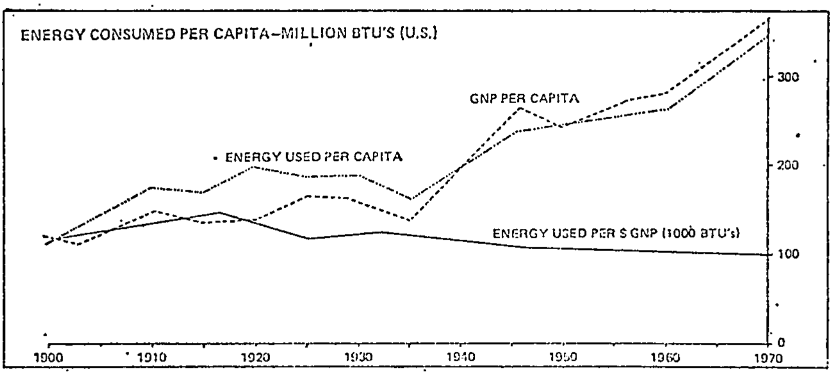
The emergence of "information as resource" which follows the above discussion and emphasises the changing profile of materials and energy intensivity which characterises the newer set of spectrum industries.

It should be underlined, again, perhaps that this is accomplished with less direct manpower and resource investment. By contrast, the newer industries comprising the post industrial core are more capital and knowledge intensive. In effect, therefore, they may offer opportunities for greater economic and social growth with less resource and environmental constraints than the older industrial forms. The shifts of manpower and social investments into human service systems also presages different growth directions for the society as is evidenced in the changing composition of the GNP noted above.

Recent projections of long range U.S. GNP relative to energy growth, appear to buttress these indications, "show only a tiny shortfall in gross national product by 2,000 even if the energy growth rate is cut from 3.4 percent per year, the U.S. average since 1950, to 1.7 percent." [10]

This rather startling conclusion is supported, for example, by the comparison of energy per dollar GNP in production compared with energy per capita.

FIGURE 11

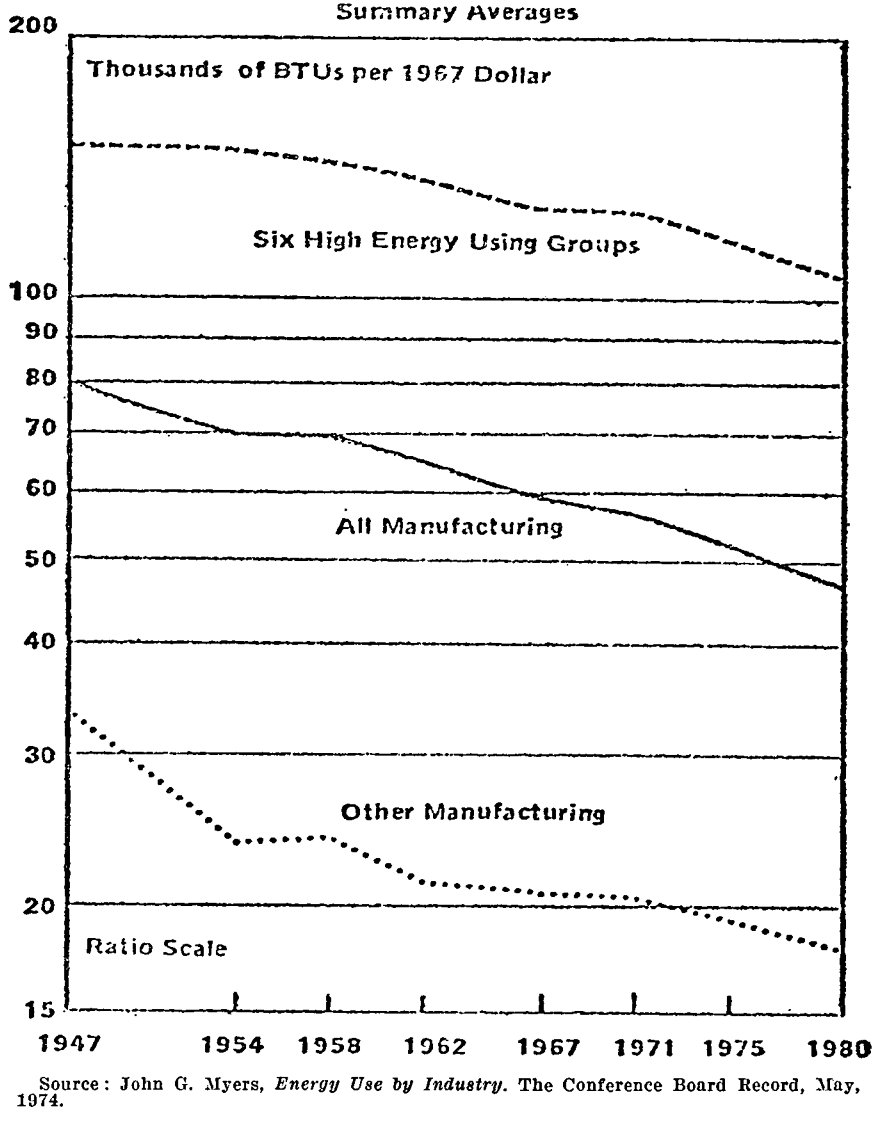


Source: Center for Integrative Studies.

Industry absorbs in total about 40 percent of all energy consumed including proportions of transportation and electrical energies as well as those used directly in production. As another study underlines, the shift to higher efficiency in energy use has particularly occurred in the large energy using areas of the industrial base—in primary metals, chemicals, stone, clay, glass, food and paper.

[10] Jorgenson, John G., *Energy Use by Industry*, The Conference Board Record, May, 1974, p. 32.

FIGURE 12.—Gross energy purchased per 1967 dollar of value added, 1947–80.



Source: John G. Myers, *Energy Use by Industry*. The Conference Board Record, May, 1974.

Significant savings in energy have been realised by the manufacturing sector. For example, energy use per unit of product declined at a 1.6 percent rate from 1954 to 1967. This was achieved in a period of stable or declining relative prices of energy.[11]

It is important also that the decline in energy use in the manufacturing industries examples was not governed by deliberate policies of energy conservation but by technological innovation and internal efficiency.[12]

The above analysis derives from an intensive study of six groups of industries accounting for nearly four-fifths of energy use in manufacturing. It is further supported by the 1975 report of the National Academy of Science which notes:

> . . . the important point is that even *before the days of recent changes* in the price and/or availability of energy raw materials, the forces of economic change were apparently working to *lower* the rates with which the U.S. economy used many raw materials and energy . . . the increased use of total energy per unit of GNP (in the years 1969–72) . . . was also a period of intense business activity to expand consumption of energy—using appliances, it was a period of large investment in air-conditioned structures—both commercial and residential.[13]

In policy terms, this may suggest that though higher pricing might affect individual energy demand, it is a declining factor in cost of product manufacture. Passing higher fuel costs down to the individual consumer level might seem to place energy costs on a more realistic basis and reduce demand, but this would have to be accompanied by more rigorous energy accounting and regulation throughout the entire use spectrum to affect real savings. It would also require appropriate incentives towards higher use efficiencies and disincentives to offset artificial demand expansion in appliance diversification, energy intensive temperative control of new construction and overpowered automobiles. Disincentives to over stimulation of energy consumption by advertising expenditures in such areas might be effected by taxing such expenditures—the revenue to be earmarked for energy conservation development.

(ii) *Growth in per capita energy use* in transportation, in products, for residential and commercial space heating and cooling, etc., illustrates specific areas of increased energy usage where considerable economics might be effected.

Transportation accounts for around 25 percent of the overall energy used in the U.S. Of this percentage over half is gasoline used in automobiles which are singularly wasteful in their fuel use with an overall end efficiency of about 5 percent. The problem here is not only wasteful fuel use with high environmental impact, but high built-in obsolescence rate in automobiles, with over stimulated demand for more production and marginally "new" models. Energy conservation by reducing auto speeds is a palliative measure only. More might be accomplished (i) by extensive restructuring of the auto industry towards smaller, longer life cars, higher fuel efficiency and more exploration in synthetic fuels, (ii) by providing more choices in mass transit

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[11] Myers, John G., *Energy Use by Industry,* The Conference Board Record, May, 1974, p. 32.

[12] Where deliberate attention has been given to this, the World Energy Conference, 1974, reported that some U.S. industries have cut total energy use by 40% between 1972 and 1974 through a combination of increased efficiency and conservation in use.

[13] Ibid. *Mineral Resources and the Environment,* National Academy of Sciences, 1975, pp. 276–277.

systems, e.g. railroads, local buses and other services which have been allowed to run down as they are no longer economically profitable. In some cases, transportation emphasis has moved to freight haulage where profitability is higher and direct and indirect subsidy incentives greater.

Residential and commercial space heating and cooling is another high energy area taking around 20 percent of our energy budget and absorbing one third of generated electrical power. Low insulation standards cause an estimated 30 percent inefficiency in all home heating and cooling systems. In addition to this there is the low efficiencies of appliances—with no design for their systemic interrelationship which might offload energy uses from one part of the system to another. Major appliances are also geared to swift obsolescence and over-stimulation of demand—with complete replacement of whole units rather than adequate maintenance and repair.

Electrical generation and use patterns afford similar examples of areas of high energy use at relatively low rates of efficiency with large amounts of waste energy. Given that most generating plants are operating at present mechanical limits, their distribution and use systems are still lower in efficiency. The Nation's electrical energy distribution system is a patchwork of quasi-independent utilities operating in a monopolistic mode with more or less captive consumers.

In all of these three major sectors of energy use, the prevailing market practices per se are unlikely to reduce consumption. Many of them are operating in the opposite direction—to over-stimulate demand. Some large consumers, for example, are outside of the commercial market system, e.g. the Federal Government itself and its various department programs consume large amounts of energy directly and indirectly.

The potential for energy conservtion, without cutting back on economic growth, is very large.

> International comparisons support the contention that the 1975 U.S. energy budget can be trimmed over time by more than one-half. For example, Sweden, West Germany, and Switzerland, with about the same level of per capita GNP as the United States, use only 60 percent as much energy per capita as does the United States. West Germany uses seven eighths as much fuel per capita as the U.S. for industrial production, one-half as much for space heating, and only one-quarter as much for transportation. None of these countries has begun to approach its full potential for energy thrift. The contention that the U.S. energy budget can be gradually cut by more than one-half without altering the nation's standard of living is almost certainly conservative.[14]

In reviewing overall energy need projections, in terms of the U.S. average of a 3.4 percent increase per year, several authorities appear to agree with the above statement of possible reductions in the energy budget without serious affects on standards of living and growth. Whilst the Federal Energy office has suggested that a 3 percent level could be achieved by 1980, the 1974 Energy Policy Project of the Ford Foundation claims that reduction to an average rate of 1.7 percent is feasible before that time, which concurs with the Data Resources, Inc. projections of the same year.

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[14] Sant, Roger, Assistant Administrator of the Federal Energy Administration, Private Communication; Lee Schipper, "Energy Conservation: Its Nature, Hidden Benefits and Hidden Barriers," Energy and Resources Group, University of California at Berkeley, 1975.

This would tend to suggest that the U.S. might be able to pursue adequate growth goals in the next decade and beyond by a mixture of policies—from conservation to real cost pricing through more rigorous energy accounting to the use of some alternate sources—which could cut energy consumption by close to 2 percent, at least, if not halving the growth rate to 1.7 percent.

The technical prospects for energy conservation are high. The actual prospects, in social and political terms, may be somewhat lower unless clearly defined priorities are placed on specific areas where conservation measures may yield the best returns.

In policy terms, a much more thorough and comprehensive review of the industries and consumer practices involved may be necessary to weed out inefficiencies, reduce levels of waste and high product obsolescence, and to encourage innovation and alternative energy sources exploration. This should be accompanied by a hard look at the direct and indirect federal subsidy programs, many of which may be found to militate against higher energy and materials conservation by subsidising obsolete and uneconomical practices.

Our discussion so far has been somewhat skewed towards oil and natural gas, what are the prospects for coal and nuclear power generation in the next ten years.

Coal has been somewhat displaced as a prime fuel partially through cheaper oil and gas and, more recently, due to its severe environmental problems as conventionally used and mined. The U.S. has one-third of the world's coal reserves, and if new technologies for improving the efficient conversion of coal to synthetic gas and oil are developed and its capacity for polluting reduced, then this could be a major renewed industry. For example, coal converts to oil; "with a yield of two or more barrels per ton, the two trillion tons of recoverable coal in the U.S. is equivalent to more than four trillion barrels of oil—ten times the total known worldwide oil supply." [15]

Even if coal could be the basis for a new synthetic fuels industry, however, there are considerable environmental problems, (*a*) of access, whose history is visible in strip mining around the country, (*b*) of byproduct pollutants in coal processing. These are certainly soluble with available technology but would require more social and economic pressures to resolve.

Nuclear power faces some of the same problems—and other hazards of longer term radioactive by-products disposal—though it could potentially supply a large part of U.S. energy needs. It is presently limited to electrical power generation and provides about 9 percent of our electricity but it could provide much more and be more varied in its applications. The pros and cons in the nuclear debate have been dealt with exhaustively in the daily press and scientific literature. In the long range, via the development of *fusion* rather than fission reactors, it is probably one of the most compact and relatively inexhaustible energy sources available.

In summarising the nuclear debate, Alvin Weinberg one of the key authorities in the area, emphasizes not only the technological and environmental aspects but the social costs of nuclear options.

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[15] Hill, George R., Electrical Power Research Institute, *The Sciences*, December, 1973, p. 10.

We nuclear people have made a Faustian bargain with society. On the one hand, we offer . . . in the catalytic burner . . . an inexhaustible source of energy . . . but the price that we demand of society for the magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to . . . to be sure we shall steadily improve the technology of nuclear energy; but short of developing a truly successful thermonuclear reactor, we shall never be totally free of concern over reactor safety transport of radioactive materials, and waste disposal.[16]

In a later statement this year, Weinberg calls for a more extensive review of nuclear energy options and advocates a phased policy of its use which would include among other things, the clustering of nuclear parks in isolated areas with the development of a dedicated "nuclear cadre" to ensure the necessary levels of vigilance. But this is a longer term view than that with which we are presently concerned.[17]

It seems unlikely that nuclear generated power will add significantly to our energy budget for the decade under consideration—though, obviously, decisions will have to be made in that period with regard to speeding or retarding its wider use. Whilst the breeder reactor program has high priority in the U.S. energy research program, other countries already have plans for commercial reactors of this type to be on line by 1986. The economic ramifications of this are difficult to assess but likely to impact in the 1990's. By then, unless the United States has decreased its energy growth rate and rationalized its energy policies it could face some difficulties in competitive pricing for energy intensive products, but this may be obviated by equivalent decline in fossil fuel prices.

Alternative sources of energy are unlikely to be developed on a large scale in the given time period of the next decade. Almost all are longer term prospects—but it is crucially important that many of them be given high research and development priorities within the next five to ten years. The obvious candidates are solar energy, fuel cells of various types, wind and tidal energies, fuels from organic and industrial wastes, geothermal source development and the possibilities of hydrogen and hydrogen-based fuels.

Even where none of these alternatives might make major contributions to overall energy supply in the short range, i.e. *within the decade*, they are extremely important areas for resource allocation for research and development, both in the sense of unanticipated break through and in the specific ways in which they may offload fossil-fuel consumption and encourage locally autonomous non-polluting systems—particularly in the cases of solar conversion for residential purposes and community/industrial uses for wastes derived fuels.

Of course a perfectly functioning free market would presumably anticipate scarcity versus demand by the "price-rationing" of com-

The Role of the Energy Market

The question "can the market be relied upon to provide the necessary adjustment to potential scarcities" begs, in turn, several questions about the market as such.

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[16] *Social Institutions and Nuclear Energy,* Alvin Weinberg, Science, July 7, 1972, pp. 33–34.
[17] Weinberg, Alvin, *Is Nuclear Energy Acceptable,* Purdue University Dept. of Nuclear Engineering Distinguished Lecture, April 20, 1976, (mimeo).

modities over time, and by forcing competitive substitution, where resource scarcities appear.

In energy—from extraction and processing through various end uses and products—we cannot refer to a free market in the classical sense. It is an elaborate hybrid market system in which relatively monopolistic corporate control, ranging through all aspects of energy production, distribution and end use), operates within a structured environment involving considerable governmental intervention. Some of the latter is advantageous to the industry in the form of preference tax incentives, indirect subsidies and quotas; some is restrictive as to pricing, public land use and lateral integration. This produces a system in which the consumer components have little or no direct participation in the balance of market forces. The domestic structure is further compounded by international cartelisation of the energy industry on one side and by nationalised governmental structures with political uncertainties on the other.

Given its hybrid, extremely complex and unbalanced character, the domestic market system is particularly unwieldy in its ability to provide swift adjustment to strains or shortages in energy supplies and in its capacity to give longer range anticipatory guidance on energy policy directions. The experience of the past few years particularly seems to confirm this observation. Pivotal policy roles cannot be left to the market per se.

No system of additional incentives or restraints applied piecemeal seem likely to aid the market's capacities in this respect—in the absence of a more coherent comprehensive and official energy policy. This may not, and perhaps should not, be done entirely by government but by virtue of governmental intervention in the market and by its representation, ideally, of all interested parties, it should be the prime initiating, guiding and regulating agency.

The development of comprehensive energy policy requires a much more coordinate. and open, review and control process in which industry, government and consumer interests participate on a more continuous basis—to anticipate supply strains. regulate critical areas of consumption and oversee resource allocation for longer range research and development of conventional and alternative energy sources and uses.

The necessary short term adjustments can only come from deliberate policies designed to decrease oil and natural gas consumption through conservation and greater efficiency in their use whilst longer term adjustments to a more diversified fuel economy are sought through the development of alternative sources technologies and growth patterns. It has been indicated in various areas of previous discussions such policies need, in no way, constrain the economy but by encouragement of innovation and enterprise can provide opportunities for more diversity and selectivity in its future growth.

4. The Materials Outlook

The assessment of non-fuel resources for the next decade is rather different from that of energy supplies. The array of energy sources is more limited than that of metals and minerals and the range of options, alternatives and substitutions in the latter is much wider. An additional difference is that energy is much more dispersed in use. We "consume" energy in utilising it whilst we do not deplete or consume materials. Materials are extracted, assembled or dis-assembled for various purposes but they are not used up or lost in the process. Some may become too dispersed after use for economic recovery and re-use but, by and large, materials use can be considered as more cyclical than energy. The distinction may be seen more clearly in the case of the fossil fuels and other combustion use materials where the degree of disassociation is too high to refer to "renewal" in less than geological time. On the other hand, where such resources are used in non-combustion ways, such as petrochemicals, they can be disassociated and recombined in many different re-usable forms.

The use of terms like depletion and consumption in materials usage is reflective of an older economic calculus based on "one-way" use criteria.

When we refer to material resources, we are really discussing the ways in which the physical elements are found in various combinations in the earth's crust, the oceans and the atmosphere. All of these dispositions are in various stages of cyclical change. Some of these changes occur at the level of geological time and are not so relevant to our short cycle needs; others, such as nitrogen, oxygen and phosphorus are in briefer periods of change in various environmental cycles: Industrial use is also cyclical—products can take from 3 to 25 years to be re-cycled.

Our *net* reserves, therefore, should include all materials in present use, those in junked form as well as in stockpiles and mineable reserves. The earth's crust, the oceans, the air are the *gross* reserves from which to draw materials and, ultimately, where we return them. Then there is the "organic" stock of renewable materials from forestry and agriculture as embracing the "common" set of air, water, soil, plants and animals. *In terms of an adequate conceptual frame, we need to view the whole of the environmental system and its complex series of regenerative interchanges and combinations as a model for our material use systems.*

Industrial growth in the past century has been specifically characterised not only by the enormous increase in the amount of materials used but the expansion of the range of the material elements coming into use. (See figure 2 on p. 11).

> Since 1900 a host of new substances, metals and minerals have come into common use. Germanium, thorium, vanadium, beryllium, tungsten, selenium, molybdenum, and titanium are a few examples of odd elements that only 100 years before were either unknown or recognised only as mineralogical curiosities. Today a great number of them are components of our industrial technology, and it is an unusual element indeed that does not have a scientific or industrial application.[18]

Significantly, of course, many of the new entries on the industrial menu are not used in anything like the same quantities as the older staples like iron, but in relatively small amounts for alloying and other purposes and in comparatively fractional amounts in electronics. The

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[18] Frasche, D. F., *Mineral Resources*, Report to U.S. Committee on Natural Resources, National Academy of Sciences, National Research Council, 1962.

increasingly diverse menu means, however, that no nation is wholly self sufficient in the range of elements required for advanced technological processes. We may note, as a passing example here, the standard telephone handset which uses upwards of 27 different material elements drawn from over 20 countries around the world.

The Availability of Materials

Recent price changes on the world market combined with political uncertainties and the emergence of the energy crisis has encouraged predictions of impending scarcities and possible exhaustion of material resources at the world level. Such predictions appear to have little basis in reality and suffer from specific weaknesses:

One of the key policy relevant key problems on this area and in that of energy resources, is the availability and reliability of information.

Much information available in government files, but much is in the hands of private organisations . . . current resource estimates could be greatly improves if these two categories of information could be brought together in such a way, and in such timing, that a running inventory of resources could be maintained.[19]

(i) *Reserves' estimation* is conventionally based on so-called available proven reserves. If considered wholly in terms of current prices and technology and linearly projected "consumption", these can be shown to last theoretically, in some cases, for only thirty to a hundred years. But even proven reserves are steadily increasing through wider exploration, technological sophistication in extraction and changing demand; for example, "reserves" of copper have risen by 3.5 times since 1935; of bauxite 7 times since 1950; metals and minerals available data suggest that in many cases these are ample for almost every material in the next fifty to a hundred years. (See figure 13.)

FIGURE 13.—Proved world reserves of selected minerals.

More Than 100 Years:	Cobalt	15–25 Years:
Columbium	Asbestos	Copper
Potash	Molybdenum	Lead
Phosphorus	26–50 Years:	Tin
Magnesium	Manganese	Zinc
51–100 Years:	Bauxite	Tungsten
Iron Ore	Platinum	Barite
Chromite	Titanium	10–15 Years:
Nickel	Antimony	Mercury
Vanadium	Sulfur	Silver

Source: Special Report, Critical Imported Materials, Council on International Economic Policy, December, 1974.

The Table (Fig. 13) of proven world reserves expressed in terms of years of adequate supply should be read with caution. For many of the metals of the 10–25 years level, the rate of recycling, sub-

[19] Varon, Bension, *Enough of Everything for Everyone Forever*, Finance and Development, Vol. 12, No. 3, September, 1975.

stitution capacities and growing intensity-of-use alters the picture considerably. Figures here are also *proven* reserves. The amount in undiscovered sources is still great and the crustal abundance is even greater—given the energy and environmental costs of extraction.

Reserve Quality. The expanding reserves concept has often been criticised as including those which cannot be economically exploited as the ore quality of the reserve may be much lower. This, in most cases, is a function of energy, price and environmental considerations.

Copper may be a useful example here, where the economically mineable grade has gone from 3 percent to 0.3 percent since 1900. The energy cost of extraction has risen but not in due proportion to the grade decline; prices have remained relatively steady; environmental costs have risen when measured in terms of overburden to be removed and rock crushed and milled. Each cost is reduced, however, by the increased use of recycled copper.

A viable approach may be assumed for most metals of this type, i.e. as ore grades decline, extraction processes tend to improve; if prices rise, substitutions are called into service; environmental costs can be reduced by better management and offset considerably by greater efficiency in primary and secondary materials usage.

Above ground reserves. Conventional reserves figures omit materials accumulated in use over the years. For interest, we have computed here the total cumulative production of selected materials between 1870–1973 which also gives this accumulation as a percentage of world reserve. (See figure 14.)

More conceptual emphasis is now being placed on this in-use pool of resources as recycling and substitution techniques improve and as the idea of materials-in-flow gains ground. This emphasis also includes the renewed interest in the recycling of municipal garbage and agricultural wastes, for fuel and materials re-use; reclamation of resources "stored" in auto and obsolete machinery dumps: progressive reprocessing of extractive tailings—and other kinds of processes which extend to the architectural rehabilitation of older structures to purposes, rather than tearing down and building new.

An in-use pool represents a stock of any material which is theoretically, but seldom actually, totally available for reuse. The in-use pool of copper in the United States is presently a little over 50 million tons compared to 60 million tons of domestic primary production—since 1840—or about 75 million tons including imports. Thus. about two-thirds of all copper ever used in the U.S. is still available for recycle one or more times in the past. The amount of copper in the domestic in-use pool represents annual consumption of 1.4 million tons/year.[20]

[20] Goeller. H. E.. Senator Chemical Engineer, ORNL–NSF Environmental Program. Oak Ridge National Laboratory. Oak Ridge, Tennessee, *An Optimistic Outlook for Mineral Resources*, paper presented at the University of Minnesota Forum on Scarcity and Growth: Toward a National Materials Policy, sponsored by the National Commission on Materials Policy, June, 1972.

FIGURE 14

METALS–MINERALS, CUMULATIVE PRODUCTION TOTALS: WORLD AND UNITED STATES

WORLD

[Production and reserves in million metric tons]

	Period	Production	Reserves	Cumulative production as a percent of reserves
FERROUS				
Iron [1]	[2] 1870–1973	21,741.9	[3] 90,518.6	24.02
Steel	1870–1973	13,430.5		
Chromium (chromite) [1]	1870–1974	118.9	1,692.5	7.0
Cobalt [4]	1905–74	.53	2.45	21.6
Manganese [1]	1870–1974	434.0	1,814.0	23.9
Molybdenum [5]	1905–74	1.41	5.99	23.5
Nickel [4]	1807–1974	12.6	45.26	27.8
Tungsten [6]	1807–1974	1.8	1.78	101.1
Vanadium [6]	1939–74	.27	9.7	2.8
NONFERROUS				
Aluminum [7]	1893–1973	152.3	[3] 1,059.9	14.4
Antimony [4]	1925–74	2.24	4.14	54.1
Beryllium [1]	1935–74	.056	.380	14.7
Cadmium [4]	1925–74	.37	.753	49.1
Copper [1]	1887–1974	199.45	408 2	48.9
Magnesium [6]	1938–73	4.5	2,358.2	.2
Lead [1]	1887–1973	96.8	149.7	64.7
Tin [4]	1870–1973	12.9	10.14	127.2
Titanium [8]	1925–74	52.0	340.1	15.3
Zinc [1]	1887–1974	153.5	135.1	113.6

[1] Ore.
[2] 1946–1947 excluded.
[3] As of 1969– 70.
[4] Metal content.
[5] Ore and concentrate.
[6] Concentrate.
[7] Primary metal.
[8] Concentrate; ilmenite and rutile combined.

Data: Various sources, compiled Center for Integrative Studies.

FIGURE 14—Continued

METALS-MINERALS, CUMULATIVE PRODUCTION TOTALS: WORLD AND UNITED STATES—Continued

UNITED STATES

	Period	Production	Period	Cumulative production as percent of reserves	U.S. years of supply-projected demand [1]
FERROUS					
Iron [2]	1870–1973	5,334.2	1875–1973	147.03	38.5
Steel	1870–1973	4,608.8	1929–73		
Chromium (chromite) [2]	[3] 1870–1961	1.9	1948–73		[4] 0
Cobalt [5]	1943–74	.021	1943–73		[4] 0
Manganese [2]	1880–1974	5.58	1880–1973		[4] 0
Molybdenum [6]	1915–74	1.11	1915–73	370	61.4
Nickel [5]	1870–1974	.259	1871–1973	3.4	62.2
Tungsten [7]	1900–74	.148	1940–73	137	26.2
Vanadium [7]	1911–74	.12	1955–73	115.4	8.6
NONFERROUS					
Aluminum [8]	1893–1973	58.7	1918–73	91.9	2
Antimony [5]	1925–74	.056	1944–73	61.5	4.01
Beryllium [2]	1935–66	.01	1936–73	40.0	54.0
Cadmium [5]	1925–74	.13	1929–73	79.8	23.3
Copper [2]	1870–1974	60.4	1870–1973	74.0	37.4
Magnesium [7]	1938–73	1.83	1948–73	14.9	6.97
Lead [2]	1870–1973	32.4	1870–1973	86.5	53.5
Tin [5]	1920–73	.543	1870–1973	10,627.9	1.0
Titanium [9]	1925–74	16.4	1940–73	57.1	37.7
Zinc [2]	1870–1974	42.5	1870–1973	156.3	16.7

[1] Based on Bureau of Mines low forecast projections, (Mineral Facts and Problems, 1975 Edition) of cumulative demand to year 2000 computed as average demand per year. 1973 is the base year for Bureau of Mines forecasts and for determination of years of supply.

[2] Ore.

[3] No U.S. production since 1961.

[4] Other U.S. resources—estimated quantities recoverable in the future on the basis of new technology and/or changes in price—were not considered.

[5] Metal content.

[6] Ore and concentrate.

[7] Concentrate.

[8] Primary metal.

[9] Concentrate; ilmenite and rutile combined.

Data: Various sources, compiled Center for Integrative Studies.

Large amounts of these above ground reserves are around us in various degrees of recoverability in present structures, in factory dumps, in stockpiles, mothballed ships, obsolete equipment and other forms.

(ii) *Changing Materials Usage.* Though attention has been focused on the high growth in materials' use over the past fifty to a hundred years less has been given to changes in materials' use intensity. In advanced countries, increased economic growth in recent years has not been accompanied by concomitantly increased use of materials in many specific cases.

A broad measure is provided by the value of (U.S.) total resource output (minerals, lumber, agriculture) relative to gross product. This ratio was 0.36 in 1870 and declined to 0.21 in 1920. A further decline to 0.12 took place in the next 25 years: the rate of decline more than doubled. From 1920 to 1954 the share of minerals alone declined by 50 percent. In the decade, 1957–66, industrial production increased by 57 percent use of important minerals expanded by well under 20 percent (e.g. copper 18.6 percent; steel 16.4 percent; zinc 4.2 percent) while the use of alloy steels increased 49 percent; aluminum 77 percent; synthetic rubber 82.5 percent; and plastics 240 percent. As the precision of material production improves, as end use products are standardised, as materials strength is enhanced, less input is needed for a given output.[21]

Malenbaum, quoted above, has analysed intensity-of-use characteristics for a variety of resources. His projected data for the U.S. is given in Figure 15.

This growth in capacity to "do more with less" also corresponds in general terms to what we have characterised as the post-industrial shift in materials' usage technologies and paces the decline in energy intensity per GNP unit already discussed.

FIGURE 15

UNITED STATES:[1] INTENSITY OF USE (PER BILLION DOLLARS GDP)

Commodity	1951–55	1966–69	2000
1. Crude steel (1,000 metric tons)	157	136	85
2. Iron ore (1,000 tons)	102	76	45
3. Refined copper (metric tons)	2,240	1,920	1,400
4. Primary aluminum	2,090	3,480	5,000
5. Zinc (metric tons)	1,480	1,230	900
6. Fluorspar (metric tons)	890	1,140	1,300
7. Sulfur (metric tons)	9,060	8,860	8,500
8. Total energy (1,000 metric tons coal equivalent)	2,160	2,070	1,875

[1] Includes Puerto Rico and overseas islands.

Source: Malenbaum, Prof. Wilfred, "Materials Requirements in the United States and Abroad In the Year 2000," U.S. Department of Commerce, March 1973, p. 33.

Coupled with the accumulation of stock of goods in service, of saturation of demand for many products and materials, and with stable or declining populations, it suggests that the draw down on material resources by the technologically advanced nations will decrease relatively over the next few decades. In the case of the U.S., the conventional picture of a disproportionate use of such resources is distorted by the fact that the U.S. is also a large exporter of both raw materials and manufactured products.

[21] Malenbaum, Wilfred, *Materials Requirements in the United States and Abroad in the Year 2000*, National Technical Information Service, U.S. Department of Commerce PB–219675, March, 1973.

(iii) *Recycling and Substitution Factors* also affect estimates of reserves. As the materials' recycling range is increased, more go into multipurpose use cycles. (See figures 16 and 17.)

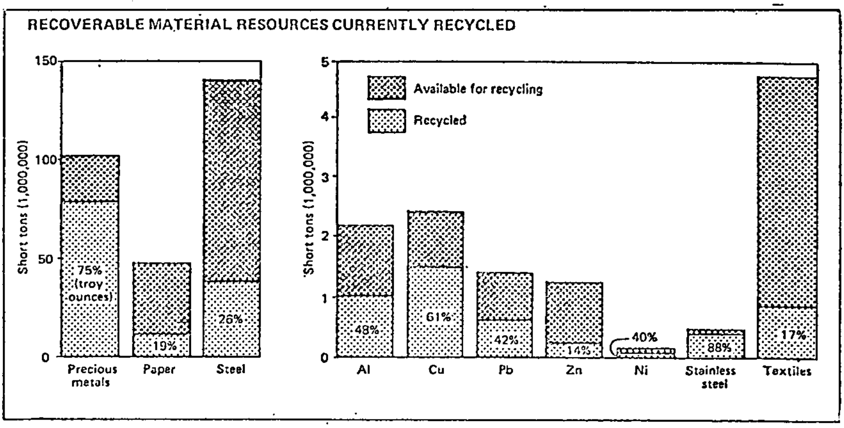
Recycling means gains in the economy of energy use and, importantly, reduction in social and environmental costs. In many cases, this could reduce the energy burden and processing costs for new raw materials.

Materials' substitution works in several ways to enhance the supply/reserves situation. One is the simple substitution of one material for another, e.g., copper for conductivity is supplemented by other metals and non-metallics giving comparable performance. The range of possible substitutions of this type is very large. (See figure 18.)

The other kind of substitution is *functional*, where a wholly different way of carrying out a specific function is developed, e.g. nuts and bolts replaced by adhesives, communications substituted for physical transportation, microminiaturized electronics in place of bulky mechanical systems for various purposes, plastics and composite materials replacing metals.

The range of such possibilities is increasing rapidly as the molecular design of materials to specific function is enhanced and as new functional substitutions are made. Such replacement and displacement of traditional functions is accompanied by changes in demand in the materials range and, in many cases, by a marked decrease in economic, social and environmental costs.

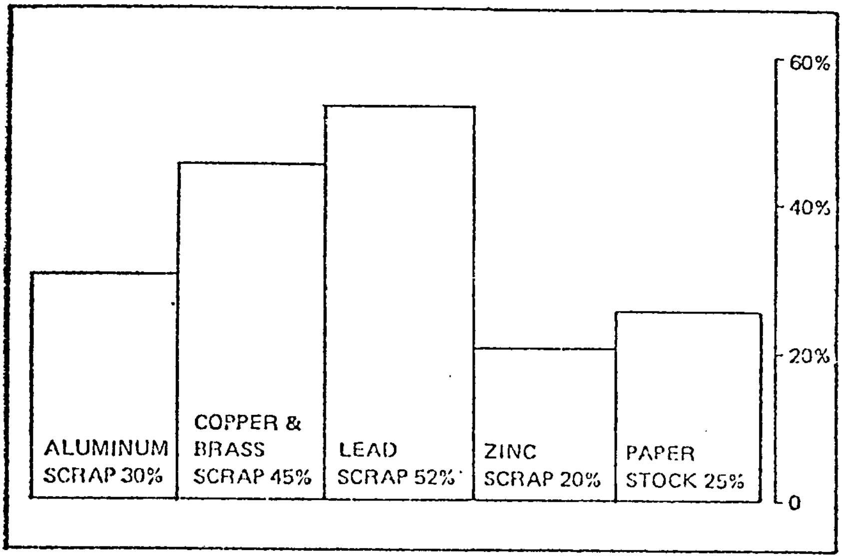
FIGURE 16



Data: Environmental Science & Technology, Vol. 6, No. 8, August 1972, p. 702.

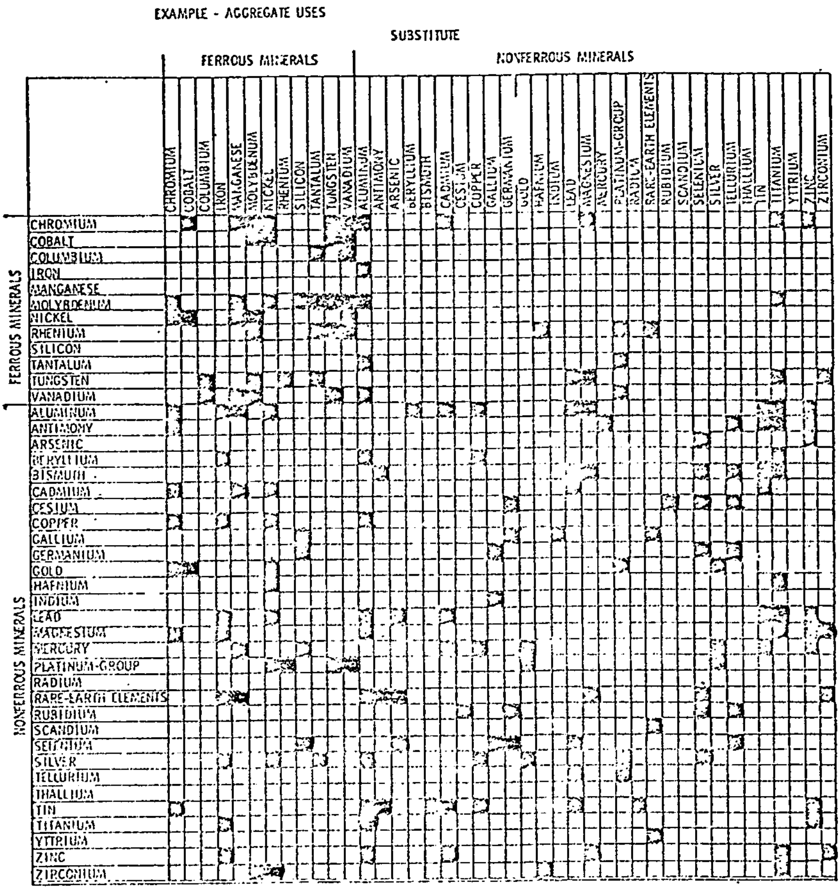
FIGURE 17

SECONDARY PRODUCTION ACCOUNTS FOR A MAJOR PORTION OF RAW MATERIAL SUPPLY



Adapted from "The Economics of Recycling Waste Materials," hearings, Subcommittee on Fiscal Policy, Joint Economic Committee, 92d U.S. Congress, Nov. 8 and 9, 1971.

FIGURE 18



SUBSTITUTION MATRIX WORKSHEET

NOTE: FILLED IN BY USBM COMMODITY SPECIALISTS.

Source: World Mineral and Energy Resources: Some Facts and Assessments by J. N. Hartley with contributions from E. A. Eschbach and O. J. Wick, Battelle, December 1974.

U.S. Materials Position

One key aspect of the critical nature of the potential demand for various materials is related to dependence on external supply. This is reflected in the accompanying table of net imports of selected commodities. (See figure 19.)

Of the nineteen materials listed, some are only required to augment domestic production, others are more critical where no sizeable deposits are available within the U.S. or where it is preferable to import rather than exploit domestic sources.

The critical import list may be reduced to nine metals in terms of current usage—chrome, aluminum, platinum, iron ore, nickel, natural rubber, manganese, zinc, and tin. Their critical aspects may be summarized as follows: [22]

Chrome. None mined in the U.S. Use of recycled metal supplied about 10 percent of 1973 demand, plus 20 percent from strategic stockpile sales with 70 percent imported.

Aluminum. As metal and bauxite are only price critical. If external supplies become more costly, domestic aluminum-bearing clays could become competitive but it would take more R. and D. investment on a true scale of up to twenty years for self sufficiency at present use rates.

Platinum. None mined in the U.S. In major catalytic uses is recoverable with only 1 to 2 percent loss, and higher price substitutes could be developed.

Iron Ore. Relatively self sufficient. Even where 30 percent is imported, domestic production from existing reserves could be increased if this position became difficult in terms of competitive pricing.

FIGURE 19

U.S. NET IMPORTS OF SELECTED COMMODITIES

	Net imports 1973 (millions)	Net imports as percent 1973 consumption [1]	Major suppliers 1969–72 [2]
Alumina	$209	35	Australia (50), Jamaica (22), and Surinam (18).
Bauxite	143	90	Jamaica (54), Surinam (23).
Chromium	63	70	U.S.S.R. (32), South Africa (30), and Turkey (18).
Platinum group metals	145	95	United Kingdom (39),[3] U.S.S.R. (32), and South Africa (12).
Iron ore	534	28	Canada (50), Venezuela (31).
Nickel	544	65	Canada (82), and Norway (8).
Natural rubber	347	100	Malaysia (40), and Indonesia (39).
Manganese	100	82	Gabon (35) and Braz l (33)
Zinc	303	48	Canada (60) and Mexico (24).
Tin	215	65	Malaysia (64) and Thailand (27).
Titanium	48	29	Japan (73), U.S.S.R. (19), and United Kingdom (8).
Cobalt	54	95	Zaire (45), and Belgium-Luxembourg (29).[4]
Mercury	12	78	Canada (59) and Mexico (17).
Tungsten	27	41	Canada (61) and Peru (9).
Lead	27	17	Canada (29), Peru (21), Australia (21), and Mexico (17).
Columbium	NA	63	Brazil (62), Canada (16).
Vanadium	NA	25	South Africa (55) and Chile (35).
Flourspar	52	83	Mexico (77) and Spain (12).
Copper	143	5	Canada (31), Peru (27), and Chile (22).
Phosphates (U.S. net exporter)			

[1] In quantity terms. Calculated by dividing net imports by total consumption. In some cases consumption includes withdrawals from (or additions to) Government and/or private stocks.
[2] Figures in parentheses are in percent.
[3] United Kingdom sources for raw materials are South Africa, Canada, and U.S.S.R.
[4] Of Zaire origin.

Source: Special Report, Critical Imported Materials by the Council on International Economic Policy, December 1974.

Nickel. Essentially price critical, i.e. if external prices doubled U.S. import dependence could be cut from 65 percent to around 20–30 percent.

[22] Based on the *Special Report: Critical Imported Materials*, Council on International Economic Policy, the White House, December 1974.

Natural Rubber. Use and supply closely related to the competitive pricing of synthetic rubber. U.S. completely dependent on imports for natural rubber but availability of substitutes is likely to assure supply.

Manganese. U.S. wholly dependent on imports, but large world reserves and diversity of potential suppliers render this position more favorably.

Zinc. Import dependency for about one-half of supply. Domestic production could be expanded to reduce this in three to five years, or less if necessary.

Tin. Import dependency for about two thirds of supply but secondary recovery and substitutions could be expanded. Stockpile also held of about 2-year U.S. requirement.

In assessing the U.S. reserves of some 70 non-fuel and fuel resources (including uranium and petroleum), the National Commission on Materials Policy 1973 estimated "identified domestic sources" on a scale through huge, very large, large, moderate, small and insignificant. Excluding twelve of these, with insufficient data to estimate, only six were identified as small or insignificant in terms of potential domestic supplies, i.e. antimony, asbestos chromium, fluorine, mercury, mica.[23]

As will be noted from the above discussion, however, even where certain materials are wholly import dependent for the U.S., there is no critical world scarcity. The question is one of adequacy of supply, not merely one of self-sufficiency. Whilst noting that, "the U.S. is importing some materials that could be produced domestically because of price", the National Commission on Materials Policy 1973 underlined that certain items may be critically important where no U.S. source exists, In most cases, however, the diversity of external supplies seems to indicate no apparent shortages in the next ten years relative to possible embargoes or OPEC type cartelization. Increased price competition may increase manufacturing costs, but as raw materials constitute a relatively small fraction of such costs, this does not appear to be a critical growth factor for the U.S. other than where it may influence balance of payments or force the pace in domestic exploitation with other resultant energy and environmental costs.

Though the U.S. industrial materials outlook is good, the main problems are likely to come from economic availability rather than physical scarcity. The former depends on "market forces" not all of which may be of a wholly economic character, but rather effected by social and political changes both within and outside of the U.S. Instead of depending wholly on the invisible hand of such forces, however, healthier directions for U.S. growth should be sought in terms of policies which emphasize:

More efficient use of materials by increasing their performance per unit input, by recycling and waste reduction and by cutting rapid obsolescence in certain areas of product use. In effect, we need to design into products their disassembly and recycling phases, e.g., where plastics may be made bio-degradable or, as in military aircraft manufacture, where alloy composition may be

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[23] *National Commission on Materials Policy, Final Report,* June 1973, pp. 4B–8, 9.

stamped on components to aid recovery on scrapping. Production and use and scrapping should be gauged in terms of the whole materials use cycle.

Increased research and development in materials use technologies and substitutions at each stage in the industrial process—including more comprehensive energy accounting in extraction, production, manufacture, distribution and end use.

External policies and agreements for more equitable access to the world resources pool—not only with regard to U.S. requirements, but in terms of equity of advantage and sharing for all participants in the world economy.

The latter point is an important one for future growth policies. One of our major market areas, for example, is the EEC group of nations—which U.S. aid policies helped reconstruct after World War II. The same advantages for mutual benefit should now be explored with the lesser developed nations. Their development and growth should not be viewed simply in aid terms but a mutually reciprocal basis. They are in dire need of many comodities of the advanced nations, such as the U.S., and more innovative trade linkages could be explored than are presently used. The return on investment might be much longer-term than the EEC case but the potential is much greater for both the U.S. and for the greater stabilization of world economy on which our future growth ultimately depends.

THE MARKET AND POLICY

The market structure in the materials area is more complex than that of energy as, (*a*) it deals in a vastly greater range of raw materials, processes and end uses, (*b*) it is, therefore, much more diversified in the number of businesses, degree of competitive practices and vertical integration. This very complexity of the myriad interdependencies and interlinkages of extractors, primary and secondary processors, by-product uses, etc. each acting with limited responsibility for their own sector, makes it difficult for the "market" to adjust to very rapid changes in supply positions. It is also a hybrid market structure in which government intervenes to a considerable degree via regulation, taxing and subsidy procedures.

In some of the more critical areas of materials supply it is unlikely that the commercial market *alone* could act with sufficient flexibility to safeguard the economy from potential scarcities due to higher pricing and tight supplies. Also, as we shall later discuss, the more systemmatic kinds of materials use policies which may be necessary to sustain prefered growth directions would require a much closer working relationship between the "market" and government.

Towards a Regenerative Resource System

In terms of a more adequate energy and materials' policy we need to move in the next ten years towards a *regenerative resource system* which emphasises the more efficient performance per resource unit used. This speaks to the needs of a more diversified conceptual frame for growth—as going beyond the fiscal economy towards the inclusion of social and environmental costs and growth advantage.

The idea of a regenerate resource system expands our immediate considerations of U.S. resource adequacy towards a more fundamental assessment of industry, agriculture, services and other human systems in terms of potentialy *symbiotic* and *regenerative* modes of using energy and materials—as an external *metabolic system*. Just as we have successively mapped the flows of vital elements in our internal body metabolism so we now need to begin to do the same for our external metabolism—which comprises all the ways in which we use energy and materials in the overall economy.

This approach should be extended to include not only industrial and agri-industrial uses, residuals and pollutants but also the overall flow of energy and materials in our domestic, urban and other sectors. It would be a physiological rather than merely a pathological approach as at present—where we rush to identify economic and environmental malfunctions in one sector without much regard for its relationship to the larger system. Within such an approach, social and environmental factors may be found to be economically advantageous rather than the reverse. Currently piecemeal attention to pollution, "wastes" and "residuals" disposal is often costly because we have no systemic ways in which to extract valuable materials presently labelled as pollutants; we burn, bury, or void into rivers and lakes, large amounts of resources as industrial urban or agricultural wastes—or we engender considerable expense in getting rid of a noxious residual in one industry whilst another industry may be producing the same substance as its primary product.

In effect, we need to review our energy and materials use systems in more organic, biological as well as in more economical and rational terms. At present, most parts of our agri-industry economy work in comparative autonomy. We have extractors, primary processors, secondary manufacturers, end-users and their sub systems—with the scrapping and reclamation sectors at still greater remove. Whilst each may operate relatively efficiently, the overall system efficiency is low. In many cases, the flow from raw material through end-use to scrapping and re-use could be optimised at much lower economic, social and environmental costs, and thereby allow for more diversified growth at less overall cost.

As may be seen in the accompanying figure 20 of the average life cycles of products, many are in very short lifetime uses whose more systematic organisation via closer industrial collaboration could, (*a*) extend product lifetimes where applicable, (*b*) effect considerable energy and materials investment by broadening responsibility for resource conservation through the entire cycle from primary processing through end-use to re-use. In some isolated cases, now observable in aluminum cans, where the cycle from manufacture to recycle is brief and clearly identifiable, the materials system might be based more economically, organised on rental/lease to govern the whole cycle, thereby spreading the responsibility for economy of use and conservation of resources.

More symbiotic relationships could be designed between primary processors and by product users by optimising alternative process paths to specific products thus providing more efficient by-product utilisation of wastes and residuals.

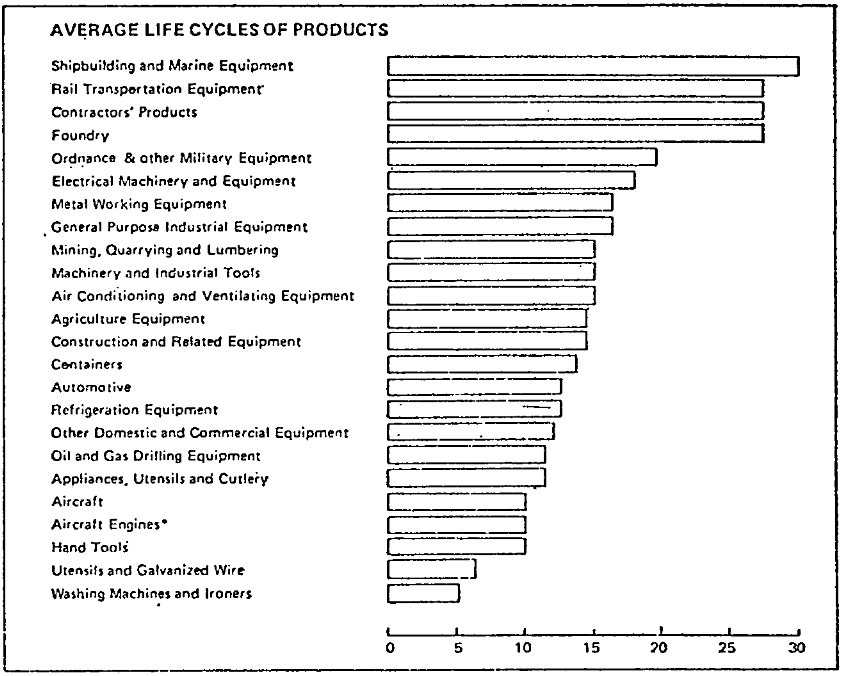
In larger terms, one may envisage the much tighter relationship as now possible in the overall market continuum with the capabilities inherent in new information and communications capabilities already described. (See figure 21.)

This figure suggests how various stages could be strengthened to increase feedback through subsystem in the continuum enabling adjustments to be made more swiftly to meet changing profiles of resource availability and market/consumer needs. This would contribute greatly towards stabilising the economy, allow for swifter identification of key growth points and enhance longer range forecasting and planning capabilities.

Policies for a Regenerative Resource System

Some of the technical basis for devising such policies may be found in input/output techniques, energy accounting, materials flow studies and in areas of technology assessment.

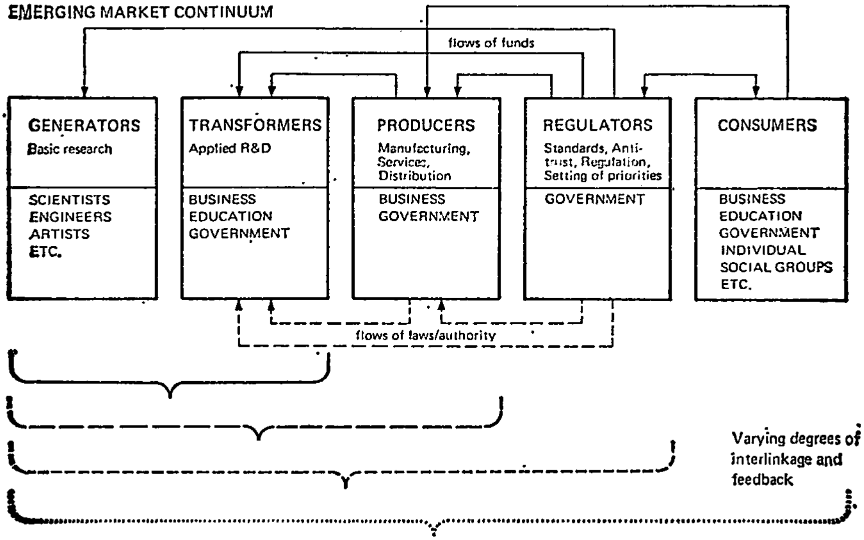
FIGURE 20



* 1. 3–10 years depending on the type, size, etc.
2. Classifications above are for steel based products.
3. Metals now average 42 years in building: weighted average—total refined metals recirculated every 22 years with variable loss.

Adapted from:
1. McHale, John, World Design Science Decade. 1964–1975. Document 4. *The Ten Year Program.* Carbondale, Illinois. World Resources Inventory, Southern Illinois University, 1965.
2. Survey and Analysis of the Supply and Availability of Obsolete Iron and Steel Scrap (Revised edition) Columbus, Ohio, Batelle Memorial Institute. 1957.
3. Iron and Steel Consumption Problems, Washington, D.C., U.S. Department of Commerce, June 1967.

FIGURE 21



Source: "The Changing Information Environment: A Selective Topography," J. McHale, Chapt. in "Information Technology: Some Critical Implications for Decision Makers, 1971–1990," The Conference Board, N.Y., 1971.

Specific policies to encourage approaches to such a system might include:

(i) setting up a study group(s) to review the overall concept and coordinate the various technical approaches to it already underway.

(ii) assessment of the dis-incentives built into present energy and materials use policies and the regulatory and tax structures governing the uses of new and "old" materials. Many of our current policies of tax incentives and depletion allowances directly encourage greater exploitation of new materials—and discourage more economic recycling and re-use strategies.

(iii) possibilities of increased lateral integration of extractive, primary processing and byproduct industries both in energy and materials. This may fly in the face of present anti-trust regulation but ways could be found, and incentives created, to encourage more rationalisation and collaborative arrangements to take advantage of scale and total process systems in various agri-industry groups without creating monopolistic practices.

(iv) initiation of annual or biennial "growth" reviews. Paralleling the various reports of the President, these should not deal only in financial costs but be primarily concerned with physical energy and material flows and costs—(*a*) in maintaining domestic standards of living, (*b*) employment and productivity in the overall economy, and (*c*) coordinated estimates of social, environmental and economic impacts of changing growth patterns—with a running inventory of resource use, rates of intensity-of-use, consumption, status of alternative sources and substitutions.

N.B. Much of this kind of information is already produced in many different forms but requires more concerted efforts to present in more integrated fashion for both the decision-maker and the general public.

This discussion of a more systematic and regenerative approach to resource use may be extended, in larger perspective, to speak of *the regenerative society* as a conceptual model for future growth. Our fixation on one-way use of physical resources and lack of coordinate responsibility for the hidden social and environmental costs and diseconomics also extends to human resources.

Many of our prevailing modes in education, work and organisational style tend to view people in single-use and discard fashion. The human life cycle could be more gainfully employed (or enjoyed) in a system which made more allowance for change, growth and regenerative renewal throughout life.

Concluding Remarks

It has been generally assumed in considering economic growth per se, in advanced societies such as the U.S., that this is predicated on the continuation of high material demands and consumption as approaching exponential levels—thus leading inevitably to resource scarcities and high environmental deterioration.

This viewpoint fails to take into account many of the technical and resource economy changes which we have discussed—the expandable nature of many reserves, increased energy aand materials intensity-of-use, technical advances in substitution and recycling and the emergence of new industrial growth-points which are much less energy and materials intensive.

Although no strong sets of data or other evidence has been assembled, it may also be suggested, in terms of the U.S. particularly, that as living standards rise and more people achieve sufficiency levels of affluence, we could approach satiation or stabilisation of demand in many areas.

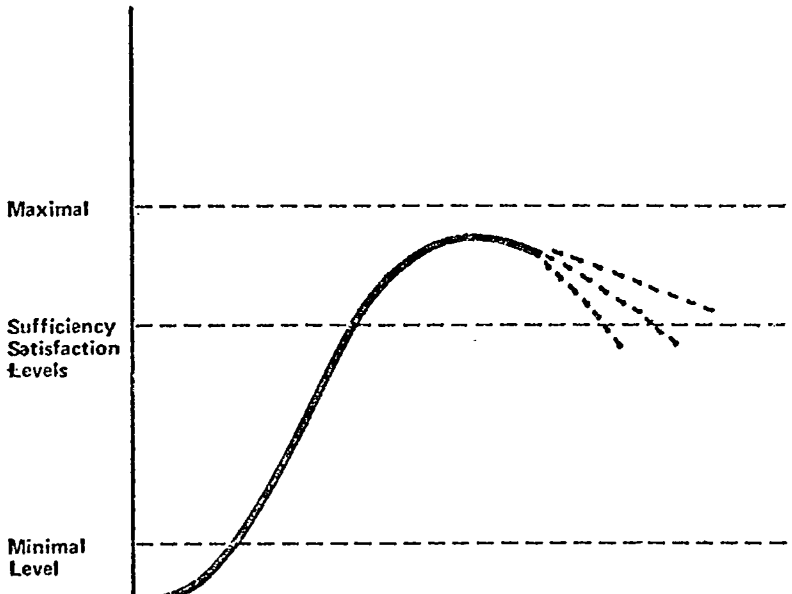
U.S. population growth has slowed and we may expect only about a 15 to 25 percent increase in the next 20 or 30 years. Many of the physical structures and facilities to serve such a population are already in place. Changes in the location of work place to residence, in leisure pursuits and entertainment will entail changes in the disposition of energy and materials usage. The new "sun belt" migration, for example, is also coupled to changes in life style which are more oriented to increased leisure and recreational pursuits.

Many of those coming to maturity in the next ten years already appear to have different attitudes and values than their parents. Some of these attitudes reverse older "conspicuous consumption" trends as evidence of achievement and turn towards less materially goals. styles and life satisfactions. As the work force composition changes from a production to services orientation there may further intensivity of resource use in production. Though energy and materials use is still high in many service needs, they tend more to be people and organisationally intensive sectors.

Demands may, of course, be artificially maintained and stimulated but, as advertising revenues indicate, this is an increasingly costly process. The growth tendency in more materially advanced societies, may not be towards more products and more things—but towards better quality, wider ranges of choice, and access to more services. The recent rise in U.S. consumerism is patently not a movement towards getting more goods to consume but a demand for better performance, longer life, safety and durability in those already available. It has also been accompanied by non-material demands for more balance and diversity of growth in environmental concerns and quality-of-life issues.

One might hypothesise therefore, that in conditions of relative affluence wholly material demands in terms of personal consumption peak out below maximal satiation, and then seek satisfaction through progressively dematerialised and, eventually, symbolic means. (See figure 22.)

FIGURE 22



TRAJECTORY OF NEED SATISFACTION

As needs and aspirations rise and are met on the ascendancy phase they tend to go beyond sufficiency/satisfaction levels to 'conspicuous material consumption' -- then to descend towards more symbolic modes of satisfaction which become less material.

Source: Human Requirements, Supply Levels and Outer Bounds: A Framework for Thinking about the Planetary Bargain by John McHale and Magda Cordell McHale. A joint publication of the Center for Integrative Studies, State University of New York at Binghamton and the Aspen Institute for Humanistic Studies, Program in International Affairs, New Jersey, 1975.

There is an observable shift, then, where people begin to pursue styles of life and goals for personal growth, which move away from the energy-intensive, materially costly and conspicuous consumption phase of development, towards concerns with different ranges of life experience. The expansion of *shared* amenities and services becomes important, and even where the individual may not use them, he or she will tend to support to their collective availability as a draw-down on the public purse.

Overall these kinds of social and value changes within society, accompanied by the technological and resource-use shifts which we have discussed, suggest that the growth requirements of the next decade could probably be satisfied with less per capita energy and materials use, lower environmental impacts and an expansion of economic productivity in more diverse ways.

There is a strong policy need to explore and survey, in more continuous fashion, such changes in citizen attitudes and preferences in relation to growth goals. This should also be done in ways that present more vividly the range of costs, benefits and options which changing directions would entail.

Again, we should not assume that the changing nature of such demands will be automatically taken care of by conventional market forces. On the contrary, the market has lagged behind in responding to the economic provision of many services, to consumer issues like quality in products and environmental conservation. Even in its traditional function of providing diversity of choice we may observe this lag in many major products and services—in failing to meet the need for smaller, less resource hungry automobiles or better mass transit, for more diverse, flexible, and economic housing, and for ranges of consumer items where quality and durability has been sought.

Part of this problem may be found also in the lack of coordinate policy frameworks on such issues in government which now controls many of the incentives through which alternative growth policies may be pursued—tax structures, direct and indirect subsidies and other regulatory practices. Previous policies have often been constraining upon more innovative market directions through lack of knowledge of better social, economic, and technical options and have thus often rewarded vested inertia rather than new enterprise, whether public or private. It is to be hoped, therefore, that the current debate on U.S. economic growth will lead to greater clarification of these issues.

It seems clear from our present review that the continued growth of the United States during the next decade will be constrained more by its capacity for institutional and technological innovation rather than by any potential resource shortages. Directions for more selective and diversified growth are already implicit in many ongoing social and attitudinal changes. In terms of global requirements, the economic growth of the United States as a major force in the world economy is essential, not only for the health of that economy but to assist in meeting the basic needs and growth expectations of the less fortunate both in the local and the larger world society.

MINERAL RAW MATERIALS AND THE NATIONAL WELFARE

By PRESTON CLOUD*

The ultimate dilemma (is) that all of our knowledge is in the past and all of our decisions are about the future. Ian H. Wilson, Michigan Business Review, July 1974, p. 15.

The state is more than a device for serving the immediate preferences of its citizens. Its purpose is to achieve collective objectives, and the collectivity—the nation—includes a constituency of generations not yet born. George F. Will, Newsweek, May 31, 1976, p. 76.

SUMMARY

All of the minerals that man can ever hope to produce and use are in the four-tenths of a percent of the mass of the earth that makes up its outer crust, and most of these are in the outer two to three kilometers. In practical terms only a minute fraction can be thought of a *potential mineral resource*, because the energy required to get at it, concentrate it, and clean up after removing it, rises rapidly as grade decreases and depth in the crust increases. *Reserves* of a mineral (including, loosely speaking, those of a metal or other element found as a native element or contained in a mineral) include only those deposits that are known to exist as a result of physical prospecting, and which, in addition, can be extracted and brought to the market at a profit. Reserves increase as new deposits are found and explored, or as advances in extractive technology, new transportation systems, or price increases transform previously submarginal resources into reserves.

Mineral raw materials are the basis of industrial society. Although they represent only 5.6 percent of the $1.5 trillion United States GNP for 1975, their increase in value as a result of various transformations represents about 40 percent of the GNP at the stage of finished products, and in some sense they underpin all the rest of the GNP. (See figure 1.). Minerals are the vitamins that keep industrial giants healthy.

Scarcities of mineral resources arise where grade of ore declines to levels at which costs of energy and materials required for mining, extraction, and environmental restoration begin to climb steeply. (See figure 2.). Below this grade it is possible to continue mining only those products that are sufficiently prized for their inherent properties or exceptionally strategic nature, or for which new mining or extractive technologies or economies of scale reduce the grade level at which energy costs begin to climb steeply. Even now, however,

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16 percent of the total U.S. energy budget goes for materials production. As that percentage grows, the cost of energy becomes increasingly critical, as does the prospect of deleterious environmental effects from energy production and use itself. A steep general climb in energy costs for materials production would have a sharp braking effect on the economy. Moreover, as energy restraints limit access to materials, so do material restraints limit access to energy. Industrial society must have adequate resources of both, and that will take much well-directed effort.

Only a few geochemically abundant substances are both so far from the energy barrier and so widely distributed that there is little danger they will cease to be available in a sane world. Iron, aluminum, magnesium, and the silicates are examples. The industrial society built on them alone would be austere indeed, however. For many others, recurrent shortages and for some, economic depletion can be predicted within the first half of the 21st century. Petroleum, natural gas, and helium (except in the atmosphere) will be gone except insofar as resources are withdrawn or stockpiled. Global shortages can also be expected for antimony, bismuth, copper, gold, and molybdenum. As for domestic supplies, additional shortages exist or can be expected with respect to sheet mica, commercial asbestos, fluorspar, tin, columbium, silver, strontium, the platinum group metals, mercury, and probably others. (See figures 3–9 and table 1.)

We need to generate a less materials-consuming set of demands while striving to satisfy genuine needs. If our primary goals as a nation are the achievement of a closer approach to equity, ample but not extravagant living conditions for all, a balanced population, preservation of a diversity of clean habitats and natural areas, and opportunity for self-fulfillment in constructive types of activity, extractive products can certainly be made available to attain such goals in the U.S. Achievement of these goals, however, is threatened by excessive consumption, waste, pollution, and continued population growth even in the affluent nations, let alone the deprived three-quarters of the world. A critical reexamination of both goals and means is thus needed. It is hazardous to rely on market signals alone in foreseeing and generating compensatory reactions to resource scarcity. Warnings can arise faster from other sources if we will but heed them—the energy crisis is a good example. Moreover, the now very large and increasing number of consumers, consuming more per-capita than ever before, results in shorter warning times between general perception of impending shortages and their emergence as real crises. Market signals need to be supplemented by strategic planning activities in which a variety of competent specialists interact to discern trends in resource use and misuse, the likely consequences of permitting such trends to continue, and the prospects and consequences of various kinds of ameliorative action.

Ten suggestions for minimizing or avoiding shortages of mineral supplies are as follows; including very rough guesstimates of cost and listed in the order of priority as I would rate it at this time:

1. *Establish a strategic research and planning commission or center for mineral resources* to be staffed by geologists, extractive

chemists, mining engineers, materials scientists, ecologists, and economists with instructions to monitor mineral resources and materials and with authority to propose action at top executive and legislative levels. Costs; $5 million to provide facility, $3 to $5 million annually to operate.

2. *Create legislation limiting the weight and horsepower or number of cylinders of automotive vehicles* to that required for the use to which put. No monetary cost. Much expected saving to user in reduced costs of intial investment and subsequent operation. Large conservation of fuels and metals with no reduction of basic individual freedoms. Reduction of adverse environmental impact.

3. *Accelerate geologic mapping and related geological research*, including geochemical censuses to define metallogenic provinces and epochs. Cost for adequate increases about $12 million a year.

4. *Convert space-heating and cooling systems to solar energy* as far and as fast as possible (creating many new jobs in the process). Cost in the billions of dollars over a 10 to 15 year interval, perhaps as much as $200 billion total, but with eventual large and permanent saving in costs of energy raw materials. Cost would be mainly to private user, perhaps with a federal subsidy to home owners.

5. *Increase support for solar energy technology, fusion energy research, geothermal energy exploration and research, and more efficient energy conversion and transport systems.* Cost perhaps $40 million a year.

6. *Rejuvenate and modernize research and training programs in mineral science, mining, and extractive technology.* Cost for an adequate program about $15 million a year—$3 million a year to 5 institutions.

7. *Support studies related to metallogenesis and the theory of ore-finding.* As little as $3 million a year could have a beneficial effect.

8. *Support materials science research aimed at the more conserving use of or substitution for scarce raw materials.* Expected costs about $10 million a year—$2 million a year to 5 institutions.

9. *Intensify exploration of the continental shelves and slopes.* Cost for adequate increases perhaps $15 million a year.

10. *Allow prices to rise to levels that encourage more conserving practices and more intensive exploration.* Prices might even be encouraged to rise, with beneficial side effects, by imposing stringent requirements on evironmental protection and cleanup, charging for depletion quotas on the scarcer commodities, and increasing taxes on raw materials generally so that they can be reduced elsewhere. There is no inconsistency in recommending conservation and intensified exploration in the same context. It will take all we can achieve of both to meet national requirements in the coming years without ruinous trade deficits. Moreover, some increase will be needed, even as we strive toward a steady state, in order to enhance the material lives of the now deprived and provide for the roughly 1 million new U.S. births that will continue

to arrive yearly for some years to come. No direct costs other than to user, some savings in reduction of regulatory activities, potential increases to federal and state revenues.

Among other actions called for, I see it as of central importance to move away from traditional modes, including traditional emphasis on material growth, and to define new and more humanistic goals and better ways of arriving at them. Because traditional growth patterns lead to resource scarcity, any alternative pattern that reduces such pressures makes resource scarcity easier to cope with. Thus I stress that *the only kind of growth that is both beneficial and capable of being sustained by national and world resources is growth in enhancement of the human conditions—EHC.* This sums up what I hold, along with peace itself, should be the central goal of the Nation and the world.

EHC can be achieved by taking steps to put the means of livelihood in the hands of all people, by emphasizing nonmaterial ways of achieving a sense of personal value and standing in the community, by eliminating planned obsolescence and emphasizing the quality and value of working material stock rather than the rate of fiscal turnover as a measure of economic well-being, by deemphasizing the use of nonessential material consumption and waste as prestige symbols, by bringing populations into balance with the carrying capacity of the nation and the planet for lives of high quality, by decentralizing industry and populations, by legislating incentives and disincentives that will promote these goals, and, finally, by getting the top people into the top jobs instead of letting them go to willing mediocrities or as political rewards. In the body of the report I discuss how an index of EHC (K_{ehc}) can be measured comparable to GNP and with more relevance to the quality of life.

Two suggestions directed toward the elimination of unemployment and the attainment of a high EHC index are as follows:

1. *Establish a program of sabbatical educational and advanced training leaves for all members of the working force.* During one full year out of seven (on a rotational basis) everyone would go back to school or into special training or research programs to acquire new skills or to improve still-needed traditional skills. This would *account for 14 percent of the working force*, a number substantially larger than that of the presently unemployed. Among other effects discussed, such a plan might also reduce job-hopping and *provide management with a more stable, more interested, and regularly upgraded working force.* The initial fiscal costs to management would be less than the reduction from the 50 to the 40 hour work week, while the gain to society (and management) in the form of healthier, happier, better informed citizens could be great.

2. *Establish an array of new Urban Grant Universities (UGU's)*, remote from present cities, as nuclei for a larger number of smaller, pleasanter, better dispersed cities, and more accessible educational opportunities. The UGU's would be granted tracts at the edges or corners of scenic, well watered, public lands for their foundation and partial support. By developing appro-

priate programs, combined with easy access to recreational lands, and by contractual arrangements with industry, private foundations, and government, each UGU would seek to attract *light* industry, commerce, cultural activities, and, of course, people to the region. Thus UGU's *could nucleate the growth of new and pleasanter cities while simultaneously reducing some of the pressures on existing urban complexes, achieving a healthier dispersal of populations, and providing experimental opportunities for new types of construction, urban services, and strategy in the use and conservation of materials.*

Politics must be transformed into statesmanship to make such things happen. But, if they could be made to happen, I believe they would provide strong impetus toward more humanistic and less materials-consuming goals for the Nation, toward a better balance between man and nature, and therefore toward enhancement of the human condition.

Introduction

Omitting land and livestock, the basic ingredients of the economy are the same now as they were at the founding of the Republic—the four M's—mind, manual skills, money, and materials. Capital and labor became larger and materials smaller fractions of the GNP before commodity prices started rising again a decade or so ago, but nothing happens without materials. Under the influence of mind, manual skills, and money their multiplier effect on the economy is enormous. Non-energy raw materials move through the system driven by a sustained flow of energy to ever-higher forms and uses, until finally they end up either by being recycled or becoming a waste-disposal problem. This is illustrated by Figure 1. In the U.S., for instance, during 1975, the initial value of mineral and energy raw materials used was only 5.6 percent of the GNP (4.2 percent domestic). By the time the stage of finished products was reached, however, the combined value of materials plus inputs of energy plus manual and managerial skills accounted for some 40 percent of the GNP. And, in some sense they underpin all the rest of it. Everybody "consumes" raw materials in the form of transportation and communication, housing, work space, and daily operations. Thus, mineral and other raw materials exert a strong positive multiplier effect on the economy.

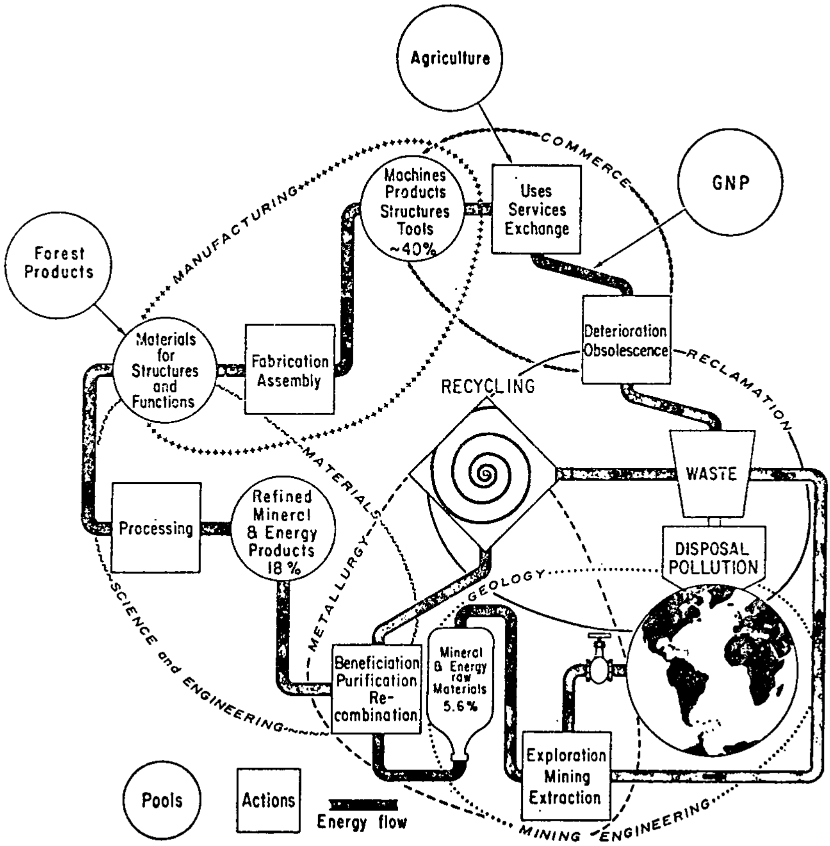

FIGURE 1.—Flow of materials and energy in an industrial society (percentages given are of 1975 GNP for the United States).

Multiplier effects, of course, can be either positive or negative. Thus an ample and continuing supply of new or recycled materials supports a solvent industrial economy, while diminishing supply, grade, or ease of access causes aches and pains. Scarcities in an economic sense arise as a result either of excessive demand or inadequate supply. And inadequate supply can arise either from approaching physical depletion or from a variety of factors that lead to excessive costs. Chief among the latter factors affecting mineral raw materials is decreasing grade of metalliferous deposits, requiring higher energy inputs both per ton of metal recovered and for management of growing volumes of waste and related needs for environmental restoration—all caused by the need to process increasing volumes of host rock for equivalent quantities of materials sought.

The issue of mineral supply, however, involves many other complexities of geology, technology, economics, demography, and the sociopolitical conceptual environment within which these factors act and interact. A clear perception of it is difficult enough without the complacency fostered by simplistic statements about needs, rights, the power of the free market, infinite anything, or the whole earth being made of minerals—which, of course, loosely speaking, it is.

The problem is to find, separate, and bring to bear on improved human welfare an optimal quantity and selection of those minerals and mineral products that can enhance it without imposing avoidable adverse effects on living systems or the physical environment. Interior Secretary T. S. Kleppe expressed it well on his nomination to that position when he remarked, "We must strike a delicate balance between resource use and resource protection, and keep in mind that the economic penalty for an error in the direction of overprotection can always be corrected, while the damage from resource abuse may be irreparable." As they say in the Caterpillar tractor ads, "We must have minerals . . . But we must also have an inhabitable environment." So the cost of minerals in both dollars and energy units is going to go up, and that cost must be internalized, which means it will be transmitted to the user. Higher dollar prices for energy and raw materials, in fact, are not a bad idea. That they have been so ridiculously low considering their enormous significance for industrial economies is in large part why they have been used so profligately. One benefit of higher prices could be more efficient, more conserving uses of materials. Posterity would benefit from such practices.

All forecasters worth listening to agree that futurology is an inexact art and that the longer the interval forecast the more inexact it is likely to be. That is usually where agreement ends. Nevertheless, the conduct of human affairs requires that we attempt to look into the future, if only to decide on a plan of action for the next election. I hold, in addition, that the very fact that we have some ability to foresee the consequences of our actions makes us answerable to posterity for them, and that the least we can do is to avoid thoughtless or premature foreclosure of options for the future—not only for the short term, but also for the intermediate and long range.

It may even be that one of the reasons "predictions" often prove wrong is that they stimulate anticipatory reactions. Suppose one makes the entirely correct prediction that present trends cannot be sustained. If that prediction is followed by leveling off or reduction of population and per capita demands for materials-consuming products and more conserving uses generally, a constructive result is achieved by reactions that may, in retrospect, make the prediction *seem* incorrect. It doesn't matter whose prediction was right as long as balances are restored. As for substitution of materials or technologies, invention of new resource-conserving materials, or development of new extractive or mining processes, they require recognition of opportunity that can benefit as much or more from geological perceptions of impending problems as from economic or technological signals, if only they can be heard.

My goal here is to articulate those characteristics and processes that either impose limitations on or afford opportunities for the advancement of mankind and the Nation insofar as mineral resources are concerned. Under mineral resources I include metals, a variety of nonmetalliferous resources, and mineral fuels such as coal, oil, gas, and uranium. I draw on many sources, in particular the works of the Bureau of Mines and the Geological Survey, and I have discussed the issues with many associates. But I have submitted this paper to no one for review or approval and I alone am responsible for all views and judgements expressed.

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Entropy, Economics, and Mineral Production

Most economic assessments of mineral potential are too simplistic. There is a geological parallel to Borgstrom's passionate plea to "those economic analysts who . . . take refuge in an abstract verbal world far removed from the stark realities of our globe and its staggering needs." (*See* Borgstrom, 1969, p. 73.) A comparable set of analysts is all too prone to overlook or minimize geological variables and technological limitations in the stubborn faith that market forces will provide whatever warning, inducement, or corrective action may be needed to restore interruptions in the flow of minerals sought. Brooks and Andrews (1974), for instance, drawing attention to the obvious fact (leaving out the hydrosphere and probably Earth's fluid core) that "The entire planet is composed of minerals", conclude that "The literal notion of running out of mineral supplies is ridiculous". Under a loose and impractical definition of "supplies" that, of course, is correct, and it serves to support the notion of economic omnipotence. But nobody ever suggested we'd run out of quartz or that metals couldn't be recycled, or even that some materials would not find substitutes. Goeller and Weinberg (1976) follow their ringing defense of a cornucopian outlook with the concession that they see "no insuperable technical bars to living a decent rather than a brutish life", *provided* of course, that we speak of "*a stable population*" (emphasis added).

I agree, but would phrase my agreement with a different introductory emphasis, including the urgent need for very early stabilization and eventual reduction of population. Therein lies the crux of the matter. *Neither U.S. nor world populations have stabilized*, and although the U.S. may be headed in that direction, we cannot divorce our fate from that of the larger world. On the 200th anniversary of our independence, the real population of the U.S. (allowing for census oversights) was close to 222 million and that of the world about 4.23 billion. World population is currently increasing at a rate that yields a doubling time of about 35 years—or around 30 years in the poor three-quarters of the population. *Given its age structure, and assuming current birth rates continue* and no further immigration takes place after the year 2000, U.S. population will stabilize at about 270 to 300 million between the years 2020 to 2045, depending on whose numbers you like.

Those are trends we have to deal with, either by altering them or by seeking to meet the demands for materials that the housing, feeding, transportation, and employment of these additional new citizens will create. Without dramatic economies and advances in recycling it will not be possible to meet those demands except by large infusions of new virgin raw materials.

By now all are familiar with the consequences of exponential growth—growth that increases by seemingly small but compounding proportions, such that 1 percent annual growth gives a doubling time of about 70 years and 7 percent growth doubles the initial quantity in 10 years. As long as growth in consumption of materials continues, *even 100 percent recycling meets only half the needs for each doubling time!* Given the goal of stabilization at present percapita levels of materials use, we would still have to increase production over the next 50 to 70 years just to meet internal demands.

What does this entail? Georgescu-Roegen (1971) and a few other economists understand that the really basic limiting factor in resource production, apart from a breakdown of society itself, is not likely to be currency so much as it is energy. That is a consequence of the second law of thermodynamics, not susceptible to repeal, which says that the entropy of the universe always increases. In practical, oversimplified terms, this means that disorder always tends to increase, that order can be restored or increased only by an investment of energy, and that available or "free" energy is converted by use into unavailable states.

The mining, extraction, and beneficiation of ores to produce metals represents an increase in order at a cost in available energy—about 16 percent of all energy used in the U.S. in 1975 for a domestic mineral production that fell 25 percent short of demand. *Energy cost increases exponentially as the grade of ore decreases to some grade at which* there is an inflection in the rate of energy demand such that *it ascends toward the vertical.* This is clearly explained in papers by Page and Creasey (1975), Cook (1976), Hayes (1976), and Skinner (1976), including the problem of metals needed for energy production.

Figure 2 illustrates the problem. It shows how, as the grade of ore decreases toward the left beyond certain critical values, energy costs climb abruptly and dramatically. This, in effect establishes *cutoff grades* below which metals cannot be produced from those ores at tolerable prices and existing technology. Nor is it easy to foresee what technology might drastically reduce such energy demands. Energy costs, of course, include not only those of actually producing and beneficiating the ores, but those of transportation to the market and a suitable fraction of the energy costs of all plant equipment and facilities involved in production, beneficiation, and transportation. The 16 percent of the U.S. energy budget that presently goes for mineral production will increase substantially as we seek to reduce our dependence on foreign sources. As the price of energy goes up the hard-currency cost of non-energy mineral procurement will also increase with consequent braking effects on the economy.

This follows inexorably from the second law of thermodynamics and the decreasing grades of new primary ores. Economics enters the picture only to the extent that the growing energy investment is reflected in rising prices that, in turn, will stimulate the geological search for higher grades of ore and the technological search for substitute materials and practices. A question to consider is why we must wait for economics to tell us what appropriate expertise can foresee now, albeit dimly, when the lead times needed for the development and introduction of uncertain new materials and technologies are so long as to introduce stresses the economy could do better without.

Even the hoary economic fallacy that decreasing grades of ore are invariably compensated for by increasing volume, the so-called arithmetic-geometric, or grade-tonnage ratio, has now been laid to rest for the very ores (porphyry copper) that gave rise to this concept initially. A comprehensive study of grades and volumes by Singer and others (1975) shows that this is not true for copper ores in general, and that, in particular, "large-tonnage very low grade deposits in the porphyry class . . . are . . . very rare."

The point is not that economics is not crucial, but that an economic philosophy rooted in the concept of ever increasing material growth as the basic or even sufficient ingredient has dominated U.S. affairs to the point of conceptual bankruptcy, whereas other aspects are equally important and in some instances should be overriding. It is time to balance the decision-making process by introducing a better mix of economic considerations and viewpoints and by paying comparable attention to other factors, including the long range values of economy in the use of most materials (an interesting example of a commodity in limited supply where conserving usage is essentially valueless because of its by-product relation to another substance is the gas helium).

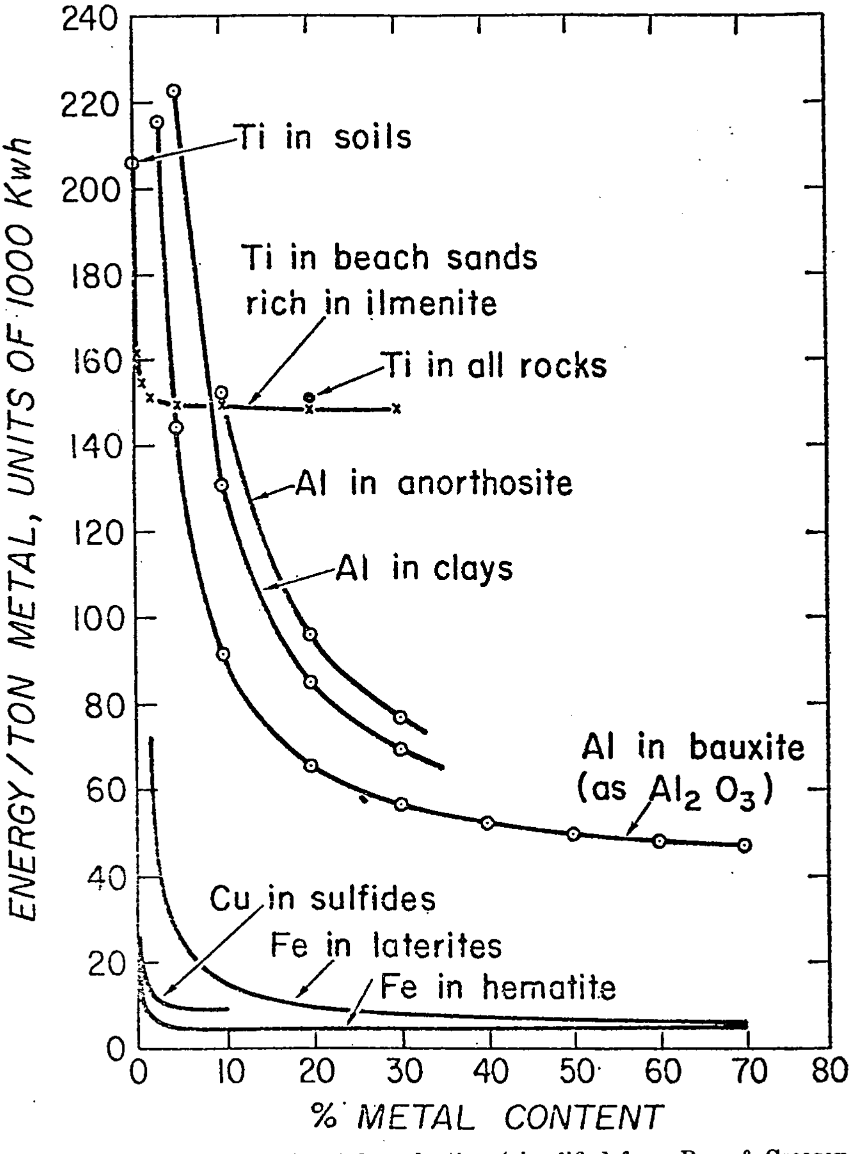


FIGURE 2.—Energy costs of metal production (simplified from Page & Creasey, 1975).

Mineral Deposits, Reserves, Resources, Total Stock

If the whole earth is made of minerals, why isn't it all one big mineral deposit? Indeed that is implied by the suggestion, often made, that, as grade of ore decreases, we will turn to mining "common rock." Like many other reassuring oversimplicities, there is not only an element of truth but also food for dangerous complacency in this one. Indeed, to the extent we obtain lead and zinc from limestone and copper from sandstone, we mine "common rock" now. But the idea is misleading to the non-geological public in the same sense that the idea of an earth made up of minerals, while literally true, is misleading. The zinc-rich limestones and copper-bearing sandstones are, in fact, very unusual rocks. It is the *uncommon features of a rock that make it mineable.* It is the local concentration of elements beyond, and usually far beyond, their normal abundance in Earth's crust to commercially exploitable levels that we designate a mineral deposit. Even if the whole earth were accessible to us, which it is not, other factors would limit our exploitation of it—above all energy accounting, but also considerations of public health, safety, and environmental quality.

The *nature and origin of mineral deposits* is succinctly discussed in a very readable paper by Skinner and Barton (1973). Except for placers and residual aggregations produced by weathering at Earth's surface, practically all mineral deposits are formed by local concentration from mobile fluids of some sort. Many of these are warm, salty, aqueous solutions that move through rock, depositing minerals chemically just beyond points of temperature change or constriction, in response to boiling or fluid mixing, or because of chemical reactions with particular adjacent rock types. Others are actual rock melts that produce chemical or gravitational segregation of particular minerals during crystallization. And still others are vapors, special kinds of open water bodies, fluids that were buried along with ancient sediments, ground water itself, or some mixture of these things.

As a consequence of reactions within these different solutions, melts, and vapors, or between them and the rocks through which they flow, different kinds of mineral deposits are formed, many of them having highly irregular shapes and being difficult to discover and exploit. And, of course, the metal elements, in which we are particularly interested, display a wide range of normal geochemical abundances in Earth's crust, depending on rock type.

Some metals are so abundant and so widespread that it is fair to expect that technological advances and market pressures will assure a continuing supply sufficient to meet all demands of a sane world for thousands of years. They include iron, aluminum, and magnesium. At an intermediate level of abundance, but not so universally available are manganese, chromium, and titanium, all with crustal abundances greater than 0.01 percent by weight. All of the foregoing elements are found as essential constituents of minerals. Together with the silicates and other rock-forming minerals, they make up 99.23 percent of Earth's crust and provide a fall-back position for industrial technology and civilization.

All other metals, those with crustal abundance less than 0.01 percent by weight, are relatively scarce and commonly of restricted occurrence. They tend to occur by atomic substitution in silicate minerals rather than as essential components of minerals and to form very irregular and highly localized ore bodies. These are the ones where scarcities now threaten or can be expected to arise. Their increasing scarcity or practical exhaustion will force changes in technology or institutional structures. They should be the focus of strategic research and planning in terms of mineral exploration, extractive technology, and materials science and engineering. The difference between the abundant and scarce minerals is somewhat like the diff :erence between abundant and scarce game, fish, or trees. The abundant ones are easy to find and harvest, the scarce ones difficult and uncertain. *"Luck" in finding and harvesting the difficult and the uncertain is reserved for those who have prepared themselves properly for the job.*

Reserves are mineral deposits that have been discovered, defined as to volume, and shown to be commercially exploitable under existing technology, transportation networks, and market values. They differ from *resources*, which include probable undiscovered mineral deposits, as well as those known to exist but of unknown, unproven, or submarginal economic feasibility. McKelvey (1973) has developed a classification of mineral deposits that is now standard in Interior Department reports and widely accepted elsewhere where such estimates are made. Cloud (1975) also has discussed reserves and resources in relation to another quantity, called *total stock.*

On the premise that man is unlikely to recover minerals from below the outer 10 to 40 kilometers that comprise Earth's outer crust, we can think of the entire quantity of an element within that crust as the *total stock* of the element. *Resources and reserves are fractions of this total stock* as defined above. It is easy to estimate total stock. We know the mass of Earth's crust within narrow limits and average crustal abundances of different metals and other chemical elements are reasonably well setablished from many analyses of different rock types. Multiply mass of the crust by percentage abundance and that's your total stock.

Similarly, reserves are easy to estimate. Just get the numbers from all mines in the nation or the world and add them up. Within the Interior Department, the Bureau of Mines publishes such figures regularly, along with thoughtful analyses of their implications, while the Geological Survey deals with the more complex and quantitatively much more uncertain problem of resources (as in its 1973 compendium on "United States Mineral Resources," and in reserve figures provided for the Bureau of Mines "Commodity Data Summaries 1976", used in the compilation of data for this paper).

Reserve figures, together with demographic data and a variety of economic indicators provide data for short range planning. They are, however, almost invariably conservative, owing to local tax laws and other factors that make it disadvantageous for a mining company to develop or reveal larger reserves than are needed to meet their own short-range projections. What we would like to get at are reasonably reliable figures for potential resources that could provide a basis for strategic intermediate and long range planning. This is more difficult, but it can be done within broad limits. For instance, Skinner and Barton (1973) estimate that most of the world's ore deposits are to be found in the upper 2 to 3 kilometers of Earth's crust. That substantially narrows the target.

In addition, the new general model of the earth comprised under the term *plate tectonics* gives us clues about the best places to look within that outer 2 to 3 kilometers. Viewed in the context of 4.6 to 4.7 bbillion years of Earth history, a new theory of metallogenic provinces and epochs related to times and types of plate motions and events within plates is emerging. Such research could be one of our best sources of strategic planning information and it should be strongly encouraged and supported.

Meanwhile crustal abundances provide some clues for the estimation of potential resources (McKelvey, 1973 and earlier). Resources that may some day become reserves are orders of magnitude less than crustal abundances but have some relation to them. In the case of copper, for instance, I have estimated (Cloud, 1975), using abundance data and probabilities, that of the roughly 10^{15} metric tons in Earth's crust, no more than 1 to 10 billion tons might eventually be recovered. And Erickson (1973) and Skinner (1976), who do not find it reassuring, have derived ultimate resource estimates for metals that far exceed those of individual commodity experts indicated elsewhere in this paper.

I like to illustrate the distinction among total stock, reserves, and resources with the story of the economist, the geologist, and the engineer who found themselves wrecked on a desert island with only the clothes on their backs. When a can of beans from their wrecked vessel floated ashore the geologist and the engineer had an animated discussion over how they might get at the beans with no tools of any sort. The economist, however, proposed to solve the problem by assuming a can opener. Assuming a can opener, all of the cans of beans that had up to then floated ashore on their island and had been observed by them comprised a *reserve.* All the cans of beans that were aboard their ship and might float ashore on their island cnostituted a *potential resource.* And all cans of beans that happened to be floating about anywhere in the ocean or lying about on the ocean floor made up the *total stock.* It is easy to see that the potential resource can be only a tiny fraction of the total stock.

EXTRACTIVE PRODUCTS, ECONOMIC GROWTH, MARKET SIGNALS

Let me turn then to questions posed by the Chairman and staff of the Joint Economic Committee. The central questions so posed concern the adequacy of extractive products to sustain "needed economic growth" and the reliability of market signals in stimulating adjustments to resource scarcities.

Any response to those questions depends on what one means by "needed economic growth." How can growth be considered as an end in itself rather than as one possible means toward specified goals? What are our goals? What do we *need* growth for? What do we mean by need? Is it the same as *demand?* How can we generate a less materials-consuming set of demands while satisfying real needs? If we define our goals as a closer approach to equity, with ample but not extravagant living conditions for all, a balanced population, preservation of a diversity of clean habitats and natural areas, and opportunity for self-fulfillment in constructive types of activity, extractive products can certainly be made available to attain such goals within the U.S., much of the rest of the Europeanized world, and a few other places.

Despite some progress toward those ends, however, continued growth of population, percapita consumption of materials, waste, and pollution threaten their attainment even here in the U.S. In the more densely populated three-quarters of the world, ample living and self-fulfillment are probably unattainable for most, even at present population levels under existing political and social systems. Such goals, moreover, are certainly unattainable at projected population levels among that three-quarters of the world's people where some 40% of them are under 15 years old and current growth rates yield average population doubling times of about 30 years.

I am aware that the focus of the Joint Economic Committee is on the U.S. and that growth has until recently served a useful purpose here as our predecessors filled up a nearly empty continent and brought its resources to bear on the improvement of the human condition. But I hold that the U.S. cannot isolate itself from the rest of the world, if only because so large a proportion of our raw materials come from foreign sources. I also ask, now that the continent is full and demand approaches and in some areas exceeds supply, are the principles that worked so well during our westward expansion well suited for the decades ahead? Or do we need new mechanisms for assuring that the means of livelihood and self-fulfillment are made available to all?

Thus I claim that *a critical examination of both goals and alternative means is called for before we can constructively discuss future economic growth.* It is clear that some material growth will be needed to provide material essentials for those additional Americans who are bound to keep coming for the next 50 to 70 years even if we agree on zero population growth and reduced percapita material consumption as ways of working toward a harmonious, ample, and more equitable national existence. We must also somehow work toward these things without taking the challenge out of life, and there's the rub. As that, in fact, is the thrust of the last question raised by the Committee, I will defer further comment on this issue until then.

The second central question concerns the reliability of market signals for generating adjustments to resource scarcities. I would say that the recent (and recurring) "oil crisis" is a good example of the kind of failure of market signals that we can expect to see more of in the future. Hubbert (1969 and earlier) pointed out well before it happened that domestic petroleum production would peak in 1970 and that we should be developing alternate sources of energy. Yet, even after the Middle Eastern embargo, many saw the whole shortage as a plot on the part of the oil companies and some still do. One economic columnist and Nobel Laureate mocked the whole idea of limited oil supplies, writing to the effect that oil was so abundant that there were places where you had to hold your thumbs against the ground to keep it from gushing out. If that were the case, why are we importing more than 40 percent of our oil now, and why do we expect to import 50 percent of it by 1985 despite balance of payment problems?

Not only are market signals later in being sent than warnings that can arrive from other sources, but also increasing numbers of consumers, consuming larger quantities more voraciously, are likely to result in shorter warning times between general perception of impending shortages and their emergence as real crises. Market signals, to be sure, should be heeded, but the time has passed when it is an adequate procedure to rely upon them as the sole planning mechanism. They need to be supplemented by special studies and strategic planning activities in which earth scientists, materials engineers, economists, and others interact. Their collective talents should be brought to bear in a balanced way in attempting to foresee trends, the likely consequences of permitting those trends to continue, and the prospects and consequences of various kinds of preventive or ameliorative action.

Potential Mineral Resources

A related question is, what are the best and most recent estimates as to ultimate supplies of the most critical fuel and non-fuel resources. As discussed under "Mineral deposits, reserves, resources, total stock," ultimate supply involves so many variables that we can make reasonably reliable estimates only for a few commodities that are either so abundant and widely distributed that potential resources approach that part of the total stock that occurs in say the outer one to three kilometers of the crust, or that occur in regular and predictable patterns. As noted earlier, only iron, aluminum, magnesium, the rock silicates, and few others are abundant enough to be considered in this light. Coal, oil, natural gas, and to some extent, the metals mentioned, occur in regular and predictable ways.

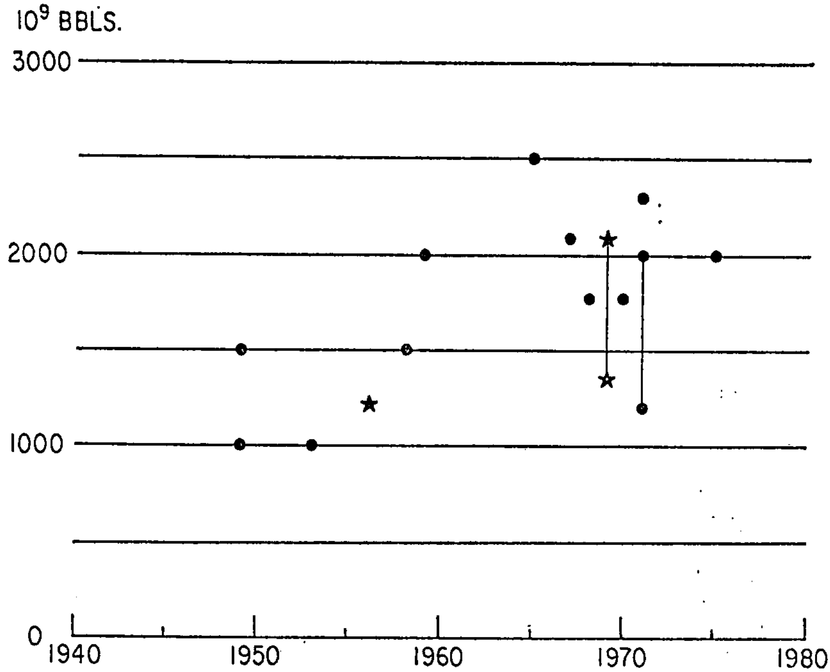


FIGURE 3.—Recent estimates of ultimately recoverable global crude petroleum (stars indicate estimates by M. K. Hubbert).

There is little disagreement about these commodities. Virtually all the information strategic planners need to have about coal is summarized in a single slender book by Averitt (1975). The many estimates of ultimately recoverable oil and gas, despite much dispute, agree within a remarkably narrow range. Figure 3 shows that fourteen different estimates of ultimate world petroleum production made during the last quarter century range only from 1 to 2.5 billion barrels. It is estimated by M. K. Hubbert (whose data are indicated by stars in Fig. 3 and now accepted by the geology departments of most or all petroleum companies) that world production will peak around 1990 and decline thereafter, as U.S. production has been declining since 1970. Coal has a lifetime measurable in hundreds of years *at current rates of consumption*, but would only last about 140 years if called upon as the sole source of energy at projected rates of increase. Natural gas will be depleted only a little later than or at about the same time as oil (and helium will be gone with gas). The only factor that could significantly affect these estimates would be improvement in tertiary recovery methods (brought about by higher prices or technological breakthrough) that would allow a larger fraction to be removed from the ground than the slightly more than 30 percent of the oil now obtained by primary and secondary recovery methods. At best this might double production, which (allowing for other factors) would increase crude petroleum lifetimes by somewhat more than one doubling time, or a bit over 28 years at currently projected rates of demand.

As for other commodities, estimates of potential resources are given in reports by the U.S. Bureau of Mines (1976a, 1976b) and the U.S. Geological Survey (1973, and in USBM, 1976a). Of interest because of its theoretical approach and large estimates is the brief paper by Erickson (in U.S.G.S., 1973) relating resource estimates to crustal abundance and tabulating U.S. and global estimates for 31 metals. A much briefer summary on "Mineral Resource Perspectives 1975" (U.S.G.S. Prof. Paper 940) tabulates domestic commodities in terms of probable availability beyond the year 2000. It finds domestic *reserves* of few metals to be adequate but suggests that identified subeconomic resources and estimated undiscovered resources can make up the difference for most. Commodities in insufficient domestic supply at any level beyond the year 2000 are tin, asbestos, chromium, antimony, mercury, and tantalum.

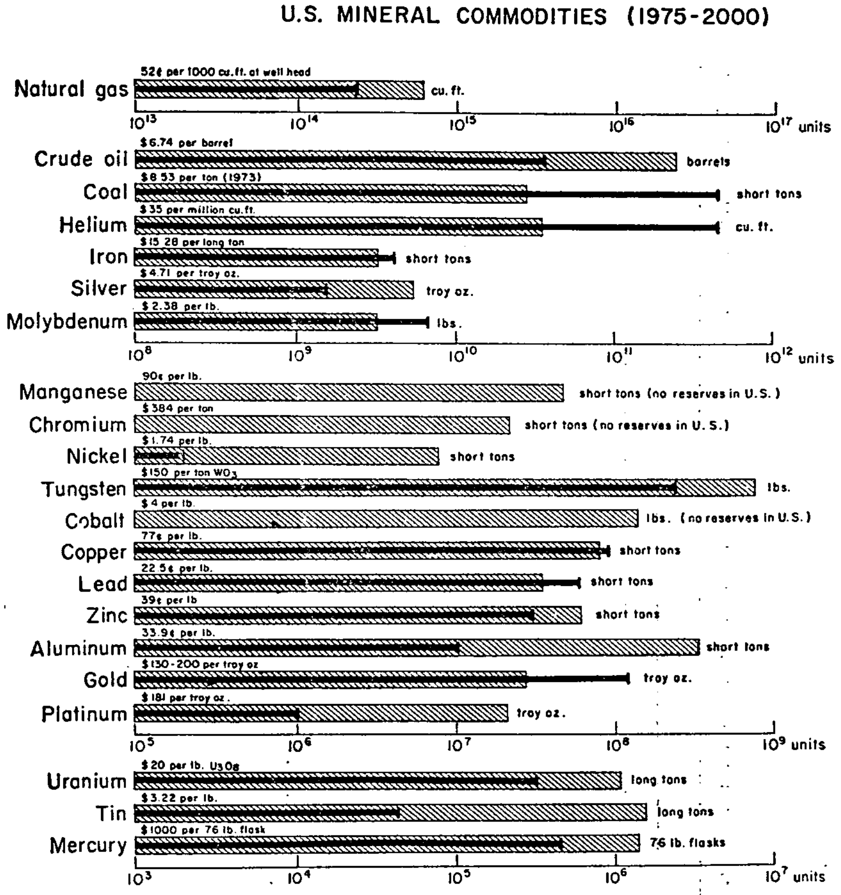
Data on reserves and estimated resources from the most recent U.S. Bureau of Mines preprints and reports (U.S.B.M. 1976a, 1976b) are summarized in terms of lifetimes under projected demands and adequacy to meet demands through the year 2000 in Figures 4–7 of this paper. In the lifetime estimates of Figures 6–7 I give not only the projected lifetimes of established reserves, but also for hypothetical reserves 5 and 10 times as great and for Bureau of Mines *resource* estimates. Additional notation indicates where geological evidence shows or strongly implies potential resources to the right of scale.

Table 1, below, compares reserves and estimated potential resources cited in Bureau of Mines reports (1976a, 1976b) used in compiling Figures 6 and 7 with estimates by Erickson (1973) of ultimate resources and his reserve figures for 25 metals. This illustrates the range from conservative to optimistic resource estimates. My own judgment is that the U.S.B.M. resource estimates used in Figures 6 and 7 are minimal, although they do suggest where some supply problems may arise later in this century or early in the 21st. Where Erickson's resource estimates suggest shortages, we can expect serious and persistent problems.

TABLE 1.—UNITED STATES AND GLOBAL RESERVES COMPARED WITH 2 SETS OF INDEPENDENTLY ESTIMATED POTENTIAL RESOURCES OF 25 METALS

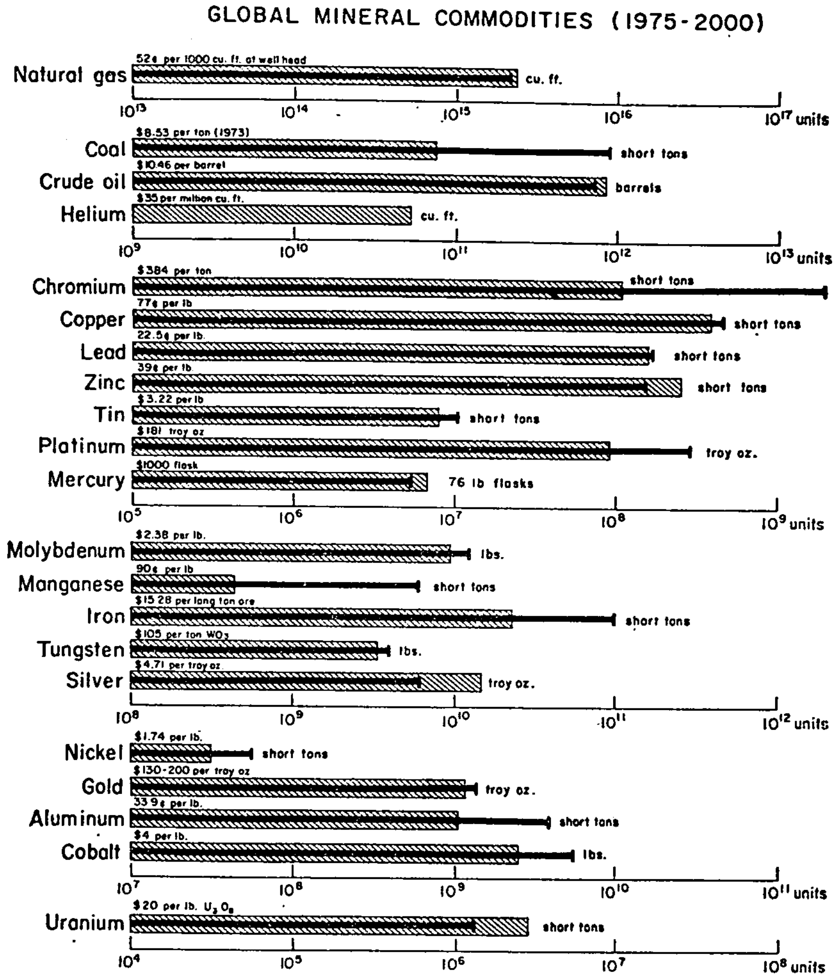
Element	United States						World					
	Reserves, metric tons × 10⁶		Resources, metric tons × 10⁶		Ratio, resources/reserves		Reserves, metric tons × 10⁶		Resources, metric tons × 10⁶		Ratio, resources/reserves	
	USBM, 1976	Erickson, 1973	USBM, 1976	Erickson, 1973	USBM, 1976	Erickson, 1973	USBM, 1976	Erickson, 1973	USBM, 1976	Erickson, 1973	USBM, 1976	Erickson, 1973
Aluminum	9.07	8.1	45	203,000	4.96	24,000	3,480	1,160	5,720	3,519,000	1.64	3,000.0
Antimony	.091	.1	.093	1.1	1.02	11	4.14	3.6	5.06	19	1.22	5.0
Beryllium	.025	.073	.073	3.7	2.92	50	.38	.016	1.105	64	2.91	4,000.
Bismuth	.012	.013	.016	.007	1.33	.5	.059	.081	.133	.12	2.25	1.5
Chromium	None	1.8	5.17	189	-------------	387	1,693	696	4,383	3,260	2.59	47.0
Cobalt	None	.025	.764	44	-------------	1,760	2.45	2.14	4.28	763	1.75	360.0
Copper	81.6	77.8	372	122	4.56	1.6	408	200	1,860	2,120	4.56	10.0
Gold	.0034	.002	.0068	.0086	2.0	4.1	.037	.011	.054	.15	1.46	14.0
Iron	3,600	1,800	89,900	118,000	25	65	86,900	87,000	689,000	2,035,000	7.93	23.0
Lead	53.5	31.8	108	31.8	2.02	1.0	150	.54	299	550	1.99	1,000.0
Manganese	None	1.0	66.77	2,450	-------------	2,450	1,814	630	3,266	42,000	1.80	67.0
Mercury	.016	.013-.028	.031	.20	1.94	15-6.8	.17	.11	.604	3.4	3.55	30.0
Molybdenum	2.96	2.83	15.92	2.7	5.38	1.0	5.99	2.0	28.62	46.6	4.78	23.0
Nickel	.181	.18	13.8	149	76.2	830	45.3	68	90.8	2,590	2.00	38.0
Phosphorus	2,268	931	6,350	2,940	2.80	3.0	16,068	15,000	76,107	51,000	4.74	34.0
Selenium	.035	.025	.157	.14	4.49	6.0	.168	.695	.628	2.5	3.74	36.0
Silver	.043	.05	.162	.16	3.77	3.2	.17	.16	.642	2.75	3.78	18.0
Tantalum	None	.0015	.0015	5.6	-------------	4,000	.0676	.274	.261	97	3.86	354.0
Tellurium	.0082	.0077	.037	.0009	4.51	.11	.039	.054	.148	.015	3.79	.3
Thorium	.13	.54	.27	16.7	2.08	31	.71	1	1.83	288	2.58	288.0
Tin	.043	Small	.198	3.9	4.60	Small	10.1	5.8	37.6	68	3.72	12.0
Tungsten	.108	.079	.435	2.9	4.03	37	1.78	1.2	5.17	51	2.90	42.0
Uranium	.242	.27	.395	5.4	1.63	20	.967	.83	1,691	93	1.75	112.0
Vanadium	.104	.115	9.104	294	87.5	2,560	9.707	10	56	5,100	5.77	500.0
Zinc	27	31.6	45	198	1.67	6.3	135	81	245	3,400	1.81	42.0

FIGURE 4.—Reserves of 21 key U.S. mineral commodities compared with cumulative demand to year 2000 (data from U.S. Bureau of Mines).



Shaded bars represent cumulative demand through 1999. Median lines show largest, most recent reserve estimates. Prices in 1975 dollars. Scale is logarithmic, unit quantities and scales vary as indicated and all lines begin at zero to left of diagram. See table 1 for more optimistic resource estimates.

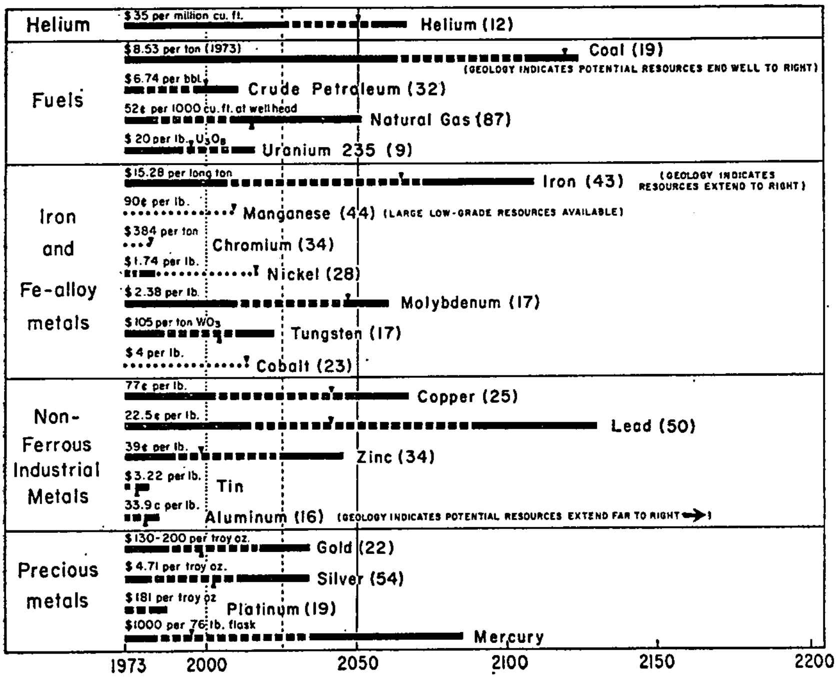
FIGURE 5.—Reserves of 20 key global mineral commodities compared with cumulative demand to year 2000 (data from U.S. Bureau of Mines).



Shaded bars represent cumulative demand through 1999. Median lines show largest, most recent reserve estimates. Prices in 1975 dollars. Scale is logarithmic, unit quantities and scales vary as indicated and all lines begin at zero to left of diagram. See table 1 for more optimistic resource estimates.

FIGURE 6.—Apparent lifetimes of reservers of 21 key U.S. mineral commodities compared with lifetimes of hypothetical reserves 5 and 10 times as great and with potential resource estimates (data from U.S. Bureau of Mines).

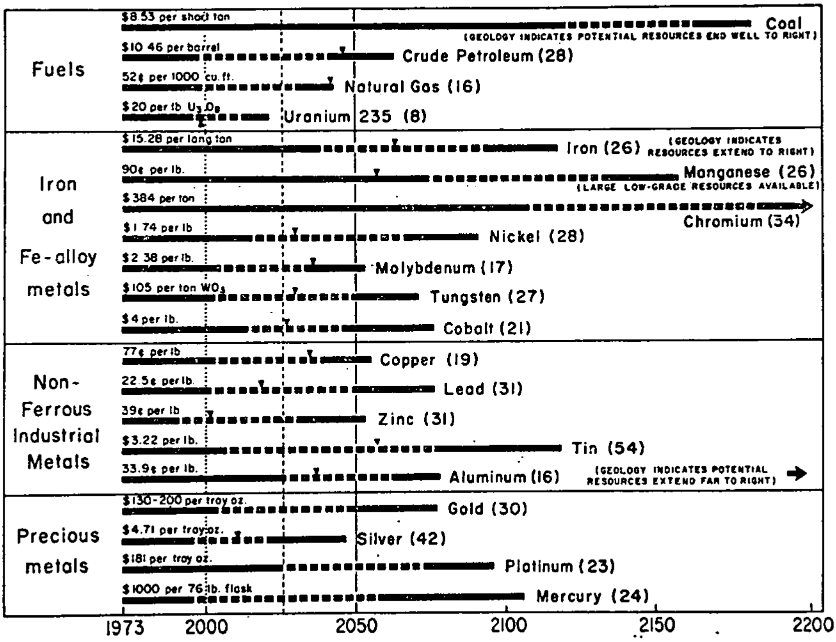
LIFETIMES OF U. S. DOMESTIC MINERAL COMMODITIES



Solid bars at left are for known reserves. Short-dash lines in middle are for 5x known reserves. Solid lines at right are for 10x known reserves. Circles indicate resources only, no or scant reserves. Solid triangles denote lifetimes implied by USBM resource estimates. Bracketed numbers at right are years for projected doubling of demand. Prices in 1975 dollars.

FIGURE 7.—Apparent lifetimes of reserves of 20 key global mineral commodities compared with lifetimes of hypothetical reserves 5 and 10 times as great and with potential resource estimates (data from U.S. Bureau of Mines).

LIFETIMES OF GLOBAL MINERAL COMMODITIES



Solid bars at left are for known reesrves. Short-dash lines in middle are for 5x known reesrves. Solid lines at right are for 10x known reesrves. Solid triangles denote lifetimes implied by USBM resource estimates. Bracketed numbers at right are years for projected doubling of demand. Prices in 1975 dollars.

Skinner (1976) in a recent illuminating and very readable analysis of the ultimate limits of metal production, using the crustal abundance method, arrives at eventual resource estimates close to Erickson's, although he gets much smaller numbers for platinum, gold, and mercury and somewhat smaller numbers for several others. (He also shows why sea water and the deep ocean basins are of little interest for most metals, so that future metal production must come, above all, from continental types of rocks.) Thus the Erickson resource estimates given in Table 1 can be taken as *outside limits.*

After, and probably well before these outside limits are exceeded, industrial society, regardless of how vast its energy sources, will be confronted with geochemical limits on the addition of new virgin metals that will require adapting its technology to one that can subsist on recycled materials plus rock silicates and the geochemically abundant metals—iron, aluminum, magnesium, titanium, manganese, and phosphorus.

On balance it seems that difficulty with global metal supply beyond the first third of the 21st century is to be expected only for antimony, bismuth, copper, gold, and molybdenum. Similar difficulty with U.S. supply threatens for antimony, bismuth, tin, copper, gold, mercury, nickel, platinum, selenium, tantalum, thorium, lead, zinc, and perhaps others. It must be stressed, however, that we have no assurance that undiscovered potential resources will be discovered such as to limit shortages to the commodities named, or that they will be discovered in the quantities estimated by Erickson and Skinner, as they have made quite clear.

Shortages Anticipated and Their Effects

For *most* mineral commodities it is more likely that the next half-century will be marked by temporary shortages and dislocations than depletion in the sense that grade of ore will decline to levels where approach to the energy boundary (Fig. 2) and other costs of mining and extraction will exclude them from the market. For some, however, depletion is in prospect. Domestic petroleum will be essentially gone by the end of this century, natural gas early in the 21st century, and helium will last thereafter only as long as stockpiles hold out or to the extent it may be extracted from the atmosphere. By mid-century crude petroleum and natural gas will be essentially exhausted worldwide, along with helium. Domestic supplies of tin, commercial asbestos, columbium, fluorspar, sheet mica, high-grade phosphorus, strontium, bismuth, the platinum-group metals, mercury, even molybdenum, and perhaps chromium and nickel are either non-existent or so localized and limited that there is only faint prospect of new domestic addition by discovery. We will almost certainly continue to remain dependent or become dependent on imports for most of them. Domestic mercury will very likely be depleted. Although we now import most of our manganese and aluminum ores, however, large low-grade domestic resources of these elements exist and could be tapped at significantly increased costs.

Energy promises to dominate the future economic picture. As Figure 2 indicates, dramatic increases in energy required to obtain metals from ores of decreasing grade could severely limit the availability of some metals. As crude petroleum and natural gas are depleted we will need to seek relief from other sources, more efficient uses, and better energy-conversion systems. Main elements of the energy picture are indicated in Figure 8. This suffices to indicate that a number of options remain to be explored, and that, although we are having energy problems and probably will continue to have them in one way or another, *we need not panic or rush headlong into "solutions" that* *may be premature or unnecessary, such as a massive proliferation of converter or breeder (fission) reactors.* We have some decades of grace during which to seek more conserving ways to use and transform our energy, to explore and develop solar energy systems, and to continue research toward a practicable fusion reactor before we are forced to make decisions with such potentially far-reaching adverse consequences as the generation of vastly larger quantities than already exist of plutonium–239 or long-lived radioactive wastes. For more information on energy a good, readable, up-to-date summary is that of Holdren (1975), while a classic, though now somewhat dated summary is that of Hubbert (1969).

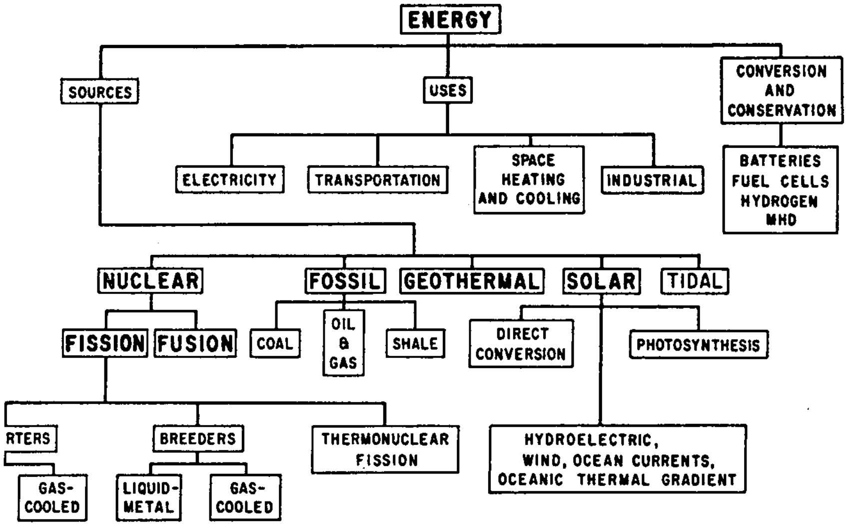


FIGURE 8.—Main elements of the energy picture.

It deserves emphasis, however, that, although alternate energy sources of vast potential exist, there would be little useful energy without metals to build the machines and superstructure needed to capture it, convert it to useful forms, transport it, and apply it to the performance of work—including getting more energy to produce more metals. *As energy restraints limit access to materials, so material restraints limit access to energy.* It would be unfortunate if either were to dominate our thinking to the exclusion of concern for the other.

The Committee has asked what effect expected increases in cost will have on traditional ways of growth. Let us start with the *causes* of probable cost increases. *New supplies of many mineral commodities will cost more primarily because decreasing grades of ore require moving larger volumes of material at greater energy costs per ton.* (See figure 2.) This, in turn, increases the scope of adverse potential environmental impact and thus the costs of prevention of such impact or restoration after it, both in mining and energy production.

Now consider what is implied by "traditional ways of growth". Material growth has traditionally been considered in industrial societies as a basic good, a goal in itself. This probably has some relation to the fact that population growth was early seen not only as responsive to religious teachings but also as a means of increasing the labor force. Then growth of production became a means of keeping the labor force employed and of enhancing national wealth and influence. Under such an ethic, where production to maintain employment exceeds the essential needs of the people plus foreign trade outlets, demand must be created to absorb the overproduction. This has traditionally been achieved by increased levels of consumption, obsolescence, and waste, including enterprises such as arms races and even destructive ones such as war.

I believe that the time has come in the generally upward course of human and societal evolution when we should be trying to break away from traditional modes of growth. Those modes tend to shut out the deeper values of life. They are the central cause of environmental deterioration. And they violate the rights of our unborn and thus voteless descendants—in particular their right to have the planet passed on to them in the best possible condition and with a maximal variety and flexibility of vital options. Indeed I have the impression that the growing awareness of Earth's limitations is interacting with other concerns to generate outlooks toward growth for its own sake that are crying to be led to new norms in mans' relation to nature, including his use and abuse of natural resources. A recent Harris Poll, for instance showed 90 percent of respondents favoring reduction of consumption and waste. Here is a response so nearly unanimous as to constitute a *public mandate for abandonment of tradition and the installation of a new ecologic ethic in which healthy balance takes precedence over growth.*

If we need the word growth to catalyze human reactions consider a new kind of growth. Instead of worrying about whether or not GNP continues to increase let us promote growth in *enhancement of the human condition.* I will call it EHC.

I have more to say about EHC, but will reserve it for the final section. Here I only want to emphasize that traditional ways of growth are neither relevant to the last quarter of the 20th century nor sustainable in the old pattern. At the very least population must come into balance, and growth in material over-consumption and waste by the already affluent must give way to an increased flow of essential goods and products to the deprived. As I hope to make clear at the end, this does not require high levels of unemployment, stagnation of the means of production, or a return to agrarian society. It does, however, call for strategic research and planning involving all sectors of society.

Avoidance of Shortages

Minerals—in particular metals—are the vitamins and enzymes that keep industrial giants healthy and productive. When they are not available in appropriate proportions, even giants fade, some to oblivion. In dealing with the question of how to avoid or minimize limitations in the availability of such essential elements, and to reduce their constraints on the economic health of the Nation, I will confine my response to specific possibilities for anticipating and avoiding shortages. The geochemical basics of where and why shortages are bound to arise in contradiction to conventional economic wisdom are briefly, simply, and clearly analyzed by Skinner (1976).

The passage of the Mining and Minerals Policy Act of 1970 (P.L. 91–631) was a constructive step in dealing with the problem of future shortages, but still only a step. Interior is doing a good job of monitoring and reporting, but we lack a clearly articulated National Minerals Policy that defines goals, means, and responsibilities and brings the Commerce and State Departments more actively into the interplay of forces. Foreign policy implications of our consumption and production of minerals are apparent from Figure 9, yet how many of our embassies in countries listed on the right of this graph have mineral attaches and how much consideration is given to mineral-resource considerations apart from oil in evolving foreign policy? I have elsewhere listed the kinds of questions that should be asked and suggested some institutional arrangements that should be considered in formulating a comprehensive National Minerals Policy (Cloud, 1973), I and others have also suggested responses to some of these questions (Cloud, chairman, 1972). Still other recent responses are given in the final reports by the Committee on Mineral Resources and the Environment of the National Academy of Sciences, obtainable from those sources.

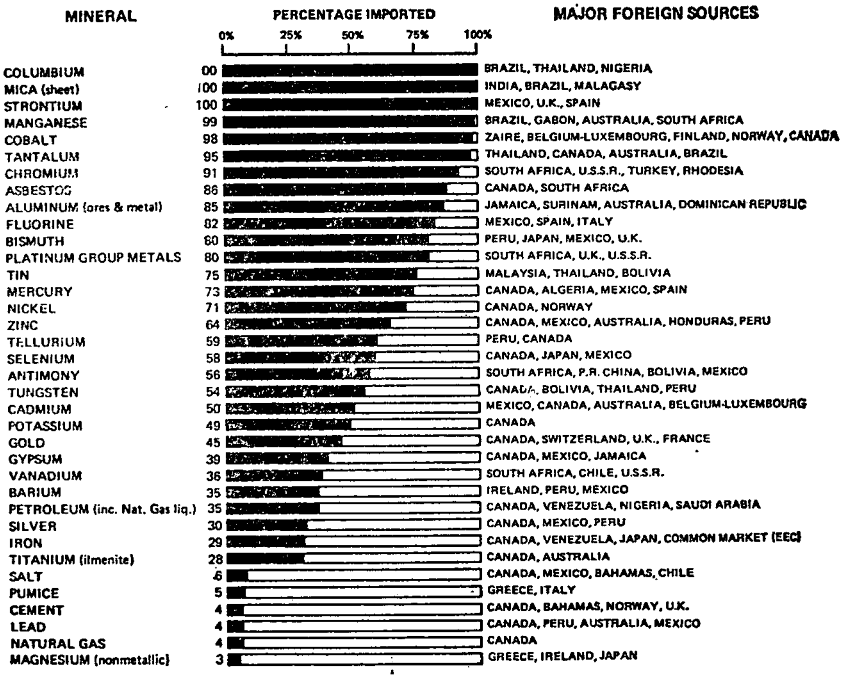


FIGURE 9.—Percentage of U.S. mineral requirements imported during 1975 (source: Morgan, 1976, figure 8).

Based on the foregoing I have distilled 10 explicit, high-priority suggestions for ameliorating, deferring, or avoiding shortages in mineral supplies, as listed below. They are given in the order of priority that I judge to be most relevant to societal needs at this time, and with very rough guesstimates of cost:

1. *Establish a strategic research and planning commission or center for mineral resources* to be staffed by geologists, extractive chemists, mining engineers, materials scientists, ecologists, and economists with instructions to monitor mineral resources and materials and with authority to propose action at top executive and legislative levels. Costs: $5 million to provide facility, $3 to $5 million annually to operate.

2. *Create legislation limiting the weight and horsepower or number of cylinders of automotive vehicles* to that required for the use to which put. No monetary cost. Much expected saving to user in reduced costs of initial investment and subsequent operation. Large conservation of fuels and metals with no reduction of basic individual freedoms. Reduction of adverse environmental impact.

3. *Accelerate geologic mapping and related geological research*, including geochemical censuses to define metallogenic provinces and epochs. Cost for adequate increases about $12 million a year.

4. *Convert space-heating and cooling systems to solar energy* as far and as fast as possible (creating many new jobs in the process). Cost in the billions of dollars over a 10 to 15 year interval, perhaps as much as $200 billion total, but with eventual large and permanent saving in costs of energy raw materials. Cost would be mainly to private user, perhaps with a federal subsidy to home owners.

5. *Increase support for solar energy technology, fusion energy research, geothermal energy exploration and research, and more efficient energy conversion and transport systems.* Cost perhaps $40 million a year.

6. *Rejuvenate and modernize research and training programs in mineral science, mining, and extractive technology.* Cost for an adequate program about $15 million a year—$3 million a year to 5 institutions.

7. *Support studies related to metallogenesis and the theory of ore-finding.* As little as $3 million a year could have a beneficial effect.

8. *Support materials science research aimed at the more conserving use of or substitution for scarce raw materials.* Expected costs about $10 million a year—$2 million a year to 5 institutions.

9. *Intensify exploration of continental shelves and slopes.* Cost for adequate increases perhaps $15 million a year.

10. *Allow prices to rise to levels that encourage more conserving practices and more intensive exploration.* Prices might even be encouraged to rise, with beneficial side effects, by imposing stringent requirements on environmental protection and cleanup, charging for depletion quotas on the scarcer commodities, and increasing taxes on raw materials generally so that they can be reduced elsewhere.

Economic Versus Physical Availability

It is hard to separate physical and economic availability. As economists are fond of pointing out, availability in the long run depends on what the market will bear. Even though the world's richest deposit of diamonds required the movement of 75 million tons of rock to get 3 tons of gems, diamonds continue to be available. We can and doubtless will obtain iron and aluminum from increasingly low grades of ore. But, as Figure 2 shows, there is usually an inflection point in the energy costs of metals recovery with decreasing grade beyond which it is not profitable to pursue lower grades unless and until new and much more efficient mining and extractive procedures can be devised. Skinner (1976) explains why even such developments are likely to be significant only in the case of 12 geochemically abundant elements that make up 99.23 percent of Earth's crust and why energy costs become a real barrier for the 76 elements that comprise the other 0.77 percent.

Non-metallic mineral resources are, on the whole, far less of a problem than metals. Some, such as sheet mica are likely to cause problems, but I would guess that demand for a good many of the scarcer nonmetalliferous products might eventually be met by advances in crystal chemistry or materials science.

On the larger issues, declining grades strongly suggest that marginal returns will diminish relative to real inputs of labor and capital. As Skinner (1976) clearly shows, it is a gross economic oversimplification to suppose that declining quality of itself will give rise to expansion of reserves. As mentioned earlier, this doesn't apply even in the classic case of copper, or for the other 75 geochemically scarce elements beyond the energy barrier.

I don't believe either that current reserve figures ignore accessibility or other factors. On the contrary, they are characteristically conservative. However, I should say that I have used the most optimistic reserve estimates in preparing Figures 4–7, in order to make it clear that, under the best of circumstances, much research, exploration, and development will be needed to meet projected future "needs".

Finally, I would say that it is not only efficiency in terms of energy that counts in establishing accessibility, but that *energy and materials are both crucial in broadening the materials base.* Improved exploration theory, discovery of new commercial resources, and improvements in extractive technology can have large and unpredictable effects; but decline of average grade is certain, and energy and efficiencies of scale are the central factors in compensating for that down to the energy barriers of Figure 2.

Another question asked concerns "the possibilities of price increases not leading to supply increases because there is no more." Leaving out nuances that will be explored by economists, I see this as essentially the same question dealt with above. Again, quoting a response economists like to give, there is always more somewhere at a price—albeit perhaps a price it would be uneconomic to pay. When helium from natural gas is exhausted, there will still be helium in the atmosphere. When copper-bearing rock declines to concentrations of copper to the left of the energy inflection point of Figure 2, there will still be copper-bearing rock at lower grades. Costs of recovery in energy and otherwise, however, will be so high that, for practical purposes, the resource will have been depleted. That is what geologists mean when they speak of depletion. Economists and some energy technologists to the contrary, *nothing is infinite, except perhaps space and the human mind, and even they cannot transcend the laws of thermodynamics.*

Restructuring Economic Norms, Values, and Habits

Finally we arrive at the question of actions called for. As I noted earlier, and as a few fore-thinking economists such as Nicholas Georgescu-Roegen, Kenneth Boulding, Emile Benoit, and H. E. Daly have stressed elsewhere, GNP has outlived its usefulness as an index of progress. It measures rate of fiscal turnover rather than value of the nation's material stock or the quality of life enjoyed by its citizens. Traditional growth patterns lead to resource scarcity. Thus any alternative that reduces conventional growth pressures makes resource scarcity more manageable.

In my view, the only kind of growth that is both beneficial and capable of being sustained by national and world resources is growth in *enhancement of the human condition—EHC.* EHC can be achieved by taking steps to put the means of livelihood in the hands of all people, by emphasizing non-material ways of achieving a sense of personal value and standing in the community, by eliminating planned obsolescence and emphasizing the quality and value of working material stock rather than rate of fiscal turnover as a measure of economic well-being, by deemphasizing the use of non-essential material consumption and waste as prestige symbols, by bringing populations into balance with the carrying capacity of the nation and the planet for lives of high quality, by protecting and restoring the environment, by continuing education, by decentralizing industry and populations, by legislating incentives and disincentives that will promote these goals, and finally, by getting the top people into the top jobs instead of letting them go to willing mediocrities or as political rewards.

Growth in EHC is what I think, along with peace itself, should be our central goal. The usual complaint against such "impractical, fuzzy" goals is that they are not susceptible to numercial analysis. But I would argue that we can put numbers on EHC that are more deeply meaningful than those we compute for GNP. For instance, we could arrive at an index K_{ehc} using measurements of the value of operating capital stock, area of protected public lands, number of advanced or specialized degrees granted, and other goods minus measurements of "bads" such as poverty, population growth beyond replacement levels, alcoholism, violent deaths and crimes of violence, unrecycled waste, man-days of respiratory discomfort and other measurements of pollution. By aggregation of such factors, abbreviated to a fine alphabet soup, we could even make up an impressive equation. Then the value of K_{ehc} for any given year, and whether it was a positive or a negative number, would sum up how well or how poorly societal affairs were being managed.

As for how to achieve the subsidiary goals of EHC, I have suggested some steps in the section on *Avoidance of Shortages*, above.

An urgent issue that remains to be discussed is how to put the means of livelihood into the hands of all people without excessive production, waste, planned obsolescence, stimulation of prestige consumption, large military establishments, and other stimuli that we normally think of as creating jobs.

Through various social arrangements that now exist, the nation has aleady approached something that is very like a guaranteed individual income. It seems logical to me to go the rest of the way, coupled with incentives and disincentives that encourage people to seek and retain employment and that do not encourage multiplication of dependents, while, at the same time, not penalizing those that come. But where will the jobs be, particularly if more women are to have the option of making meaningful careers for themselves?

One step that would reduce unemployment without stimulating production, while simultaneously reducing problems of technological obsolescence would be a program of *sabbatical educational and advanced training leaves for all members of the working force.* During one full year out of every seven *everyone* (on a rotating basis) would go back to school or into special training or research programs with industrial, governmental, foundational, public service, or academic institutions to acquire new skills or to improve still-needed traditional skills.

This would account for 14% of the working force, a number substantially greater than that of the now unemployed. It would also prepare people whose skills had obsolesced to undertake relevant new tasks and it would improve the outlook and performance of those who had simply grown stale on the job. If employers were required to budget for such training programs and guarantee appropriate positions without loss of seniority to returning employees, such a plan might also reduce job-hopping and provide management with a more stable, more interested, and regularly upgraded working force. Such a plan, it is true, *might* not be the most efficient use of the labor force, but if social welfare and joblessness is a concern, it could be highly beneficial. Fiscal costs to management would be less than in the reduction from a 50 to a 40 hour work week, while the gain to society (and perhaps even to management) in the form of healthier, happier, better informed citizens could be great.

Urban decay is an important negative aspect of EHC, largely as a product of increasing immigration to city centers, paralleled by the flight to suburbia on the part of the affluent. From 54 percent in 1950, the fraction of the U.S. population living in cities of 50,000 or more increased to 71 percent in 1970. It is expected to reach 85 percent by the year 2000, when current projections call for it to be concentrated mostly within a few gigantic urban complexes. The main problems are already in the larger cities, and they appear to be worsening. If people are determined to live in cities it might be better all around if these cities were smaller, pleasanter. provided with better public transport, closer to recreation centers, and more widely dispersed. We might also consider emulating the steps some European countries have taken to provide incentives for rural families to remain on the land or in country towns.

As for smaller and better dispersed cities, that goal might be combined with materials conservation, decentralization of commercial activity, and the sabbatical leave plan suggested by creating a new system of *Urban Grant Universities*. These UGU's would not be in existing cities, but would be at the edges or corners of large tracts of scenic, well-watered public lands. For each UGU, a substantial block of public land would be granted to the parent state for its foundation and partial support of the incipient UGU. By developing appropriate programs, combined with easy access to recreational lands and other conveniences. as well as by contractual arrangements with industry, private foundations, and government, each UGU would seek to attract *light* industry, commerce, cultural institutions and activities, and, of course, people to the region, generating support funds by contracts and the leasing of UGU lands. Thus UGU's could nucleate the growth of pleasant, modest-sized, economically viable new cities while simultaneously reducing the pressures on existing cities, achieving a healthier dispersal of populations, and providing experimental opportunities for new types of construction, urban services, and strategy in the use and conservation of materials.

Utopian? Far from the question of resource adequacy? Perhaps. But isn't enhancement of the human condition what society and its use of resources is all about? Isn't conservation and dispersal of the means of production part of it? And don't most major advances in societal affairs begin with dreams? The problem is to make them happen. And that's where politics becomes statesmanship.

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RESOURCE SUBSTITUTION

By WILLIAM A. VOGLEY*

SUMMARY

This paper explores some fundamental concepts in the area of resource substitution. It is directed, in general, to the series of questions proposed by Senator Hubert H. Humphrey, chairman of the Joint Economic Committee, in calling for papers as part of a study series *U.S. Economic Growth From 1976–1986: Prospects, Problems, and Patterns*. It is restricted to the non-energy resources—those resources which are usually characterized as "materials".

Conclusion 1

Certainly within the time frame of 1975–1985, and with only slightly diminished certainty within the time frame 1975–2025, the physical characteristics of materials availability will not cause any increase in the real costs of materials to the world economy. Thus, physical constraints on production of materials are not a threat to continued economic growth.

Materials have become available to society at decreasing real costs over the past century. For the next decade, known deposits of materials produceable at current prices are more than sufficient to meet projected world demands. For many materials, the same is true through A.D. 2000. Beyond that date there is a degree of uncertainty introduced. To analyze periods beyond A.D. 2000 it is necessary to make estimates of ultimate recoverable resources—mineral deposits that, if found, could be produceable at current cost levels. Such estimates, along with demand projections, made by the author clearly indicate that through A.D. 2025, mineral material costs need not rise because of exhaustion of geologic deposits. When technological progress which led to the historical decline in real costs and possibilities of material substitutes are also considered, it is clear the above conclusion is justified.

Conclusion 2

The process of materials substitution is extremely complex, and the traditional economic theorem that it is a function of relative prices is inappropriate to understand the process. Much fundamental research needs to be done to further understanding of the substitution process.

Materials demand is derived from society's consumption of goods and services. Thus, materials needed are determined by the structure

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and size of final demands for goods and services, the state of technology to produce these goods and services, and the comparative attractiveness of a material over its alternative materials. Material prices are certainly part of this picture, but, in fact, have played a relatively minor role in determining patterns of material uses. Thus, to explain substitutions which have taken place, and to look ahead for evolving trends, a very complex set of factors must be examined. The current state of knowledge in this area is unsatisfactory. Much fundamental research is needed.

Conclusion 3

There are serious emerging institutional problems surrounding the production and use of materials and these issues should be subject to intensive research and evaluation to develop proper governmental policies. Specifically, economic stockpiles of selected materials should receive serious Congressional consideration.

The successes of the oil cartel, the use of the embargo as a political weapon, the rise of nationalized mineral industries, the emergence of multi-national mineral firms, and the growing awareness of environmental and social costs of mineral developments have generated a host of institutional problems. These problems could result in a short fall of mineral supplies in both the short and long term, and thus cause mineral shortages to have an impact on the quality of life in the U.S.

These institutional issues are exceedingly complex and require intensive research and evaluation to be better understood. In one area—embargos—stockpiles are a clearly dominant policy choice. A well designed stockpile policy may also be partially effective in meeting the other economic issues raised. The others do not have a clearly dominant solution. These are the policy areas most in need of addressing by the Congress.

PART I. RESOURCE ADEQUACY

The framework for this requested paper is the broad topic of "The Substitutability of Capital and Labor for Natural Resources in the Future". Capital, if it is to be defined meaningfully at all except in a monetary sense, is the stock of stored productive services in durable goods existing in a society. Clearly, this stock is a matter for societal decision vis-a-vis the proportion of the output of the society which will be devoted to consumptive uses versus that devoted to investment goods. Thus, capital is not a uniquely determined resource and the amount of capital available to society over time is dependent upon that society's decisions. Labor also is a dynamic, renewable factor of production and the amount of labor devoted by society is a function of the cultural, economic and physical characteristics of the population of that society. Resources are made available by devoting capital and labor to their production from a naturally occuring deposit. Production of goods and services can take place only with inputs of capital, labor and resources combined through a technology. The lack of any one of these factors will cause production to be either zero or extremely low. It is conceivable that labor can produce a product completely without the use of tools (capital), but the example is trivial.

The question comes down to the required input of capital and labor to produce the resources which are needed in the production functions for society. Thus, the question is whether or not the *cost* of available resources, in terms of the capital and labor required to make them available, will rise to such levels so as to severely dampen the quality of life for society.

The answer to that question within the 1975–85 period is an unequivocable "no". The answer to that question over, say a 50-year period, is still "no", but not without some uncertainty. The answer to that question for even much longer periods of time is still "no", but with increasing uncertainty as the time period lengthens.

Natural resources of an unreproducible nature, i.e., materials of non-agricultural origin, have been the subject of much concern recurrently through the history of industrialized societies. Exhaustion of these resources has been a recurrent theme of many writers, who point to growing demands and geologically limited availability. It is interesting, and reassuring, to note that the universal result of scientific examination of this question is that, historically, there has been no evidence that exhaustion of materials has served as a constraint upon mankind. There appears to be no evidence that the future will be radically different from the past.

For the next ten years, this is clearly the case. There are *known* deposits of all mineral materials needed to supply requirements, at current prices and at projected growth rates for world demand, for the next decade or more. For many materials, known deposits producible at today's prices are adequate to meet projected needs through the end of the century. Thus, in the time frame of 1975–1985, there is no reason from *geological factors* for materials cost to increase.

Looking beyond the planning horizon of known reserves, however, a degree of uncertainty is introduced. Reserves of any material are expensive to find, develop and hold. Investments in reserves must be balanced against using those investments to provide other goods demanded by society. With all other things equal, a society that found and held a 40-year reserve of materials would, in current consumption terms, be poorer than one that opted for a 15-year reserve. The reserves which actually exist are the result of decision-makers with investment funds who, following their own criteria, have decided it is worthwhile to search for and hold reserves. Where reserves are cheap and easy to find, they tend to be a much higher multiple of current production than in the case where they are expensive. For example, reserves of silicon are virtually infinite, since it is not hard to find sand. Reserves, on the other hand, of petroleum in the U.S. are relatively a small multiple of current production, because they are expensive to find. That, by the way, is not true in the Middle East where reserves are a very large multiple of current production. The critical point is that the status of reserves in no way implies that future prices will rise or fall. They measure, much more simply, the investment in future reserves as a deliberate calculus of present versus future value.

In order to consider resource availability beyond the time horizon of proved reserves, it is absolutely necessary to make estimates concerning future discoveries of deposits which would be economically recoverable at today's prices, i.e., deposits as good as those called reserves. To make such estimates of ultimate recoverable resources involves the geological sciences. There are several methods used by geologists to estimate undiscovered resources, but these methods are subject to considerable debate and uncertainty.

Most of the surface of the earth has not been explored for mineral deposits. The bulk of existing reserves of most materials are located in the industrialized countries—U.S., Canada, Australia, and Russia. Because of transportation costs to market, exploration has been conducted intensively only in the relatively few areas of the world that are accessible to centers of industrial demand. There is no reason to believe, however, that the occurrence of minerals in the earth's crust is related to the distribution of industrial activity on the earth's crust. Thus, there is no reason to believe that the currently explored areas will be any less or any more productive of mineral deposits than the major areas, including under the oceans, which have not been explored. Even under the most conservative kinds of assumptions relating to findings in unexplored areas of the world, estimates of ultimate recoverable resources are high. I have made such estimates for a number of materials for an ongoing study. The results of the study will be published sometime within the next several months. The attached table, which for some 16 mineral commodities compares reserves plus ultimate recoverable resources with demands for the entire world over the next 50 years, illustrates that, with a broad margin for error, such deposits can be discovered so as to prevent an increase in real cost of mineral materials to society.

The real cost of availability of material resources to society has been declining over the past century. This decline is hidden by short-term price fluctuations in the case of some materials, and is strongly hidden by the current cartel pricing of energy in the world markets. There is little or no evidence which indicates this long-time trend of declining real cost is about to be sharply reversed. The geologic evidence strongly argues in the opposite direction.

TABLE 1.—COMPARISON OF RESERVES, ESTIMATED ULTIMATE RECOVERABLE RESOURCES, AND CUMULATIVE CONSUMPTION, WORLD, 1972-2025, BY SELECTED MINERALS

[Short tons]

Commodity	Scale	Reserves, 1972	Estimated ultimate recoverable resources	Total	Cumulative consumption, 1972-2025	Ratio of total to cumulative consumption	Reserve exhausted by 2000
Aluminum	10^9	3	1,776	1,779	5.4	379.4	Yes.
Copper	10^6	373	8,995	9,368	1,218.0	7.7	Yes.
Lead	10^6	141	3,406	3,547	1,889.0	1.9	Yes.
Tin	10^6	11	821	832	78.0	10.6	Yes.
Zinc	10^6	238	13,042	13,280	1,060.0	12.5	Yes.
Chromium	10^9	1	12	13	1.0	13.0	No.
Cobalt	10^6	3	4,645	4,648	8.0	606.0	No.
Iron	10^9	93	1,109	1,202	84.0	14.3	No.
Manganese	10^9	1	77	78	.7	111.4	No.
Molybdenum	10^6	6	640	646	10.0	64.6	No.
Nickel	10^6	70	10,909	10,979	220.0	49.9	No.
Tungsten	10^6	2	685	687	4.0	171.8	No.
Vanadium	10^6	12	17,696	17,708	6.0	2,951.3	No.
Phosphorus	10^9	8	80	88	38.0	2.3	Yes.
Potassium	10^9	101	480	581	7.0	83.0	No.
Sulfur	10^9	2	31	33	11.0	3.0	No.

Note: Estimates by author. Cumulative consumption estimate based upon high economic growth and high population growth for world. No recycling is assumed, so cumulative consumption overstates drain on reserves and estimated economic resources.

A second factor, important in deciding whether or not materials cost can contribute substantially to decline in quality of life, is the fact that materials are an extremely small part of the total economic value of goods produced. The total value of materials consumed in the U.S. economy in recent years (excluding energy) is below 50 billion dollars per year. With a total value of output of 1.5 trillion dollars, cost increases for this portion of the economy can be large without imposing significant strain on the quality of life and can be offset by advances in productivity in other phases of production.

Summary

Resources are an essential ingredient in the production of goods and services. The availability of resources is related to their mode of occurrence in the earth's crust, thus they do differ from capital and labor. Historically, resources have become available at decreasing real costs, and, from a geological point of view, there is no reason to expect real cost to rise over the next several decades.

Part II. The Process of Substitution Among Materials

The demand for materials in a society is of a derived nature. Society's demands for ultimate consumption are either in the form of investment goods or consumer goods—products and services which involve in their production the use of materials. These materials perform physical functions which are necessary for the production of the product ultimately demanded. For example, the materials contained in an automobile are used because they provide strength, conductivity, or beauty to the final product. In the same way, the materials involved in producing a haircut are used because they provide certain characteristics having to do with combing or cutting of the hair, and a comfortable seat while the process is taking place. It is the exception that a non-energy material is consumed as such in the final products of the economy.

Since it is the properties of the material which are desired, not the material itself, the possibilities of substitution between materials is extremely wide. It is the thesis of this section that that process is complex, involving three major elements, within each of which there is great complexity. These elements are (1) the structure or composition of the final demands of the economy; (2) the state of the technologies used to produce those final demands; and (3) the comparative attractiveness of the competing materials, not only in terms of cost per unit, but also in terms of other factors such as stability in supply, ease of workability, and tradition.

Structure of Final Demands

The issue here is how the changes in structure of final demand might impact on material substitution, not on the demand for materials as a whole. The latter is a subject of great interest, and work is being done on it by those interested in the impact of economic growth on the total materials demands.

From the point of view of substitution, the role of structure of final demands has to do with the *shifting* of consumer preferences as the per capita size of national income grows. These shifts can be characterized in general as a shift from a goods, especially producer-consumer-durable goods, toward a more service-oriented economy. It is not clear that the impact of such a shift is a decline in total materials requirements, but it is clear that the shift does lead to a different pattern of services demanded of materials. The consumer-durable goods economy places relatively large demands upon those materials which can be fabricated into "appliances" broadly defined. The service-oriented economy also generates major materials demands; for example, materials needed for transportation systems, opera houses, auditoriums, schools, universities, etc. These materials, however, may be of a different nature than the former case.

Therefore, different patterns of material input into world economies at different stages of development can be observed. Differences in the composition of material inputs can arise solely because of changes in the composition of the final demands of these economies. Thus, even without direct substitution of one material for another, there will be differential patterns in specific materials use arising from this factor.

User Technology

Of major importance in the substitution of one material for another is the factor of user technology. Although no quantitative data are available, it is clear in many cases that this is the dominant engine of substitution.

What is involved here is the means by which the economy's final demand for goods will be met. The example of communications can serve to illustrate the point.

Man has always had the innate desire to communicate. The amount of this communication has always been limited by the technologies available, and the cost of communication. Initially, of course, communication was entirely face-to-face and the limit of communication was by sight and sound. The materials involved in such communication could be considered as zero. With the development of skills of writing, materials began to be devoted to communications. These materials initially were both mineral in origin, i.e., stone tablets; and from reproduceable sources, i.e., parchment. As the technology of communication developed, the demand for communication services increased. The communications industries today are major consumers of materials in the form of wood pulp for paper, metals for wire communication networks, and material components of radio and television transmitters and receivers. The development of a user technology which made a service available, has led to major material demands.

The question here is the substitution of materials in these demands. User technology development has significantly reduced material requirements for some means of communications. For example, the development of the solid-state electronic technology has tremendously reduced the material content of radio receivers. The development of microfilm storage has reduced the material costs of the storage of printed information. The laboratory demonstrated technology of transmitting voices on laser beams holds a promise of greatly reducing the material content of telephone transmissions. The development of microwave technologies and commercial satellites, in turn, has reduced the need for long-line cable materials.

The list could go on and on. The essential point is that the translation of the demands for goods and services by a society into demands for materials is through technology. The nature of this technology plays an extremely important role on the level and character of the requirements or demands for materials. To explain the observed change in patterns of demands for materials through time, an understanding of what happened in the area of technology is absolutely essential.

The significance of this observation is that one must go well beyond examining the situation with respect to any given materials to understand the process of substitution among materials, and to understand the impact of any perceived material shortages on the quality of life. Public policy must be based upon an understanding of the complexity of materials issues, rather than a commodity-by-commodity *ad hoc* approach. The objective is a healthy, dynamic, adaptive technological system, rather than a piece-meal set of specific commodity programs.

Economic Factors

Traditional text book economic analysis treats the demand for a raw material as ultimately being related to relative prices. The argument runs that, within a given technology, the firm will pick the least cost combination of raw materials for production. There will be trade-offs between using more, say, of steel, and using less, say, aluminum in the manufacture of a refrigerator. Traditional economic theory argues that if the price of aluminum declines relative to the price of steel, then, to achieve the lowest cost combination, the producers will use more aluminum and less steel.

What happens in material substitution is much more complex than this simple model. Historically, other factors than unit price seem to have been of primary importance. While it is true that producers will attempt to achieve the lowest cost for their final product, it is not clear that this translates into a simple price-demand relationship for raw materials. The producer is seeking lowest cost for the total production function for the product concerned. Since raw materials are usually a relatively small portion of the total cost of the final product, non-cost attributes of the raw material and its indirect effect on other costs may well outweigh any price differentials between the competing inputs. To use an example from outside of the materials field, but one which is well-known, consider the switch from coal to diesel oil to power American railroads. This substitution, which took place extremely rapidly in the 1940's, was not the result of differential price shifts between diesel oil and coal. It was the result of the total overall efficiency of the diesel engine versus the steam engine. Virtually no price differential (within reason) between the two competing fuels could have stopped the transformation.

Another more recent example was the belief in the early 1960's that aluminum would replace iron castings in automobile engine blocks. This was a widely held belief in the automobile industry in the early 1960's and some major projections concerning future aluminum demands were made based upon such a substitution. In fact, the substitution did not take place, due to a very complex set of circumstances which—to this day—are not thoroughly understood. One of the problems which surfaced in cars which did use aluminum cylinder heads was an adverse reaction to one-time overheating.

The essential point here is that substitutions between materials may arise from developments completely outside of the price behavior of materials.

Another factor which strengthens this conclusion is the fact that, although materials are often a very small portion of a final product's value, they are an essential ingredient of that product. A cut-off of the supply of materials to a producer will cause output to drop to zero. Thus, the producer, because of the major losses involved from a loss of output, may place great weight in his decision as to which raw material to use upon security of supply in face of many kinds of difficulty. When a firm commits to a raw material in its production function, a decision not subject to rapid change, it will consider such things as the stability of the industry to provide supplies, the probability of political or economic cut-off of supplies, the ease of storage to maintain stockpiles, as well as the pure cost functions feeding into the accounting costs of the product.

Summary

The conjunction of the above factors is what makes the substitution process complex. The tendency is to consider such processes as continuous, but in fact they are highly discontinuous. Once, because of technological change or a shift in consumer preferences or from factors other than price, a substitution has taken place, it tends to be irreversible. Clearly, radio producers are not going to return to vacuum tube technology, with its consequent material demands, in place of solid-state transistor which uses virtually no materials. Nor are we likely to return to the use of coal to heat homes or power railroads. Yet, of course, substitutions do take place and many of them are in the direction of moving to more abundant materials and in the direction of materials savings *in toto*. It is correct that the process of substitution through the last century has contributed to the maintenance of a firm position of materials adequacy for the world as a whole.

There are counter-examples which are perhaps worth examining, at least as a caution. One of the substitutions in materials which has occurred over the past 50 years has been the relative decline in use of natural fibers and the growth of synthetic fibers. This was a change from a renewable agricultural resource to a finite mineral-based resource. The reasons for the switch include all three of the factors mentioned above. The synthetic fibers provided increases in services; for example, permanent press clothes. They provided economies in manufacture by uniformity in fiber specification, and they provided stability in supply, because supplies were not a function of weather. Such a substitution cannot be explained primarily by the per pound price of nylon versus the per pound price of cotton, and it is an example of a change which shifts the material base of the technology.

The conclusion stated concerning substitution rests upon these factors. It is a process which is very poorly understood and one which is a prime target for major fundamental research effort.

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Part III. Institutional Problems

It is very important that society organize itself so that materials flow is without constraint and relatively certain. Although, as argued above, there are no geologic reasons for material shortages to impact on the quality of life, an interruption of material flows to the economy would be disastrous. The time for adjustment for change in raw material inputs to production functions is long, and the failure of a component in these production functions will stop production. This is equally true whether that failure is from a lack of capital through a lock-out, a lack of labor through a strike, or a lack of material inputs through an embargo. Each of these political weapons stops production.

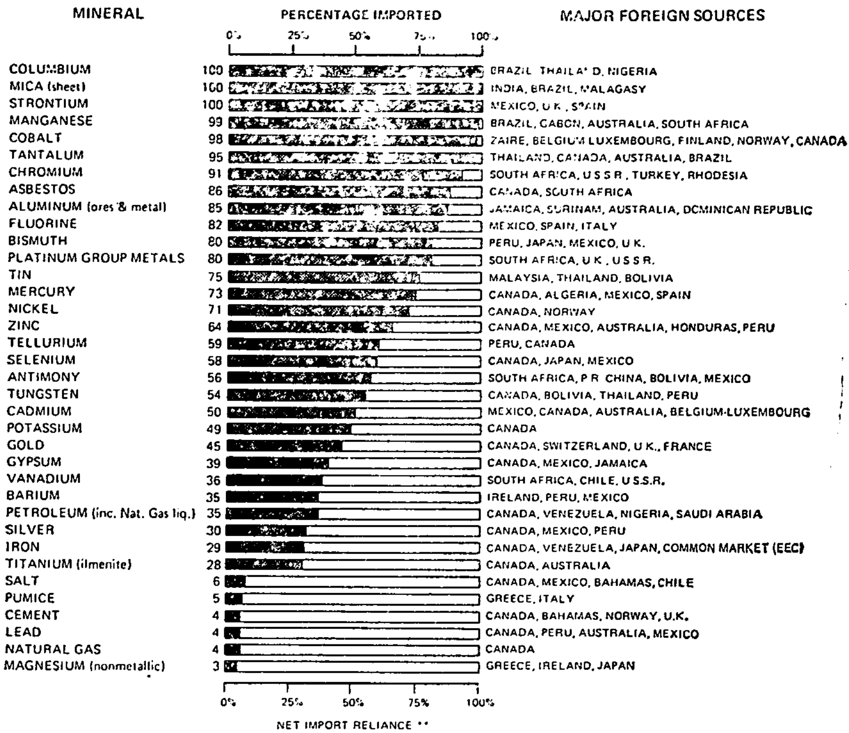
Each of these political weapons or the threat of them, can be used to increase the share of productive income flowing to the owners of that factor. Capitalists can use lock-outs to hold down labor costs; labor unions can use strikes to increase the share of income going to labor; and raw material producers can use embargoes and cartels to increase the share going to the raw material component of the production function.

The problem facing the U.S., and the world, over the next ten years is one of institutions. The issue is what can be done to reduce the potential damaging impact of raw material supply interruptions or price manipulations on the quality of life of the U.S.

Embargoes

In the case of raw materials, which are relatively cheap to store, the least cost protection to society from either a political or economic embargo is the existence of stockpiles. Without going into the very difficult issues as to how big a stockpile, who should finance it and who should hold it, it is obvious that the stockpiling strategy is the least-cost one to employ in uncertain situations. This leads clearly to a recommendation that the question of economic stockpiles be placed high on the agenda for congressional consideration as an insurance that raw material interruptions from natural or man-made factors will not substantially interrupt economic activity. The following chart details those minerals where the U.S. imports some significant proportion of current supplies. Each of these should be subject to analysis in the stockpile study.

IMPORTS SUPPLIED SIGNIFICANT PERCENTAGE OF MINERALS AND METALS CONSUMPTION* IN 1975



* APPARENT CONSUMPTION - U.S. PRIMARY + SECONDARY PRODUCTION + NET IMPORT RELIANCE

** NET IMPORT RELIANCE = IMPORTS – EXPORTS ± GOV'T STOCKPILE AND INDUSTRY STOCK CHANGES

BUREAU OF MINES, U.S. DEPARTMENT OF THE INTERIOR (import-export data from Bureau of the Census)

Cartels

The OPEC cartel is serving as a successful example for other producer countries. Many studies, both within and without the government, have targeted a number of commodities for possible cartel action and, in fact, cartels of various characteristics have been formed. A cartel impacts on economic welfare by restricting the supply of a material and raising its price well above long-term costs. The objective of the cartel is quite clear—to maximize the profits or rents to be earned from the deposits controlled by the cartel. The cost to society is also clear in that a disproportionate share of other goods must be exchanged to obtain the materials.

The most effective anti-cartel policy is to place reliance upon the market forces to speed the collapse of the cartel. A study done by the Secretary of Interior indicated, historically, that the life of cartels which are not supported by governments is less than three years. Economic pressures on the cartel are very great, both from supplies outside of cartel production, and consumers, reacting both to price and possible embargo uncertainties, seeking production functions which minimize or eliminate the use of a material concerned. When the cartel is of a traditional nature, i.e., an organization of producers, opening up and permitting market forces to operate in the non-cartel areas of the world, is the most effective and efficient means of rapidly causing the demise of the cartel.

However, this may not be so when the participants in the cartel are national states. It is not obvious that national states will respond to economic criteria of profit and present value. National-state cartels may have other objectives covering the entire gamut of political power and coercion to matters of national prestige. The growth of government-operated firms and cartels including national states does raise a series of other more basic issues. For example, such firms or cartels may make materials available not on economic terms but in return for other kinds of payment—such as military shipments, treaties, long-term investment commitments, or other such matters. This is not to say that economics is not important to the new breed of cartel. It clearly is. But the best policy response to the new breed needs careful evaluation.

Thus, natural subjects for congressional examination are the issues of nationalized firms and cartels containing national states as members. These subjects raise non-traditional sets of problems and issues, for which new legislative and policy answers may be desirable.

Environmental and Social Issues

A factor that could create material shortages without geological basis is the closing of large areas of the world's land mass to mineral exploration or exploitation. Although mining takes a very small area of the earth's crust, much of the earth must be explored in order to find the high-grade deposits that can be mined. Withdrawal of land from exploration through preservation for wilderness purposes, or the denial of development of land in large areas because of perceived other values of that land can, over the long term, severely restrict the geologic availability of mineral resources. This issue is one which should be subject to congressional scrutiny, especially with respect to the withdrawal policies of the Federal Government.

In general, materials production generates lesser environmental impacts than energy production. Energy materials are mined in much greater volume, and their use creates most of the air pollution problem. The environmental impacts of materials center about conflicts in land use, land disturbance, emissions from smelting and refining, and water pollution. There are some specific severe problems, such as the phosphate slime ponds in Florida and the asbestos fiber problem in Lake Superior. Research is needed for mitigation of these problems; however, they do not appear to be of a magnitude that will restrict material supplies significantly.

Summary

The threat of material shortage arises from social and institutional factors, not physical availability. These factors could subject the United States to embargo action, and to high prices. Further, institutional barriers could inhibit the search for mineral deposits and investment in production capacity of many materials. The Congress can usefully explore the issues of stockpiling, public land access, cartels, nationalized firms, and environmental impacts of material production and use in the context of material flow to the economy over the next decade.

RESOURCE AND ENERGY SUBSTITUTION

By THOMAS VEACH LONG* II *and* LEE SCHIPPER**

SUMMARY

The principal conclusions of this paper are:

(1) The crucial issues regarding resource scarcities concern the *rates* and *prices* at which resources will be available and the political constraints to using them in ever increasing amounts. Increasing worldwide demand for resources may create supply-demand disequilibria. Although these will eventually be resolved by market forces, the additional costs during the periods of disequilibrium may be large and are to be avoided. While available market and policy mechanisms may well be sufficient tools with which to achieve an optimal rate of resource utilization, we know too little about how this optimal rate should be defined and evaluated.

(2) We need to increase the flexibility of our economic system to respond to sudden resource supply disruptions through broadening our understanding of and technical potential for resource substitution. This implies a need for the centralized assemblage of information regarding resource use, its careful analysis, and the development of contingency responses. These could then be instituted after brief reevaluation in order to reply more rapidly to unforeseen supply disruptions. Strategic stockpiling, of course, is one possibility that has a long history. Natural resource conservation through substitution is another important response mechanism. It should be viewed as the rational adaptation of producer and consumer to a change in the social costs and benefits associated with the use of a unit of resources, or to better information regarding these costs.

(3) Major substitutions require long times for invention, innovation, information diffusion, commercialization and market penetration. The total time required for effective substitution via technological change rather than price induction—following identification of the potential scarcity and invention of the appropriate substitution technology—is on the order of twenty-five to thirty years when information diffusion is included. Governmental initiatives in the form of support of both basic and applied research and development appear to play a positive role in reducing the lag times.

(4) On a macroeconomic level, the substitution of productive factors should be viewed in a unified framework that permits exploration of the interdependencies of capital, labor, and material and energy resources. rather than solely within a value-added formulation that focuses on the tradeoffs between capital and labor. Little definitive

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information regarding the substitution of capital and labor by natural resources is available, and even that is somewhat inconsistent. Prior to instituting policies that affect these substitutions, a much clearer understanding is required. At least a start in achieving this understanding could be made through research that examined the historical and potential tradeoffs at an enginering level for specific major industries, such as iron and steel.

(5) Scientists and engineers have recently drawn our attention to two novel modes of substitution—the tradeoff between the energy needed to drive a process and the time required, and the substitution of materials for energy resources. Assessment methods have been developed for the latter and are being explored in the former case.

(6) Consumer substitution occurs at two different levels with possible differing responses to price. On a technical level, a consumer will seek an identical amenity satisfaction through choosing a different group of goods and services that deliver an identical bundle of the desired characteristics. For example, a consumer who wants to be warm in his home may satisfy this desire by burning a given quantity of fuel, by wearing heavier clothing, or by burning less fuel with increased insulation. Alternatively, changes in relative prices may produce a modification at the personal, subjective level, where a consumer modifies his preferred set of amenities—a lifestyle change. In parallel to the above example, the consumer might decide that the cost of the "warmth" amenity was sufficiently high that he would prefer to have less warmth and to devote the money saved to the purchase of other amenities, such as increased recreation. Policies designed to stimulate the former type of substitution rather than the latter are generally less socially manipulative, and for this reason to be preferred.

(7) International comparisons of energy requirements in industrial production show that there are many opportunities for energy conservation in the U.S. through the introduction of more advanced technologies. These would include more basic oxygen and electric furnaces in steel making, as well as direct reduction; efficient suspension preheater and pre-calciner kilns in cement production; and cogeneration of steam and electricity. Parallel comparisons of energy use in Sweden and the U.S. indicate that equivalent standards of living can be attained with remarkably different levels of energy use. Therefore, there does not seem to be an immutable direct proportionality between economic growth and growth in energy use.

(8) Congressional and governmental action can stimulate enhanced resource substitution capability in our economy through three mechanisms in addition to the collection and disseminaton of comprehensive information on appropriate technologies: through the funding of both fundamental and applied research directed toward resource-conserving technological change, through assuring the existence of sufficient economic incentives for adoption of the innovations, and through direct regulatory policy or practice.

(9) The amounts and patterns of resource use that would be observed under perfect market conditions might be usefully evaluated in order to predict the quantities of the resources that could be conserved relative to prevailing practices and constraints—which might include market imperfections, peculiarites of pricing practices, lack of capital or information, or institutional barriers.

(10) One of the more critical issues we face is how to achieve a better standard of living for many in our society under resource constraints that may possibly impair economic growth. To the extent that the constraints are mitigated by the manifold of resource substitutions discussed herein, growth may proceed unhampered. But in order to ensure that this is the case over the moderate to long term, we need careful techno-economic analysis.

The attitude toward natural resource use in the preceding decade was one of ebullient optimism. Historical experience showed that possible resource scarcities, as evidenced by decreasing ore grades or smaller areas under cultivation, had been mitigated or eclipsed by technological advances or through price-induced substitutions.

This optimism has been replaced in the 1970's by a more guarded stance. We now realize that natural resource markets may be buffeted by the actions of international cartels and that national security considerations can dictate policy steps that may not appear economically efficient over the short term. Intensive resource use also may generate unacceptable levels of thermal, air or water pollution, and another constraint is thereby placed on the actions of private economic agents. Finally, we have become increasingly concerned with our obligations to future generations, who may cast their votes in economic decisions only through us. This barrage of new complexities suggests that intelligent decisions, either market-based or policy-oriented, require a much broader understanding of the technology and sociology of resource use than heretofore achieved.

Available evidence regarding resource scarcity is mixed. Barnett and Morse in their classic exposition of the economic evidence of scarcity [1] showed that, with the possible exception of forest products, the real inputs of capital and labor to the extractive sectors (including minerals, agriculture and fishing) had decreased over the period 1870–1957. Thus, they concluded that there was no economic basis for presuming the existence of either Malthusian scarcity or Richardian scarcity, the latter arising from the use of increasingly lower-grade ores. Similarly, Goeller and Weinberg [2] argue that total world resources of the most extensively used elements are so large (one million to one billion times current yearly consumption) that a transition to a society that uses only these materials will result in an age of "infinite substitutability." There is the implicit assumption that some resources are in foreseeably short supply but that substitution and technological change can ameliorate any physical shortage. They also project that this transition can be accomplished with tolerable costs, although individual sectors could be severely impacted.

A less sanguine view is taken by Skinner [3] who chaired the prestigious study by the National Academy of Sciences' Committee on Mineral Resources and the Environment. Again emphasizing the need to shift to technologies that use iron and other abundant metals for all our needs, he specifically examines the maximum economically-recoverable tonnages of scarce resources, such as copper, lead, mercury and uranium. [4] His assessment shows, for example, that society's use of mercury and gold is at a rate that is 110 times faster than iron

Editor's Note.—See references at end of paper.

and that the rate of lead use is 40 times that of iron, when the rates are taken proportional to respective crustal abundances.

This formulation of the supply picture comes closest to identifying what we believe to be the key considerations regarding resource use and the need for new resource substitution options between now and the year 2000. Let us accept for the purposes of the discussion given below that potentially recoverable stocks of resources are sufficiently large to fill society's needs over this period. The crucial issues concern the *rates* at which they can be used:

(1) *Will flows of natural resources be available at the rates needed and at prices that we (and other nations) are willing to pay?* Are capacities of current and projected extraction and beneficiation enterprises sufficient to meet projected demand? Keyfitz has recently pointed to the enormous increase in demand for resources that may attend the efforts of a large portion of the world to become middle class. [5] Will it be possible to furnish the resources required for world economic development at an accelerated rate? How effective will resource cartels be in constraining supply and thereby stabilizing prices at much higher levels?

(2) Even if we suppose that resources are available at prices commensurate with our economic vitality, *will it be politically feasible to continue to use them in ever-increasing amounts?* What are the extra-economic dimensions of the problem of resource use?

(3) *What is required for efficient societal response to sudden supply disruptions arising from embargoes, crop failures or disaster?* Does a smoothly operating price system furnish us with sufficiently rapid signals of these disruptions?

There are many facets to the answers to each of these questions, but a single pervasive one. To ensure the continued health and growth of the U.S. economy, we must understand the full dimensions of resource substitution and be prepared to set substitution mechanisms in motion. In this essay, we will emphasize *how little is known about the technical basis of and potential for substitution and technological change and about the times required for these responses.* In parallel, we will examine some *recently developed assessment methods that are being used by several active research groups to begin to explore these problems.*

The purpose of the substitution mechanisms that we shall discuss is the implementation of resource conservation as a response to possible supply constraints. The term "conservation" is almost always used emotively and left undefined. We should like to be precise.

Natural resource (energy) conservation is the rational adaptation of producer or consumer to a change in the *social* costs and benefits associated with the use of a unit of resources or to better information regarding these benefits and costs. The change may result in the increased use of a resource, which distinguishes the concept of conservation from that of preservation.

A principal function of policy intervention is to effect the rapid dissemination throughout the economy of information about the total *social* benefits and costs. For example, the perception of the energy-conserving advantages of increased home insulation can be transmitted through new tax deductions, loan programs or other governmental initiatives.

The discussion in this essay will often focus on substitutions for energy resources. This should not be taken to indicate that energy resources are necessarily scarcer than some other materials. However, under the stimulus of the oil embargo and subsequent cartel actions, the understanding of the complex economic role of energy resources in our society has been greatly expanded. In the energy market, the prices that consumers and most industrial users pay in the absence of governmental regulation or market imperfections reflect *average* producers' costs. For the first time in decades, the marginal costs of new supplies of today's energy forms, or of substitutes such as synthetic fuels, lie significantly higher than average costs. Thus, the evidence suggests that energy prices will continue to escalate. Market prices are used by both producers and consumers in calculating their optimal economic behavior. Energy users wishing to maximize their welfare will reoptimize their consumption/production activities by finding energy substitutes under the new set of prices that obtains. Government initiative may be required to ensure that considerations of national security and the environmental impacts of energy harvesting, conversion and use are reflected in this new set of prices.

A. Material-Material and Energy-Energy Substitutions

Above we have stressed the need for society to prepare itself for encroaching shortages of less abundant materials by thoughtfully examining substitution for these by more plentiful resources. There is little to be gained at this point by constructing a material-by-material list of substitution possibilities. Similarly, our technical flexibility in making energy-energy substitutions is substantial and increasing, both in industry, where boilers convertible to various feeds are increasingly prevalent, and in the home, where conventional fuel and electric use is supplemented by wind, wood and other forms of captured solar energy. Of course certain industries may be seriously affected by constraints on supplies of specific fuels because technologies that permit fuel substitution do not exist. For example, sectors as diverse as the baking and foundry industries both are critically dependent on sufficient supplies of natural gas.

Evidence of energy-energy substitutability can be found in the small differentials in prices of fuels on a per Btu basis. The *full* costs per Btu of using alternative fuels, which would include the cost of sulfur removal from high sulfur coal, for instance, are approximately equivalent. American industry is more concerned with the perturbations attending potential short-term shortages of specific fuels. Because of this, we may see industrial users convert to electrically-powered technologies, reasoning that a moderate increase in energy factor costs is outweighed by security of supply.

There are two points that should be emphasized. First, substitutions that are effected through technological change take time, and, historically, major substitutions have required very long times. Second, a discussion that divides substitution possibilities into categories such as material-material, energy-material, labor-energy, etc., is clearly artificial. Almost all two-factor substitutions involve significant interdependencies with other factors. For example, replacement of productive labor by fuels and electricity can be usually accomplished only with the installation of new capital facilities. Let us examine these points more fully.

Large scale substitutions of one resource for another have most often occurred over periods of time that extend beyond the perspective of this study series and of accurate economic projections. Time-consuming techniques or technology development must be followed by an adjustment phase in which the new method penetrates the market. An example of a successful substitution for a dwindling resource that is cited by those who are optimistic about the ability of the market to self-regulate is that of coal for increasingly scarce wood in eighteenth century Britain. It is rarely mentioned that a half century (ca. 1730–1780) of effort and expense by British ironmakers was required before a successful method of using the mineral fuel (which contained impurities that gave iron undesirable properties) rather than the renewable timber resource in steelmaking was developed. [6] Coal-dependent growth of the industry was such that production rose from 68,300 long tons in 1788 to 2,701,000 long tons in 1852. [7]

Certainly, technological responses to resource constraints should be more rapid today, but how fast can we expect them to be? The lag between the invention and the commercialization of Xerography was 13 years, and between the beginning of fundamental research on commercial polymers by DuPont and the first commercial production of nylon was 11 years.[8] Other examples are given in Table 1. A study by Lynn[9] found that in the post-World War II period (1945–64) the average lag from basic discovery to the beginning of commercial development was nine years, and the period of commercial development extended for an additional five years, a total of fourteen years. His investigation also indicated that government support significantly reduced the time required for the initial "incubation" phase, positive evidence that governmental activity in technological research and development is beneficial.

TABLE 1.—*Lag times between invention and initial commercialization* [1]

Invention:	*Interval years*
Fluorescent lamp	79
Television	22
Ball point pen	6
DDT	3
Jet engine	14
Radar	13
Crease-resistant fabrics	14
Terylene, Dacron	12

[1] Data from J. Enos, cited in Ref. 8.

Equally important in determining the total time to implement a feasible substitution is the interval required for diffusion of a process throughout an industry. A recent internationally-based review of this question[10] selected ten new technologies, including numerically-controlled machine tools, tunnel kilns, basic oxygen steel, continuous casting, special presses, float glass, the use of gibberellic acid in malting, shuttleless looms, plate cutting methods, and automatic transfer lines. As a rough generalization, market penetration to achieve a diffusion of 50 percent (as a percent of national output of the product) occurs in a period equal in length but additional to that needed for incubation and development combined.

Consequently, the total time required for effective substitution via technological change rather than price induction—following identification of the potential scarcity and invention of an appropriate substitution technology—is on the order of twenty-five to thirty years when diffusion time is included. Through thoughtful analysis and preparation, society can and will mitigate serious economic perturbations that could arise from increased rates of resource use and concomitant supply constraints. Support by governmental agencies is absolutely necessary in stimulating the basic research that is vital to the slow, creative process of invention itself, and it is also effective in speeding up the incubation process between invention and the commercial development decision. [9]

Let us return to the interdependencies among factors in the resource substitution process. Consider two steel making processes—one utilizing an older blast furnace that requires 16×10^6 Btu of heat per ton of raw steel produced and the other using only 10×10^6 Btu/ton (these numbers are not exact, only illustrative). From what could this difference arise? The lower energy consumption of the second furnace could be due to the following factors:

1. The walls are thicker, of new materials, and furnish better insulation;
2. Maintenance of the fuel combustion unit is carried out more frequently;
3. The heating up of the furnace is timed to more carefully match the time that the charge of iron moves into place; and
4. The hot gases emerging from the furnace are used to generate electricity, and the waste heat from the generation process is then piped to another area to heat offices (or, alternatively, to preheat the next charge).

In this description of "energy conserving" factors we recognize that the substitutions have been in the form of capital (thicker walls, innovative materials), labor (maintenance), information (timing), and thermodynamic optimization (the use of high temperature heat as an input to another process) for energy. While differences 1 and 2 are straightforward substitutions of energy by a single factor, the last two are not. Both require new capital items and an increased labor input, at least in a process control capacity.

Recycling activities substitute used for virgin materials, but the second-order consequences of the material-material substitution are often more important. For example, aluminum is an abundant material, and the benefits of recycling lie in a 90 percent reduction in the energy required to produce a new aluminum product, as well as reductions in capital and labor inputs.

Thus, resource substitution should be considered in a unified framework that permits a consideration of complementarities among substituting factors as well. Two recent econometric examinations[11,12] explore this question at the macroeconomic level for American industry. Both studies employ translog production or cost functions, and this functional form is somewhat controversial. The Berndt-Wood formulation[11] relates the flow of gross output to the services of four factors of production: capital, labor, energy and materials. The specification used by Humphrey and Moroney[12] is somewhat different, treating the dependence of net output in specific industrial sectors on inputs of natural resources, capital and labor. Both investigations utilize time series data, but different aggregate indices. The studies are not entirely in agreement regarding the relation between capital and resource inputs, although the differences in specification preclude direct comparison of the results. Humphrey and Moroney[12] find that there is limited substitution between capital and natural resource products, while Berndt and Wood's results indicate substantial complementarity between capital and energy, although some substitutability capital and material inputs is evident.[11]

These two publications are important because they reflect a clear break with the value-added motif, which subtracts out natural resource costs and considers only capital and labor, that has dominated econometric evaluations of the production process. Continued probing of the relation of the productive services of natural resource inputs to total output will enhance our understanding of the resilience of our economy to sudden constraints on the supplies of these resources. Of particular interest would be disequilibrium analyses and cross-sectional studies, perhaps based on international comparisons.

B. Substitution of Materials and Energy

There are three levels at which materials and energy substitute for one another. Above, we have called attention to the possibility of using recycled aluminum rather than virgin ore, with an effective substitution for energy. Additionally, we should recognize that intermediate materials carry with them into subsequent fabrication steps the energy that has been embodied in material extraction, beneficiation and other previous manufacturing processes. Consequently, loss of the material through slippage is equivalent to a waste of the embodied energy. (Here, the term "embodied" is used in the same sense "embodied labor" has been used by economists.) Any modification in a process that changes the relative proportions of materials that embody different amounts of energy also changes the energy required for the process.

Finally, materials contain real amounts of energy that can be released in the same way that it is released from fuels—through a chemical reaction. For example, sulfur reacts with oxygen in a combustion process that yields two-thirds as much energy as the combustion of coal, for chemically equivalent weights of sulfur and coal. Likewise, aluminum combines with oxygen releasing four times the energy of coal-burning, and a reaction of barium oxide with another chemical, sulfur trioxide, gives off 1.5 times the combustion energy of coal. Almost every chemical can react with another so as to furnish energy under the proper conditions. In real industrial processes, material use may substitute for fuel and electric use. The Hall-Héroult electrolysis of alumina to produce aluminum metal utilizes a carbon electrode. For every ton of aluminum that is produced, a ton of electrode is chewed up, and carbon dioxide is produced. The carbon substitutes partially for electricity in the reduction of the alumina, and the heat released in the effective combustion of the carbon in part reduces the fuel requirement in maintaining the melt.

Obviously, the determination of the most *physically* efficient production process is complicated by the need to consider all three types of substitutions in concert. One response to this has been the birth of a new discipline, called resource analysis (or in a more restricted sense, energy analysis—when applied to analyses of fuel and electricity consumption). [13] The goal of research in this area is an accurate quantitative assessment of the productive flows of resources in economic processes. As a familiar example of such an analysis, consider the production, use and eventual discard of an automobile. [14] In order to answer the question of how much energy is required in production, we must go not only to the automaker to find out the energy requirements for fabrication, but we must start back with the fuels and electricity needed for the extraction and beneficiation of iron ore and trace through the energy inputs to the blast furnace and to steel making. A refined analysis would investigate these steps for several types of carbon steels, for ferroalloys, stainless steel, automotive sheet, iron and steel castings, as well as copper, aluminum, zinc, plastic, and glass components. Fuel consumption in normal driving must be toted in, as well as the energy required for replacement parts. And the possible energy savings introduced by recycling the scrapped auto through shredding or compacting must also be evaluated. This sounds like a tall order—and it is—but it has been done. [14]

But why have such analyses focused on the energy requirements for processes, rather than the water needed or the inputs of iron ore? Certainly these are increasingly important resources, and the analytical procedures that have been developed do evaluate all material resource flows as an initial step. Energy requirements are emphasized for two reasons. First, the physical scientist recognizes that in order to make a process "go", energy must be used. In this use, the ability of a given quantity of energy to do work is partially lost. A conservation law tells us that the elements in material resources are never destroyed. Given a sufficient quantity of energy that can be utilized to do work, we can reaggregate and reconstitute any form of matter. If an automobile is left to rust in a field and the rust is then dispersed by the wind, it may still be conceivably possible to sweep up the rust using a giant electromagnet. All that would be required is enough energy to power the magnet. While the energy used in a process is also completely conserved, it is inevitably degraded, finally, to heat at ambient temperature. In the near term, before solar radiation can furnish a substantial fraction of our energy supply, we must rely on existing and finite quantities of usable energy in the form of low-entropy fossil and uranium fuels. We must husband these supplies wisely.

The second reason for concentrating our attention on energy resources is somewhat more complex, but it also comes from that branch of science known as thermodynamics. Utilizing a precise description of technologies based on an energy parameter, it is possible to evaluate their physical efficiencies. This knowledge is only one piece of the data set that is needed to assess economic efficiency, along with a knowledge of the minimum requirements of other scarce resources such as capital and labor, but it is a very important piece.

What have such analyses yielded?

(1) The detailed descriptions of processes provide a much clearer picture of how society uses resources than had been available. This is information that both free market advocates and those oriented to governmental intervention always assumed was

incorporated in economic decisions, but rarely was. The importance of this sort of knowledge is underlined by the fact that one of the largest and most profitable U.S. chemical companies keeps energy accounts side-by-side with financial books, and uses them daily in a line management system. Auto manufacturers also evaluate the total lifetime energy requirements of their vehicles, including material production.

(2) They show that there is no easy path in resource conservation. In energy conservation, a program that can yield a saving equivalent to 0.5 percent of the Nation's energy budget is a major one. This means that conservation will be difficult, and that planning must utilize a growing and accurate information base.

(3) Aside from fuel used for home heating and transportation, the demand for energy and other natural resources is a derived one, depending on the levels of their incorporation in the production of other commodities. Because natural resources are such a small component of input costs, compared to capital and labor, significant increases in resource prices may be required before there is significant industrial response. Given this, it is the individual consumer who will be the target of increased hikes in fuel and electricity prices. Because heat and transportation are necessities, much more attention must be given to the distributive questions associated with energy and other resource conservation policies. Our most pressing national problem is how we will achieve a more just distribution of income under resource constraints that may impair continued economic growth.

(4) Opportunities for resource conservation in individual processes have been probed. For instance, we now know that production of a 3250 lb. automobile requires a total of 37,250 kWh, from ore extraction through fabrication.[14] This is equal to the energy content of the fuel burned in its first year of operation (by way of comparison, an average family home uses 300 kWh/month in electricity), and one-third of this production energy could be saved by recycling the discarded auto hulk.[14] Governmental initiatives to facilitate retrofitting and adoption of resource-conserving technologies should be pursued.

C. The Substitutability of Energy and Employment in the Industrial Sector

One of the most sensitive issues in the introduction of any new technology is the extent to which it is labor-saving. Historically, wage rates have been high in the U.S., and innovations have been capital-intensive and directed toward reducing labor's share in production costs. The assertion is often made that energy has increasingly been substituted for labor in post-World War II industrial production. The basis for this assertion is not entirely clear. Two recent econometric studies conclude that labor is a substitute for both materials and energy—or for natural resource products—more generally. To our knowledge, there has been no rigorous microeconomic quantitative evaluation of the substitutions between physical inputs of labor and energy per-unit-output over time. Partially, the claim may derive from the position that the principal contribution of productive labor is in furnishing energy to the process, and if labor's input is reduced, it must be replaced by energy. But menial uses of labor have certainly been minor in this century. Alternatively, large capital facilities utilize large quantities of energy, and this gives the impression that a substitution of capital *and* energy for labor has been effected. Qualitatively, there is apparent substance to this position.

However, Table 2 shows that the relation between energy use and labor use in industrial production may be more complicated than would initially seem to be the case. For a representative set of energy-intensive industries, we see that energy use per production-worker man-hour has indeed increased, or in a few cases has been stable, over the period 1954–1967. On the other hand, energy input per constant dollar of shipment has *decreased* for every industry over this time period. Further disaggregation of these industries to examine energy use per unit physical output may be very revealing. It appears likely that increased capital input has substituted for *both* energy and labor. Because energy costs are small relative to those of capital and labor, energy use has been the tail of the dog, wagged by the interaction of the larger factor costs. This is in spite of the fact that energy prices have decreased over the period studied. This raises the converse question of how far prices must rise before energy costs enter sensitively into the industry sectors' planning.

TABLE 2.—ENERGY (BTU×10^{-3}) PER 1967 DOLLAR SHIPMENTS* AND ENERGY PER UNIT LABOR (BTU PER PRODUCTION MAN-HOUR)[1]; REPRESENTATIVE ENERGY-INTENSIVE INDUSTRIES (1954–67)

SIC code	Industry	1954		1958		1962		1967	
		Capital	Labor	Capital	Labor	Capital	Labor	Capital	Labor
2011	Meatpacking plants	$9.7	0.318	$8.3	0.326	$7.0	0.322	$6.5	0.371
2042	Prepared feeds	11.4	.313	9.9	.364	11.1	.528	12.4	.793
2812	Alkalies and chlorine	422.0	5.37	415.4	6.67	388.6	8.64	371.6	10.49
2818	Industrial organic chemicals n.e.c.	163.8	3.27	157.8	3.91	152.4	5.50	149.3	7.54
2911	Petroleum refining	147.5	7.96	146.4	9.90	142.5	13.62	128.3	17.17
3221	Glass containers	118.1	1.02	114.5	1.01	108.7	1.05	100.2	1.14
3241	Hydraulic cement	438.0	5.74	426.0	6.46	431.0	7.97	413.0	9.81
3312	Blast furnaces and steel mills	179.9	2.96	187.6	3.31	171.1	3.52	164.4	3.81
3313	Electrometallurgical products	214.2	4.08	300.0	4.66	269.6	7.00	280.0	7.61

[1] From this study.
*From the conference board, "Energy Consumption in Manufacturing," Ballinger, Cambridge, Mass. (1974).

Economic evidence regarding the substitutabilities or complementarities of labor, capital and energy is sparse and somewhat conflicting. The econometric study by Berndt and Wood [11] concludes that the capital and labor are quite substitutable, energy and capital are complementary, as noted above, and there is only a slight substitutability between labor and energy. In a similar investigation, Humphrey and Moroney [12] assert that for most of the resource-intensive sectors, the substitutabilities between capital and resource products, between labor and resource products, and between capital and labor are all of approximately the same magnitudes. This latter study tends to support the earlier, more aggregated results of Barnett and Morse. [1]

On the basis of present evidence, one must conclude that the substitutability of energy and labor is slight in our productive structure. However, even this slight effect may reflect the non-separability of capital and energy factors, [11] and policies that are based on the possibility of energy-labor substitution isolated from other changes may be misguided. The subject of labor substitution for energy and materials should be accorded more attention. At the macroeconomic level, different forms for production and cost functions should be explored and new aggregation indices developed, and quantitative microeconomic evaluations of specific technologies are also needed.

D. Substitution or Complementarity of Capital and Natural Resources

As previously discussed, the two econometric evaluations of the relation between the productive flows of capital services and natural resources (materials and energy) are not completely compatible. Humphrey and Moroney [12] conclude that natural resource products are equally substitutable for both capital and labor in five of seven S.I.C. two-digit product groups, while Berndt and Wood [11] find capital and energy to be complementary.

We believe, however, that the issue of greater consequence is not the past relation between these two factors, but that which can be expected to evolve with the introduction of new capital facilities in the U.S. A laboratory for measuring the relation exists, the production facilities in Europe—particularly in the Federal Republic of Germany and in Holland—and in Japan, where industrial plants were constructed in the 1950's and 1960's that incorporated numerous technological advances over the older U.S. physical capital stock. Although slight variations in the inputs of material resources occur, they are important only in a few cases, such as polymer production using natural gas feedstocks in the U.S. (a rapidly changing situation) as opposed to complete reliance on naphtha cracking for feedstocks elsewhere. Therefore, we will concentrate our attention on possible substitution, through technological change, of capital for energy.

The motivation for making these international comparisons is twofold. First, as will be explored below, we have found the analyses to be sensitive quantitative indicators of differences in technologies, and process technologies exhibit marked variations internationally. Thus, the possibilities for energy husbandry through international and interindustry technology transfer can be explored. Second, they provide us with information about how elements in economic society can respond to higher prices for energy goods. It is generally agreed that price elasticities of demand for energy goods generated by regression analysis of time-series data for the pre-1973 period of relatively stable fuel prices may not be reliably applied to today's volatile energy market. To the extent that sectors in different countries have faced widely different prices for energy goods, cross-national comparisons may yield superior information regarding elasticity responses. Of course, these will correspond most closely to long run price elasticities of demand.

Our attention was drawn to international comparisons when we were examining data on aluminum production in the U.K., The Netherlands and the U.S. [15] In this industry, the technology for the energy-consuming electrolytic step is the well-known Hall-Héroult process in all three countries, and we anticipated that the total energy requirements would be similar. Our anticipations were borne out by the data for the totals in the three countries: 217 million Btu/ton, U.K.; 200 million Btu/ton, The Netherlands; and 222 million Btu/ton, U.S.A. However, a careful examination of the energy requirements for sub-processes alerted us to some of the pitfalls that one faces in making international comparisons. Referring to Table 3, we see that although the total requirements are approximately the same, the requirements for individual steps are substantially different. The variation in energy use in alumina production can be attributed to different technologies and ore grades. The figures for the smelting step were more surprising. Closer examination showed that the smelting number for the U.K. is for their most efficient cells, only, and that the average U.K. value is 194 million Btu/ton. Both the Dutch and U.S. figures are national averages, but the facilities in The Netherlands are of later vintage.

TABLE 3.—ENERGY REQUIREMENTS FOR PRIMARY ALUMINUM PRODUCTION (TRANSPORTATION ENERGY IS NEGLECTED)

[All units are million Btu per ton]

Process	United Kingdom	Netherlands	United States
Ore extraction	4	4	3
Alumina production from ore	48	27	11
Aluminum production from alumina	165	169	208
Total	217	200	222

Similarly, the energy required for steel production is apparently 50 percent greater in the U.S. and the U.K. than in the Netherlands. [15] This result has been confirmed by more recent research in international comparisons of industrial energy use carried out under the auspices of the NATO Committee on Challenges of a Modern Society (CCMS), Pilot Study on the Rational Use of Energy. [16] German and Italian steelmaking facilities also are energy-efficient when compared to the U.S. Both of these European countries possess more modern facilities that utilize basic oxygen and electric furnaces, respectively, while open hearth facilities produce a larger proportion of U.S. output. Because they utilize electric furnaces, the Italians are able to inject a larger scrap charge.

A comparison of energy requirements for cement production by process and national averages is given in Table 4. The most important observation from this data is that replacement of the old capital facilities in the U.S. by modern kilns and processes of the types now operating in West Germany and Japan will yield a large saving in the national energy budget. However, transportation costs of the finished product result in this being a geographically-segmented industry, with little possibility of market penetration outside of a 200 mile radius of a plant. Thus, the large scales of the energy-efficient plants operated in Japan may be inappropriate within U.S. market structure. Nevertheless, there is ample room for improvement in U.S. technology, but this will come slowly because of the substantial capital needs and difficulties in generating cash flow.

TABLE 4.—CEMENT KILN ENERGY REQUIREMENTS

[Million Btu per ton clinker]

	Germany, Federal Republic	Italy	Japan	Netherlands	United Kingdom	United States
Wet	5.43–6.14	6.40	4.93	5.34	6.35	7.03
Semidry	3.98–5.07	4.74	3.40		4.17	
Dry:						
Suspension preheater	3.77–4.34	4.76	3.16	3.23	4.22	6.17
Other	3.98–5.43					
Shaft kilns	3.81–4.70	5.22	3.59			
Average	4.62	4.77	3.89	4.64	5.99	6.68

Sources: CCMS, Portland Cement Association report to the Federal Energy Administration, and University of Chicago data.

The most recently initiated of the CCMS studies is that investigating the petrochemical industry. Data have been particularly difficult to obtain because of proprietary interests. Polyvinyl chloride (PVC) production was chosen for a pilot study because many basic processes are represented. A preliminary analysis of the data is given in Table 5. Data for The Netherlands have been made available for public release later this year. However, earlier analyses of U.S.A. and Dutch PVC production energy requirements (Berry, Long and Makino) [15] are in good agreement with CCMS figures, and data from that study are used for The Netherlands. The primary difference between technologies in Europe and the U.S. is the use of crude oil as a feedstock in Europe, while natural gas is used in this country. The latter is clearly a more energy-intensive process, and this fact, coupled with natural gas supply shortages, is stimulating a rapid conversion to the use of crude oil as a feedstock by the American chemical industry.

TABLE 5.—ENERGY REQUIREMENTS FOR PVC

[Millions Btu per ton PVC]

	Netherlands	Italy	US conventional	Transcat
Production of crude oil or natural gas	0.13	0.13	0.17	0.17
Crude→naphtha	.60	.70		
Naphtha→ethylene	11.10	4.11		
Natural gas→ethane			7.77	8.02
Ethane→ethylene			3.83	
NaCl mining	2.25	2.06	1.69	1.40
NaCl→Cl_2	13.70	11.68	13.72	11.87
Ethane+Cl_2→VCM				14.12
Ethylene+Cl_2→VCM	11.27	13.39	12.67	
VCM→PVC	7.83	6.77	12.08	12.08
Subtotal	46.84	38.85	51.94	47.67
Feedstock	24.75	26.20	31.67	30.76
Total	71.59	65.05	83.61	78.43

Note: Primary source: CCMS. CCMS data for the Netherlands have been withheld from publication until later in 1976 to abide by a proprietary request. Data reported are updated values from University of Chicago research. They differ significantly from Dutch CCMS data only for the naphtha cracking step, where our figure is 6 times larger—perhaps due to different joint product accounting procedures. If this is taken into account, the Dutch and Italian data are nearly identical.

Note that the synthesis step for vinyl chloride monomer (VCM) formation requires approximately the same energy in all three countries, and that the figures for electrolytic production of chlorine from sodium chloride are also similar. The Transcat process, developed by the Lummus Company (U.S.A.), directly chlorinates ethane using a circulating molten salt mixture, and this technology appears to offer a possible energy saving if natural gas is used as a feedstock. The smaller energy associated with chlorine production in the Transcat process arises purely because of a smaller chlorine mass input to the reactor per ton PVC output. No current production facility utilizes this process, and the data are engineering estimates. The data for The Netherlands and Italy do not include any credit for existing cogeneration of steam and electricity, which would make these countries appear even more energy efficient in PVC production.

Another excellent illustration of the reduction in per-unit-output energy requirements through the introduction of new technology is in the float glass process for making flat glass, an innovation that already dominates American production. In this method, liquid glass is floated on a surface of molten tin, and heat is applied from above to thermally finish the top surface of the glass. The bottom surface finish is that of the smooth molten tin support. [10] Energy requirements are somewhat reduced by eliminating a chain of grinding and polishing steps, but, more significantly, the breakage that attended these steps, which was on the order of 30 percent, [10] is avoided. Consequently, a saving of almost a third in energy use is achieved.

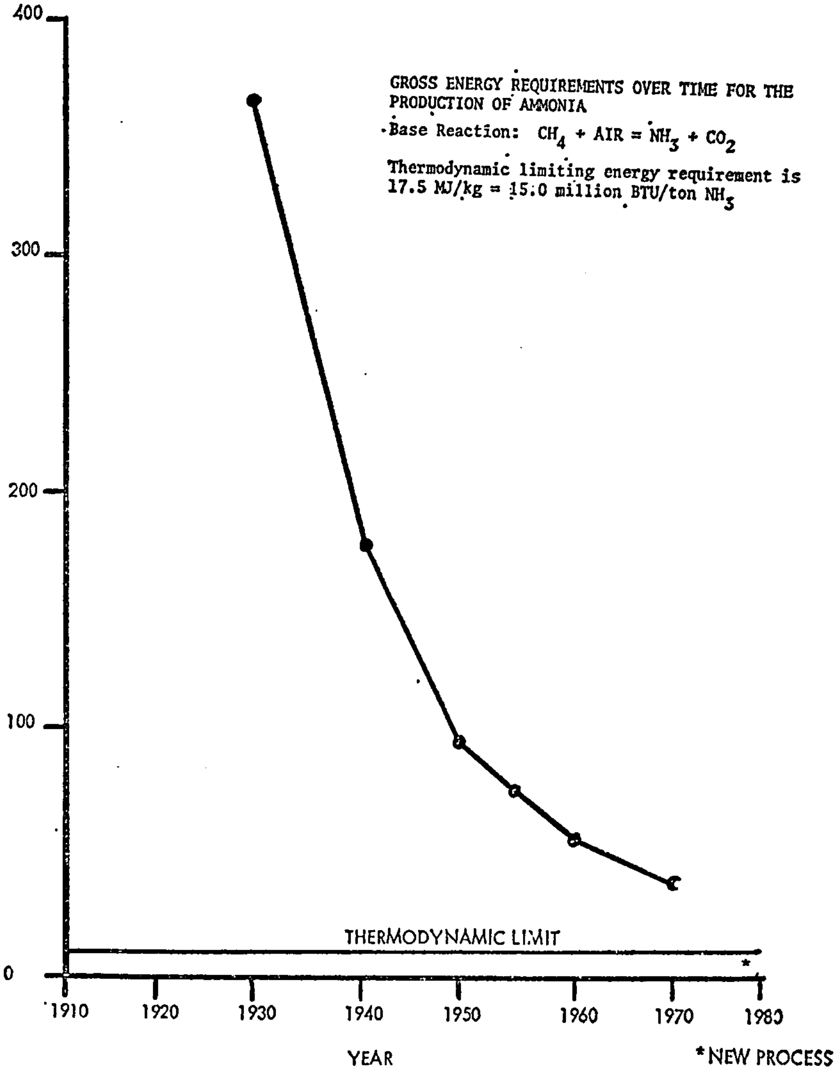
There is a clear lesson to be drawn from these observations: The introduction of new capital facilities can and will substitute for energy if it is scarce and this scarcity is reflected in its price. Industry in the European countries and Japan has evolved under higher relative energy prices than were faced when the older facilities in the U.S. were constructed. The American capital structure was not designed to optimize the use of input factors at the prices that exist today. While energy goods were priced so low in the U.S. that they previously did not enter sensitively into management decisions—they effectively had a zero price—they do so today. As a corollary, attempts to measure input price elasticities should consider the change from zero prices to present levels in setting a lower limit for the elasticity.

The U.S. could well be entering a new cycle of capital investment. A significant portion of our physical capital dates from approximately thirty years ago. The replacement of these facilities can have an energy- and resource-conserving effect. While some have commented that we should import the more efficient technologies intact, it would be to our long-term competitive advantage to leap-frog existing methods with increased attention to the construction of an economy that is prepared to meet increasing resource prices and constraints on supply flexibly.

E. The Tradeoff Between Energy and Time

Scientists and engineers are acutely aware of a substitution that is not usually considered by economists, the tradeoff between the rate at which production proceeds and the energy required. This is a particularly important phenomenon for processes involving chemical transformations. For such reactions, one can ascertain a theoretical minimum energy requirements, which corresponds to the energy needed if the transformation proceeds at an infinitely slow rate. In order to drive the processes at finite rates, commensurate with profitable operation, more energy must be expended. This is illustrated in Figure 1, which shows the decrease due to technique improvement in the actual energy required to produce ammonia toward the theoretical limit of 15.0 million Btu/ton of ammonia (based on a second-law-of-thermodynamics efficiency). It appears that an asymptote is being approached that is approximately double the ideal limit for the process. The asterisk indicates a hypothetical lower limit for an energy-conserving technological innovation.

FIGURE 1



Source: Reference 3, Workshop Report No. 9.

Thus, for real phenomena, the rate-determined practical limit to the minimum energy use in a process may be more useful in formulating energy efficiency assessment criteria than the ideal thermodynamic limit that is calculated for a hypothetical process that is thought of as occurring over periods that are infinitely long. Very little is known about the relation between the rates of finite-time processes and their corresponding minimum energy requirements, although this is a subject of active research by one group.[17] Some individuals with experience in process management have conjectured that the lower energy use limits for real industrial processes, driven at present rates, are 50 percent to 100 percent greater than the ideal limits for the hypothetical infinitely slow processes. Nevertheless, some potential for energy substitution may exist through driving processes at slower speeds.

F. Beyond Substitution in Production—The Consumer's Role

The consumer demands for energy and other natural resources are in the main derived demands, stemming from their incorporation in other goods and services. Only in the case of food items and in the use of fuel for heat and transport are resources directly consumed. In evaluating the opportunities for resource substitution at the consumer's level, it is helpful to recognize that a consumer's demands are not for specific items, but for *amenity* satisfaction.[18] For example, we heat our homes in order to be warm, and not for the pleasure of burning fuel—although roaring logs in a fireplace may be an exception. The warmth amenity may equally well be furnished by burning less fuel with greater insulation or by wearing an additional sweater or warmer fabrics. In this case, the level of amenity satisfaction remains the same, but the goods that furnish the amenity are different, and the proposed options could conceivably be available at equal cost to the consumer. At this technical level, the emphasis is on the relationship between the amenity—the bundle of desired characteristics—and the alternative bundles of goods and services that furnish that amenity. Thus, there is a consumption technology. An interesting application of this formulation was made by Quandt and Baumol in synthesizing the demand for hypothetical modes of transportation. [19]

In addition to the technical level, one must consider the personal, subjective level at which the relationship is between the individual and the chosen amenities. We will assume that this relationship is identical to that usually assumed between consumers and their preferences for goods, responding identically to market forces. As the cost of providing an amenity rises, consumers of that amenity will, in addition to seeking technical substitution possibilities that ameliorate all or most of the increased cost, seek to maximize their welfare by adjusting their preferences. If the price of a natural resource increases, consumers will forego some of the amenity for which the resource is used, expressing a marginal preference for other consumption, given the new menu of prices.

Changes in the relationship between the consumer and his preference set of amenities are lifestyle changes. Policies designed to stimulate such changes must be advanced only with a maximum of caution. The tendency to champion ill-informed technocratic manipulation of society is all too prevalent. For example, one issue that surfaces when "lifestyle" is discussed is that of "waste." Take, for instance, the household that considers switching from conventional refrigeration to a frost-free unit. In return for an unchanged level of cooling and a reduced level of effort required to maintain the refrigerator, the household uses more electricity, with subsequent higher electricity bills. What we witness is not an irrational and costly temptation to gadgetry, but a measurable tradeoff of energy and greater cost for valuable time and escape from drudgery. Similarly, substitution of automatic transmissions for manual ones increases driving energy requirements, but saves effort. Yet many drivers preferred automatic transmissions, particularly during the decades when gasoline prices fell and autos got larger.

But it is unfair to label these more energy-intensive choices as "wasteful." This is because energy use alone is not a sufficient yardstick with which to measure optimality. One person's frivolity may be another's necessity and last year's indulgence this year's need. Some forms of resource use may rightly by deemed wasteful, if, when the users are informed of the full social costs, they do not act to optimize that use.

It is clear that care must be exercised in discussing conservation via substitution of resources along with conservation via taste changes. How the resource use responds to the changes in the vector of resource prices depends on both the possibilities for factor substitution and the consumer's own long run marginal preference for the amenity that the resources make available. Whether the consumer insulates her house depends both on whether she has access to capital and information *and* whether in the long run she might come to prefer different indoor climates. These two conservation options may have different elasticities with respect to resource prices.

When projecting resource needs on the basis of highly aggregated statistics, we must recognize that some goods and services may be demanded in lower quantities than expected if increases in resource cost, though mitigated by substitutions in production processes, are nevertheless felt in those goods and services. Lifestyle changes might, for example, be expressed as preferences to live closer to work and to be able to walk to services, recreation, and entertainment. Since the demand for much of personal auto use (75 percent of vehicle miles traveled) is derived from the demand for these services, we might mistake the inelasticity in the short run of vehicle miles traveled for a long run preference to travel, when in fact consumers express their preferences by moving towards more clustered settlements that enable a high level of services and contact with others with fewer miles driven. Technical price-stimulated changes in the goods that furnish the desired bundle of characteristics will likewise modify demand.

Of course many of the changed resource use patterns can evolve from the dissemination of information about simple resource-conserving practices. People may well come to prefer lower indoor thermostats in winter, shifting their demand curves for heat towards lower quantity at a given price. More importantly, they may learn to perform certain tasks that allow for resource savings at little or no cost except for the time involved in carrying out the task. In this case, we are referring to practices such as shutting off unused lights, lowering hot water consumption where possible, putting up or removing storm windows, or combining short automobile trips so as to lower distance traveled.

However, there are also more sophisticated preference changes that can have significant impacts, for example, on energy needs for transportation and space conditioning. These include opening the shades in south- and east-facing windows in the morning and closing them as soon as the sun disappears at night; using movable shades in the summer to cut indoor temperatures; recycling materials; eliminating most auto trips under 1 mile, for which fuel intensity is 4 to 10 times the average for a given car because the engine is not warm. These changes in the way people use energy and materials may be price motivated but require education for successful implementation. Particularly necessary is the knowledge of how much energy and money can actually be saved by modified practices.

G. Energy and Gross National Product

There are few firm rules that apply to understanding the relationship between energy and gross national product. The proposition that economic growth, as reflected in an increase in GNP, requires increased use of energy is a familiar one. This assertion is based on historical data that shows a direct proportionality between these two quantities, coupled with the knowledge that energy is a necessary (but not sufficient) productive factor. However, the cost share of energy has been small but constant at approximately 5 percent of total costs [11] and did not enter into decisions. It seems likely that the observed linear relationship is more likely attributable to the complementarity of energy and capital than to a sensitive functional dependence of GNP on energy use. In any case, the relationship can be modified, through the substitution discussed above, and this is best illustrated by international comparisons of energy consumption in countries having equivalent standards of living. The first thorough study of this kind considered the U.S. and Swedish economies. [20]

This investigation revealed many small effects that have to be accounted for before energy use could be directly compared. Greater natural distances in the U.S. is one factor affecting transportation energy requirements. Fuel extraction, almost non-existent in Sweden, is important in the U.S., and a larger fraction of oil used in the U.S. is internally refined than is the case for Sweden. Air conditioning is nonexistent in Sweden, but there is little need to heat factories in the U.S., and these two uses, by coincidence, nearly compensate.

An additional consideration turns out to be important. If one counts the energy embodied in the goods and services making up foreign trade, it is found that the U.S. is a slight importer of energy, in an amount equivalent to 1 percent of the total energy use in 1973. This includes the energy used to refine fuels that are imported and exported, but not the thermal energy of combustion contained in those fuels. Sweden, in contrast, is clearly a net exporter of embodied energy, with the net embodied energy amounting to 8–9 percent of total internal consumption. On the fuel side, Sweden imports a larger share of her energy, both crude and refined, while the U.S. imports considerably less in relative and absolute terms per capita. The U.S. exports coal, and Sweden exports refined oil, because of excess refining capacity.

Moreover, geography and trade puts certain uses of energy out of reach of the normal accounting practices, since a much larger share of Swedish production and consumption passes through foreign countries than is the case for the U.S. Similarly, passenger travel by auto abroad is more important in Sweden than in the U.S., although this is partially compensated by visits of foreigners to Sweden. Over half of all airline passenger miles flown by Swedes involve foreign travel, compared with a much smaller amount for Americans. The total level of air travel in the U.S. is much larger due to greater distances and lower relative prices. What confuses the accounting is that virtually every passenger flight to and from Sweden stops in Copenhagen, where most of the outgoing fuel is debited and put aboard. Thus accounting for foreign travel, significant in comparing energy use of air travel, is difficult. Yet, in comparing the levels of "affluence" in these countries many would ask about airline travel. Clearly comparisons must be carried out with extreme caution.

Fortunately the most troublesome discrepancies or difficulties turn out to be relatively small. The greatest differences in energy use patterns emerge when one considers industrial process heat and electricity use, residential and commercial space heating, and land passenger transportation. The most important uses of energy in Sweden and the U.S. are contrasted in Table 6. As can be seen, space heating in Sweden is remarkably less intensive than in the U.S., when measured in BTU/square meter/degree day. The living space per capita is nearly as large in Sweden as in the U.S., a fact often overlooked in gross international comparisons. The energy intensity of apartment heating in Sweden is nearly as great as that in single family dwellings because apartment heating is included in rental prices. This means that the relative efficiency of space heating in Sweden vis-a-vis the U.S. *cannot* be ascribed to the greater proportion of apartments there compared with the U.S.

TABLE 6.—SWEDEN/UNITED STATES: CONTRASTS IN ENERGY USE (RATIOS)

	Per capita demand	Intensity	Total energy use	Comments
Autos	0.6	0.6	0.36	Swedish 24 mi/gal driving cycle uses less energy.
Mass transit: Trains, bus	2.9	.80	2.35	Mass transit takes 40 percent of passenger miles in trips under 20 km in Sweden.
Urban truck	.95	.3	.28	Swedish trucks smaller, more diesels.
Residential space heat (energy/degree day×area).	(1.7×.95)	.5	.81	Sweden 9,200 degree days versus 5,500 United States degree days.
Appliances	(?)	(?)	.55	United States more, larger appliances.
Commercial, total per square foot	1.3	.6	.78	Air-conditioning important in United States only.
Heavy industry (physical basis):				
Paper	4.2	.6–.9	.92	Sweden more electric intensive due to cheap hydroelectric power. Also Swedish congeneration.
Steel	1.1			
Oil	.5			
Cement	1.35			
Aluminum	.5			
Chemicals	.6			
Light industry (dollars V.A.)	.67	.6	.4	Space heating significant in Sweden.
Thermal generation of electricity	.3	.75	.23	Swedish large hydroelectric, congeneration.

On the other hand, households in Sweden generally have fewer appliances than in the U.S., reflecting a different lifestyle and lower after-tax incomes, and this results in a lower household use of electricity. In the commercial sector, the same efficiencies in thermal integrity appear in Sweden. The indoor temperatures in Sweden are higher than in the U.S. One relative inefficiency in the use of heating and hot water occurs in Sweden because of common metering and unregulated hot water and heating systems. This leads to a surprisingly large consumption of fuels for heating in Sweden, although the overall use of heating is more efficient in Sweden than in the U.S.

The greatest contrast is found in transportation. Swedes travel 60 percent as much as Americans and use but 60 percent as much fuel per passenger mile. Mass transit and intercity rail are more efficient and more widely used in Sweden, while air travel is overwhelmingly larger in the U.S. Intra-city trucking in Sweden is considerably less energy intensive than in the U.S., but long haul trucks in Sweden use slightly *more* energy/ton mile than in the U.S. The greater distances in the U.S. mean that ton-mileages (greater than 30 miles) are far greater there.

Historically higher energy prices in Sweden than in the U.S. are an important factor that has led to the more efficient energy use in that country. While pre-embargo oil prices in both the U.S. and Sweden were roughly equal, Americans enjoyed natural gas and coal resources that provide heat at a 20–50 percent lower cost compared to oil. In the case of electricity, the two countries are radically different (up to 1972). Since 75 percent of all electricity generated in Sweden was produced by hydropower, the ratio of the cost of electricity to the cost of heat from fuel was only *half* as great in Sweden as in the U.S. Industry in Sweden naturally developed a more electric-intensive technology base. Thermal generation, from oil, in Sweden, when necessary, was often (30 percent) provided by back-pressure combined heat-and-electric generation in industries or in communities, with the latter systems providing district heat. Consequently, in Sweden only about 7,000 Btu of fuel are required (in 1971–1972) for the thermal generation of a kilowatt hour of electricity. Increases in the cost of nuclear electricity and oil make the continued expansion of combined generation a certainty. The usual procedure of debiting 10,300 Btu fuel consumed per electric kilowatt-hour generated should not be applied to Sweden or other hydro-(or back-pressure-)intensive countries. This is because the actual hydro-oriented production mix lowers primary fuel requirements relative to the case for thermal generation, predominant in the U.S. Since the heat-rate is much lower, electricity is also cheaper in Sweden than in the U.S., stimulating use considerably.

A final example of the effect of different resource prices helps explain the relative efficiency of Swedish energy use. In Sweden, autos are taxed in proportion to weight both as new cars and through yearly registration. Furthermore, gasoline is taxed heavily, by as much as 70 cents/gallon in Sweden versus 12.5 cents/gallon in the U.S. Not surprisingly, the average weight of a car in Sweden is 1100 kg. (versus 1700 kg. in the U.S.). The horsepower/weight ratio is lower in Sweden, and the total miles driven at distances less than 50 km. (the most energy intensive ones) are less than half of the U.S. figure. Clearly, the higher cost of a vehicle mile in Sweden influences the energy expended.

While the greatest "savings" in energy consumption in Sweden come from price-related conservation, the structure of final demand, which is related to lifestyle, also influences energy use. Institutional factors, such as building codes and bank lending practices, encourage efficient structures. And the "Swedish Example" has by no means achieved all the "conservation" possible in that country. Present policies will allow a 50 percent reduction in heat per square meter in structures, more efficient industrial practices, wider use of industrial process-heat, and a stabilization of automobile passenger miles at 80 percent of all passenger miles (versus 90 percent in the U.S.). These future savings are being aided by an implementation program providing loans for the installation of energy-conserving technology and roughly a third of the borrowed funds is available as a grant. These funds are available to assist in cost-effective conservation measures. This suggests that there is no "absolute" potential for conservation, only a level of savings to be captured that depends on prices, preferences, and institutional practices.

Indeed, the real lesson from the two-country comparison seems not to be related to the microeconomics or technical details of any particular example of energy use or conservation. The impression that Sweden is "energy wise" and that the U.S. has been less so is unavoidable. However, the real message from this detailed study is that energy "needs" in the long run may be far more flexible than usually thought, given differences in the factors outlined here.

H. Consumer Choice and Market Penetration

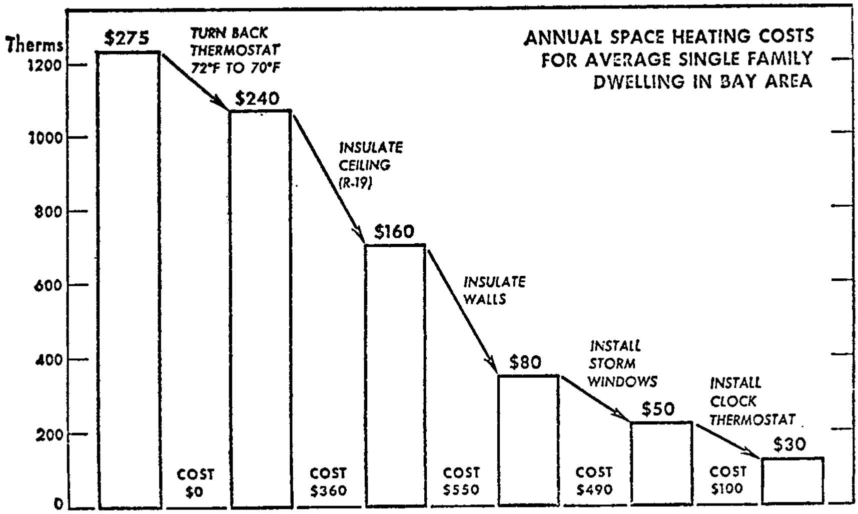
To answer the question of the desirability of natural resource substitution measures we must recall that these are but one class of the economically-valued resources used by society. While there are resource-conserving practices that are essentially costless—unaccompanied by increased outlays for other factors and involving no significant intrusion into living standards or behavior—the majority of our options do involve some modification in costs and benefits. It is necessary to consider the total dollar cost implications and not merely the natural resource consequences of changed use practices. It is insufficient, for example, to argue that the second blast furnace described initially is "better" simply because less energy is required. To the extent that the extra labor required for maintenance costs more than the energy saved, or could have been more productively employed elsewhere in the plant (or elsewhere in the economy), there is a diminution of total production due to economically inefficient practices. Similarly, an energy-based preference for cotton (natural) materials rather than petroleum-based synthetics ignores the "scarcities" of land, labor and water needed to produce cotton that are reflected in greater costs. Also, many such preferences are formed without knowledge of the energy required to furnish the irrigation water and the fertilizers employed to increase the productivity of an acre of cotton. How are we to decide which product or process is preferable?

The answer, again, is to start by considering the total cost implications of the alternatives, using the prices of inputs as guides to efficient resource use. We readily acknowledge that prices may be distorted for a variety of reasons: monopolies, subsidies, price controls or the failure to include environmental costs. Nevertheless this cost framework is a useful starting point, provided that we indicate where and when we might depart from decision making based only on the direct costs communicated by the real-world market place, with its imperfections. The private costs are useful both for evaluating what substitutions in production are possible that lower or at least maintain cost levels, as well as what changes in final consumption choices might come about as the result of changes in relative prices of different goods. We also acknowledge that in a society the tastes of individuals varies widely at a given time, and that individual tastes may change over time. These taste changes, as reflected in patterns of settlement, occupation and personal consumption can have significant energy use implications beyond those predicted by the economics of substitution in a static framework, particularly in transportation and home energy use. Therefore they are important considerations in our discussion even if they are difficult to predict.

Where substitutions are concerned, of course, the economic procedures for evaluating "desirability" are well known. One evaluates the investment and operating costs of alternatives, discounts all future costs and benefits into the present, and chooses the alternative of minimum cost. Necessary in this evaluation are both the assumed price of natural resources and the assumed trend in the price. If marginal costs are significantly higher than average costs, this is particularly important.

Given a price for a natural resource, a useful method for evaluating the "desirability" of a conservation strategy is to compare the cost of saving a (marginal) unit of the resource with the cost of producing one. A helpful example is given in Figure 2, taken from the 2-Zone Program for Retrofit of Single Family Houses, developed at the Lawrence Berkeley Laboratory.

FIGURE 2



From 2-Zone program for Retrofit of single family houses, developed at the Lawrence Berkeley Laboratory

The results of this model show how substitution of key thermal insulation features, each with a certain initial cost, results in successive lowering of the yearly fuel consumption, and more important, the fuel bill, by the calculated amounts. As Table 7 shows, each option pays for itself in a number of years, that number depending on the discount rate, the value of the energy saved, and the initial capital cost. For simplicity, the study escalates fuel prices at the discount rate. For the natural gas price assumed (about $2.30/mm Btu) options I and II pay back relatively quickly, while option III takes more than ten years. If the homeowner were forced to purchase electric heat (assuming a forced air system) or synthetic gas (at $4.00/mm Btu), then the payback time on the storm windows would be considerably shorter. The option would look more attractive. Thus we see that the microeconomics of energy supply and the substitutes for energy play a decisive role in determining which energy conservation strategies are desirable.

TABLE 7.—ESTIMATED COSTS, BENEFITS, AND PAYBACK TIMES FOR ENERGY-CONSERVING HOME HEATING OPTIONS

[Base case: Uninsulated, single-level 1,450 ft² house in Bay area]

Retrofit measure	Initial capital cost	Yearly savings on fuel bill* (natural gas)	Payback time on investment**
I. Insulate ceiling	$360	$80	4.5 yr.
II. Insulate ceiling and walls	910	160	5.7 yr.
III. Install storm windows	490	40	12.2 yr.
IV. Lower thermostat setting 70° F–68° F	No cost	35	Immediate.
V. Nightly temperature set back 70° F day; 60° F from 11 p.m. to 7 a.m. (clock thermostat).	100	70	1.4 yr.
VI. Measures II, III, IV, and V above	1,500	210	7.1 yr.

*Calculated for the effect of an individual measure on the base case.
**Interest on capital investment canceled by fuel inflation costs.

Source: 2-zone program for retrofit of single family houses, developed at the Lawrence Berkeley Laboratory.

For policy purposes we can calculate the "cost" of saving natural gas via these procedures, and compare that cost with the cost of producing new natural gas or a substitute. In nearly every case, it is considerably cheaper to make a given energy form available via substitution than it is to "produce" that form from a new source or power plant. There is, of course, much variation in the amount of energy "capturable" by conservation from use to use, region to region, and among different classes of consumers, with different discount/interest rates and acceptable payoff times. There is no a priori limit to "conservation," at least not until we approach both thermodynamic limits and the exhaustion of our ingenuity to modify ways of amenity satisfaction. Thus, conservation is not a "one-time" option, but rather a continual reevaluation of the mix of resource use that allows us to minimize total social costs for given benefit levels. For this reason planners should look to the future and attempt to avoid measures today that will foreclose even more beneficial practices in the future as energy prices and other resource costs change. If to save heat losses we restrict the amount of wall area that could be used for windows, we might deprive resourceful home builders or architects of a significant energy source—the incoming rays of sunlight streaming in through large south-facing windows, which, with proper house shading, landscaping, and use of thermal mass in the house, can provide a large percentage of the seasonal heating needs of the house even before active solar collector systems are considered.

The factors that influence resource-conserving consumer choice are identically important in determining the market penetration of resource-substituting technologies. The decisive elements in determining the rate and extent of the introduction of new methods of production or of the organization of productive structures are: The rate of diffusion of information about processes, their profitability, and institutional restrictions, regulatory policies and practices. The ambitious project by six major economic research organizations [21] on the diffusion of new industrial processes did not purposefully select natural-resource-conserving technologies for study, but most are so, as well as more productive (see above, section A, for a list of these processes). Consequently, we may draw on their results in examining penetration of technologically-based resource substitution.

There are two major conclusions with respect to the rate of diffusion of information about new technologies in an international sphere. [10] First, this is a slow process that requires up to ten years before first information has been received by the last firm, although the knowledge of the technology has spread to most firms in half that time. Thus, adoption is not a more rapid phenomenon than information dissemination. Second, there is some evidence that diffusion is faster among large firms than among small. This data, covering Sweden, the U.S. and the Federal Republic of Germany, is presented in Table 8, which is taken from Ref. 10. First information about numerical control machine tools appears to have been obtained earlier by a larger proportion of firms having more than 1000 employees than by those having less than 1000. The same holds true for special paper presses in Sweden and the Federal Republic of Germany, but diffusion of this information to large firms in the U.S. took a longer time The latter observation can perhaps be attributed to the invention of this technology in Sweden or to the possibility that information travels faster in geographically small countries than in larger ones. [10]

TABLE 8.—SIZE OF FIRM AND DATE OF FIRST INFORMATION

[Swedish, Federal Republic of Germany and United States firms]

	First information obtained		
	Before 1960	1960 or later	Total
Numerical control machine tools:			
Employing less than 1,000	22	21	43
Employing 1,000 or more	30	8	38
Total	52	29	81
Special paper presses:			
Employing less than 1,000	10	69	79
Employing 1,000 or more	7	28	35
Total	17	97	114
Special paper presses excluding U.S. firms:			
Employing less than 1,000	10	69	79
Employing 1,000 or more	7	11	18
Total	17	80	97

A firm incurs real costs in obtaining information and assessing its value in light of the firm's market position and financial status. Consequently, government can have a positive role in stimulating efficient diffusion of new knowledge by funding studies that corral information about important industrial inventions and analyze their technical features. Such studies will be particularly valuable to the small market participant and, also, to the firm engaged in another industry that would possibly enter a market if it had knowledge of the state-of-the-art technology that is available.

The subjective view of industrial managers is that profitability is the key element in the decision to adopt a new technology, assuming capital availability. However, quantitative confirmation of this relationship is difficult to obtain [8,10]. The explanation for this difficulty lies in the different financial conditions confronting a variety of firms, such as varying costs of capital, and to different perceptions of the uncertainties involved in making investment decisions. The costs of reducing these uncertainties may not be uniform. For example, the information costs discussed above may be much less for a transnational enterprise than for a smaller national concern—or at least of a different character. Also, given identical access to a technology and identical information, market participants in different countries, and even within countries and within industrial sectors, may confront different sets of factor prices, which will modify the profitability calculation. Nevertheless, there is good qualitative evidence that profitability will be a principal determinant of market penetration by resource-substituting technologies. The swift adoption of the float glass process can undoubtedly be attributed to its obvious potential for a healthy rate of return on invested capital. The reduction in the length of the production line from 1400 feet, in the older Pittsburgh process, to 640 feet carries with it a substantial decrease in investment, and variable costs are also diminished.

How large does the rate of return have to be to achieve penetration by a resource-conserving innovation? This is determined by the opportunity cost of the scarce capital—the return that would accrue if it were devoted to an alternate productive use. Conversations with executives of major U.S. firms indicate that the required rate of return may be as great as 30–35 percent, with payback times not longer than three to four years. Given energy's low cost share, even with the higher prices that now obtain, one must be pessimistic about the ability of innovations that are purely energy-saving to achieve market penetration in the absence of coupling to enhanced capital and labor productivity.

Finally, the influence of institutional factors and regulatory policies and practices is substantial and should be meticulously evaluated. Many laws and practices were framed for a world in which relative factor prices were quite different and resource security was not a consideration. We have seen an example of such an adjustment in the legislative actions that resulted in a 55-mile-per-hour speed limit on highways in order to save gasoline. Examples of anachronistic constraints on the introduction of resource-substituting technologies abound; for example, interpretations of antitrust regulations that prevent interindustry cooperation in joint projects. New regulatory procedures could equally well perform positively in this regard, and the area recommends itself for careful Congressional scrutiny.

Conclusion

To shift to the prospective real world, if economic considerations are deemed to be a key element in what happens with respect to conservation, the response of users to higher resource prices will be a combination of substitution of other resources for those now consumed, as well as an adjustment of preferences within the consumption mix—actions both legitimately termed "energy conservation." In this meaning, conservation is a normal response to changes in the total social cost of an amenity or to better information about this cost. To hold that the resource intensity of a given activity or the current mix of activities can be maintained as relative resource prices rise sharply is to imply that either economic substitution possibilities do not exist or that consumers will willingly sacrifice a larger share of income towards resources than in the past. This does not mean that market imperfections, peculiarities of pricing practices, lack of capital or information, or other institutional barriers—some of which have been alluded to—will not inhibit changes of preference or substitutions towards greater economic efficiency. But in any discussion of resource needs and substitution, the attainable and economically efficient operating points might usefully be evaluated in order to predict the amounts of the resources that could be conserved relative to prevailing practices. For example, one explicit purpose of energy-use guidelines might be to push energy-using capital equipment towards the optimum, based on certain energy price and lifecycle-cost assumptions.

At the same time, we must emphasize the need for careful assessment of the income-distribution impacts of policies that affect resource allocation. Economic efficiency does not guarantee the fairness of the resulting distribution. Distributive aspects should be considered simultaneously with the evaluation of measures whose purpose is to increase economic efficiency. As noted above, a critical issue facing us is how to achieve better quality of life for many in our society under resource constraints that may impair continued economic growth.

Congressional and governmental action can stimulate enhanced resource substitution capability in our economy through four mechanisms: the collection and dissemination of comprehensive information on appropriate technologies, the funding of both fundamental and applied research directed toward resource-conserving technological change, the assurance of the existence of sufficient economic incentives for adoption, and through direct regulatory policy or practice. We must be fully cognizant that private- and socially-optimal decisions may diverge. Private returns from socially-desirable actions may be low or the risks unacceptable. Working through the modification of market incentives, government can make private and social goals commensurate while retaining disaggregated decision-making.

If our discussion appears to have imposed narrower bounds on the scope of resource conservation than some persons would prefer, these last policy-relevant considerations nonetheless point to meaningful payoffs to users and to society from soundly conceived conservation approaches. Perhaps the most pressing need for research today is to identify the payoffs, both in physical, economic and social terms, taking due note of the direct and indirect costs of different patterns of resource use. As we have defined it here, conservation offers something for everyone. *How much* can be offered, however, will play a great role in future demands for natural resources.

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16. See: T. V. Long, "International Comparisons of Industrial Energy Use," to be published in the Proceedings of the NSF-Mitre Workshop on Long-Run Energy Demand (1976).

17. Three preliminary manuscripts discussing the theoretical foundations of this relation are available from B. Andresen, P. Salamon and R. S. Berry, Department of Chemistry, University of Chicago, 5735 South Ellis, Chicago, Illinois 60637.

18. A thorough mathematical formulation of consumer demand from somewhat the perspective we are suggesting has been provided by Lancaster (see K. Lancaster, *Consumer Demand: A New Approach*, Columbia University Press, New York (1971)). In his terminology, we refer here to a market basket of product characteristics desired by the consumer, and the possible substitutions in the goods and services that furnish the identical set of characteristics.

19. R. E. Quandt and W. J. Baumol, *Journal of Regional Science, 6*, 13 (1966).

20. L. Schipper and A. Lichtenberg, Lawrence Berkeley Laboratory Report LBL–4430 (1976); accepted for publication in *Science*.

21. The organizations are: Bureau d'Information et de Prévisions Economiques (Paris), IFO-Institut für Wirtschaftsforschung (Munich), Instituto Nazionale per lo Studio della Congiuntura (Rome), Industriens Utredningsinstitut (Stockholm), National Bureau of Economic Research, Inc. (New York), National Institute of Economic and Social Research (London) and Österreichisches Institut für Wirtschaftsforschung (Vienna).

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NATURAL RESOURCES POLICY, 1976–86

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SUMMARY

Our natural resources policy is a matter for deep concern. It is inconsistent, often outdated, and grossly over-dependent on direct regulation vis-a-vis modifications in our defective system of economic incentives. In part this results from the transitional stress associated with evolving from a situation of resources abundance to one of scarcity. More basically it stems from failure of the national policy making process either to grasp, or to find it possible to implement, the insights which economic theory and economic analysis provides concerning the basic nature of our resources problems.

A suitable starting point for reconsidering our policies is the theory of competitive markets. Economic theorists have shown that in a situation where markets exist for all assets present and future, where those markets are competitive, and where all participants in the market are fully informed, market exchange will result in an economically optimum condition. This is a situation where no further gains from voluntary exchange are possible. But the actual market system differs markedly in several ways from this ideal concept and those differences are the source of many of our natural resources problems. There is a whole class of assets for which markets do not exist at all. These are the "common property" environmental media, the atmosphere, watercourses, landscapes, large ecological systems, and the audial and electromagnetic spectra. The lack of markets contributes to environmental deterioration and excessively rapid rates of resources exploitation. In addition futures markets are highly imperfect, and major parts of the natural resources industry are far from perfectly competitive. Furthermore the national security aspects of dependence on foreign sources of energy and raw materials are public goods and such goods, as economic theory shows, cannot be adequately supplied by the market. Finally public policies often contribute to the distortion of economic incentives rather than remedy it. Corporate income taxation means that the corporate sector must use a higher rate of time discount than the non-corporate sector in a situation where already too little provision for the future is made. Special

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The responsibility for the analysis and policy conclusions in this document is, however, solely that of the author.

tax treatment of extractive industries leads to excessive investment in these industries and artificially low prices.

The sum total result of market imperfections, and defective public policy, is an excessively rapid rate of resource extraction, too much discharge of residual materials to the environment (in terms of mass, residuals must be equal to the amount initially extracted from nature), and an over dependence on foreign sources of supply of some natural resources. Because environmental resources problems and commodity resources problems are highly interdependent it is imperative that we break out of the one policy, one resource at a time approach to policy making. A coherent policy *program* is needed, one which recognizes the interrelated nature of, the economic sources of, and the economic remedies for, our resources problems.

The present congressional and administrative structure of the federal government is inadequate to the generation and implementation of such a policy program in the natural resources area. It is time to create a Department of Natural Resources and a suitably modified committee structure in Congress. The Department of Natural Resources must have a strong analytical capability and must be oriented toward viewing resources policy problems as interdependent and requiring integrated governmental action.

This paper sets out a conceptual framework for seeing natural resources policy problems in a large but coherent perspective. It also identifies some of the elements of a policy program to deal with these problems. Taken as a whole, this program is found to be strongly supportive of the goals set forth in the Employment Act of 1946.

A few of the major components of the program, stated in general, summary, terms are as follows:

1. Monetary charges for the discharge of residual materials to environmental media should be levied instead of placing exclusive reliance upon effluent standards, and many environmental management responsibilities should be transferred to regional agencies.
2. All special tax treatment for extractive industries should be eliminated.
3. Severance taxation on extractive activities should be increased.
4. A heavy tax should be levied on automobiles which obtain low gasoline mileage and taxation of gasoline should be increased.
5. Discrimination against recycled materials resulting from labeling requirements and freight rate structures should be ended.

These policy changes will lead the nation in the direction of optimum resource use and conservation, including recycling. If they are instituted no additional stimulation to recycling will be appropriate. In addition policy changes are needed in the following areas:

6. As part of a policy program, and only as part of such a program, the corporation income tax should be repealed.
7. Measures should be taken to improve the competitiveness and performance of the natural resources industries.
8. Oil and gas prices should be entirely deregulated, but only as part of a program including windfall profits taxation and help to consumers.

9. The risks and benefits of nuclear energy should be the subject of hearings by the Joint Economic Committee and subsidies to this industry should be ended.

10. Measures should be taken to limit foreign dependency on energy sources and several non-fuel minerals, foremost by various policies to stimulate conservation and by systematic stockpiling. Research and development on new technologies and a degree of price protection for domestic producers should also be part of the program.

11. The minerals leasing and location systems should be changed in several ways to make them more efficient and to yield increased benefits to the public.

12. The federal government should assist in dealing with the severe social costs associated with the boomtown developments accompanying large natural resources projects in remote areas. But the cost of such assistance should finally devolve upon the industries, and their consumers, undertaking these projects.

13. Fiscal and monetary measures should be taken to generate the needed capital investment in natural resources activities over the next decade. The present situation in macro-economic policy is almost exactly the reverse of what is needed.

14. Actions should be taken to blunt the income redistributional effects which may accompany rationalization of the natural resources price structure and other measures that are intended to protect the environment and foster resources conservation. These measures should themselves be designed to foster conservation, e.g., grants to home owners to install insulation.

It will be very difficult, with our political and institutional structure, to implement a program with these features. But our present situation demands breaking out of traditional policy making patterns which can no longer meet our needs and which threaten to lead to most unfortunate consequences.

Introduction

In my view the present state of natural resources policy at the national level in the United States is a matter for deep concern. Our policies are fragmented, suffering from multiple schizophrenia, and grossly overdependent upon direct regulation vis-a-vis modification of the defective system of economic incentives which is a primary source of our resource problems in the first place. To begin to remedy the deficiencies of our resource policies it is necessary to understand that our resources problems, from the energy crunch to the state of our watercourses, from landscapes shattered by surface mining to the deplorable quality of our urban air, are interrelated issues. Coming to grips with this web of national problems needs a coherent program of resources policies rather than the scattershot, one resource at a time, approach to legislation which exists today. If this assessment of the situation is correct, and I am sure it is, implications for our political and administrative institutions are deep and far reaching.

But natural resources policy is an enormously large and complex subject which I cannot cover completely in this paper. I will limit my explicit discussion of issues to the closely linked subjects of environmental management and minerals, including energy, policy. I will leave aside discussion of what are usually called renewable, or flow, resources, other than certain aspects of water. Also, I will not treat land use issues. I regret these omissions because they are important ones. Land use planning will probably emerge as one of the central natural resource issues in the coming decade and economic analysis pertinent to it is in a primitive state. The world food situation is causing marginal soils to be brought into cultivation when, at the same time, we are overdue for a major drought. The soil conservation issues of the 1930's are very likely to visit us once again. Timber is a resource which has shown strong evidence of increasing scarcity and is an industry whose performance and structure are greatly influenced by the exigencies of macro-economic policy. But the issues pertaining to environment and non-renewable resources are high on the policy agenda at the present time and complex enough. I hope this paper will help to illuminate some of them.

The Market System and Its Limits: The Connection Between Resource Use and Environmental Problems

To a substantial extent the present sad state of natural resources policy results from the fact that our policy making processes are in a state of transitional stress. Policy artifacts, such as depletion allowances and many other favorable tax treatments of extractive industries, are remnants of a time when encouragement of rapid use of out natural resources was regarded as clearly desirable. We have federal oil and gas price regulations that reflect the abundance of another day. At the same time we ration the end uses of some of our fuels. We have in our legal and regulatory structure a number of biases against recycling while we have on the books laws, which if successfully implemented, would place strict controls on the use of environmental resources. Our policy making processes are in throes of trying to come to grips with an inherited policy structure which, while fragmented and often internally contradictory, was largely constructed in an era of resource abundance. It reflects that context but now contains bits and pieces which mirror more recent events. The problem we face is to rebuild the natural resources policy structure in light of the spectacular jolts of the late nineteen sixties and early seventies and the deeper trends of which they are symptomatic. Confusion and difficulties are entirely understandable in this context.

There is an aspect of the situation which is more distressing, however. It is that current policy efforts, especially at the congressional level, do not give any evidence of a clear understanding of the basic nature of our resources problems and the associated integration, redirection of policies, and modification of the policy making process itself that they demand. Nothing could illustrate this more clearly than the Congress' confused attempts to develop an energy policy over the past few years. At the most basic level many of our most severe problems stem from several kinds of failures in the set of incentives which our market system, as it presently functions, generates. In more than a few instances, these misdirected incentives are further aggravated by public policies. Rather than altering perverse incentives, the inclination of the Congress has been to move steadily in the direction of establishing more and more complex regulations. Many of these regulations are now coming to be widely recognized as arbitrary and capricious in application. Moreover they usually fail to achieve their objectives or if they do achieve them do so only at great, and often unnecessary, cost.

I will elaborate on this theme. But first it will be helpful background to take a look at how economic theory sees the operation of an ideal market and what the most salient departures of actual markets, especially with respect to resource issues, are from the functioning of this model. This brief digression will provide a somewhat abstract but reasonably coherent framework for the development of a broad perspective on our resource problems.

The Ideal Market

When economists speak of *the market*, they usually have in mind a particular type of intellectual construct. This conceptual model is the product of an evolutionary intellectual process going back at least as far as Adam Smith's well known late 18th century publication *The Wealth of Nations*. The model grew out of the observation of a very special phenomenon. Economic activities—farming, mining, industrial production, selling and finance activties—were unplanned and, on the surface at least, seemed entirely uncoordinated, and yet in the end order could be seen in the results. Smith saw with great clarity that the powerful signaling and incentive forces of prices determined by free exchange in markets were at the core of the process which, via many independent economic units, transformed resources into products and distributed them to consumers in accordance with their demands. Hence, his famous phrase, "the invisible hand of the market."

Markets do in usual circumstances produce an orderly and directed production process. But economic theorists have also been very interested in finding out whether this order was just orderly or if it might have other desirable or normative properties. Theorists found that the results of an ideal market process may be regarded as desirable or normative if a basic value judgment is accepted and if the market exchange economy displays certain structural characteristics.

The value judgment is that the personal wants and preferences of the individuals who constitute the present members of a society should guide the use of that society's resources. This is also the premise which is at the root of Anglo-American political theory.

The three structural characteristics are that:

One—all markets are *competitive;* this means that no specific firm or individual can influence any market price significantly by decreasing or increasing the supply of goods and services offered by that specific economic unit. A good example is an individual farmer. He can sell or hold his crop as he wishes and yet affect the market price for corn not at all. Competition must extend to all markets including those for money.

Two—all participants in the market are *fully informed* as to the quantitative and qualitative characteristics of goods and services and the terms of exchange among them.

Three—and this has usually been implicit, all valuable assets in the economic system can be *individually owned* and managed without violating the first assumption, i.e., that of perfect competition. Individual ownership of all assets plus competition imply that all costs of production and consumption are borne by the producers and consumers directly involved in economic exchanges. A closely related requirement is that there must be markets for all possible claims. This becomes particularly pertinent when one considers questions of conservation and the role of futures markets. I will discuss this matter in a little more detail later in connection with policies with respect to non-renewable natural resources.

If all these conditions hold, it can be concluded that the best social solution to the problem of allocating the society's scarce resources is to limit the role of government to deciding questions of equity in income distribution, providing rules of property and exchange, enforcing competition, and allowing the exchange of privately owned assets in markets to proceed freely.

Market exchange, with each participant pursuing his own private interest, will then lead to a "Pareto optimum."[1] The proof that ideal markets can achieve a Pareto optimum may be regarded as one of the basic theorems of modern theoretical economics. Perhaps the most straightforward way of intuitively grasping the meaning of a Pareto optimum is to regard it as a situation where all possible gains from voluntary exchange of goods and services have been exhausted and no participant is willing to make further exchanges at the terms of trade which have come to exist. Money is the medium of exchange and prices are the terms of exchange, but behind them lie exchanges of real goods and services of all kinds. Under the conditions postulated, an exchange takes place only when both parties feel they benefit by it. When no more beneficial exchanges can be made, the economy has reached a situation where each individual cannot improve his own economic welfare without damaging that of another; in other words, unless a redistribution of assets, favorable to him, occurs. When no one can be better off without someone else being worse off, Pareto optimality has been reached. In economic parlance, an *efficient* balance has been obtained.

The connection between this market exchange model and the real working economy has always been tenuous at best. But the idealized model has served as a standard against which an actual economy could be judged as a resources allocation mechanism for meeting consumer preferences. I shall use it in this way in considering the current state of our resource problems and policies, starting with environmental resources. But, as I hope this discussion will make clear, questions of resource supply are closely interlaced with environmental considerations. The connection is revealed by considering the consideration of mass.

The Nature of Pollution Problems in a Market System

With this background, it is easy to see the nature of the malfunction of real markets vis-a-vis the ideal market which is the fundamental cause of pollution problems in market systems. We start with a simple concept from physics.

When materials—minerals, fuels, gases, and organic materials—are obtained from nature and used by producers and consumers, their

[1] Named after Vilfredo Pareto (1848–1923), a prominent Italian economist and social theoretician.

mass is essentially unaltered. Material residuals generated in production and consumption activities must therefore be about equal in mass to that initially extracted from nature. Similarly, all energy converted in human activities is discharged to the atmosphere or watercourses.

Conservation of mass-energy, taken together with the peculiar characteristics of environmental resources, has important implications for the allocation of resources in a real market system as contrasted with the ideal. While most extractive, harvesting, processing, and distributional activities can be conducted relatively efficiently through the medium of exchange of private ownership rights as the idealized market model envisages, the process of returning the inevitable residuals generated by production and consumption activities makes heavy use of *common property resources.*

The term *common property resources* refers to those valuable natural assets which cannot, or can only imperfectly, be held in private ownership and which therefore cannot be exchanged in markets like ordinary commodities. Important examples are the air mantle, watercourses, large ecological systems, landscapes, and the audial and electromagnetic spectrums. When open and unpriced access to such resources is permitted, it is apparent what must happen. From careful study of particular common property or common pool problems like oil pools and ocean fisheries, it is well known that unhindered access to such resources leads to overuse, misuse, and quality degradation. With respect to environmental degradation, this takes the form of large masses of materials and energy discharged to watercourses and the atmosphere, degrading their quality. The less massive but highly destructive dispersal of litter and junk into urban and rural landscapes stems from the same roots. Furthermore, resource extraction processes themselves can cause visual and other forms of pollution—clearcut forests, mine tailings, unreclaimed strip mine land, and acid mine drainage are just a few examples.

Costs associated with the destructive effects of these situations are of no consequence to the enterprises involved inasmuch as they are imposed on or transmitted through common property resources. The impacts of these effects, referred to as *external* costs, are imposed on society as a whole. Pareto optimality is not gained through exchange because private ownership of natural assets must be incomplete. Without ownership, the market can generate no incentive to protect environmental resources.

Conservation of mass/energy tells us that as economic development proceeds and the mass of material and energy flow through the economy increases, and if environmental resources remain in their common property status, environmental conditions must display a tendency to get systematiclly worse as the economy grows.

Another result of looking at environmental pollution problems in their mass balance aspect is that it reveals the interdependencies which must exist among different residuals streams. For example, "treatment" of a residual does not reduce the residual mass, indeed mass is increased because the treatment process itself requires inputs whose mass is also conserved. The result is that pollution control programs aimed at reducing the pollution in one medium often aggravates the problem in another. The incineration of sludge from waste water treatment plants and the emission of additional gases to an already polluted urban atmosphere is a classic example. Wise environmental policy must provide means of dealing with quality problems in all the media simultaneously.

As indicated, the main source of our environmental problems is the inability of market exchange as presently structured to efficiently allocate environmental resources, i.e., to price their destructive use appropriately. But if we could stretch our minds and envisage a situation where these common property resources could be reduced to private ownership in pieces small enough to be exchanged in competitive markets, then, distributional issues aside, the market could function just as efficiently to allocate them as it can with respect to any other resource. Prices would be generated, for example, for the use of air and water for the usually destructive activity of waste disposal. These prices would be signals and incentives reflecting the opportunity cost of using these resources for the purpose of waste disposal and would affect the whole complex of decisions about their use—the design of industrial processes used, the kinds of raw materials used, the nature of the final products produced, and the modification (not elimination—conservation of mass and energy prevents this) of residuals streams before paying for the privilege of discharging what is left. Conservation would suddenly become good business.

Instead, as previously indicated, throughout history these resources have largely remained as *open access* common property. Moreover, the difficulties of defining rights to environmental resources are such that the desirable effects of market exchange with respect to them must remain merely theoretical. However, explicit pricing of these resources through the medium of government administration could go far toward improving the efficiency and effectiveness of environmental protection vis-a-vis the policies we now have. Before developing this theme let us look more explicitly at what the ideas developed so far suggest in terms of the interrelationships between environmental and other resources use problems.

Environmental Market Failure and Resource Commodities

The combination of two simple but revealing concepts introduced in the previous section—conservation of mass and common property resources—provides considerable insight as to the basic nature of pollution type environmental problems in a market system. But the implications are not limited to environmental matters. When the use of certain (environmental) resources is not priced, the entire price structure is then distorted. Thus the price of extractive resource commodities, which *are* exchanged in markets, will deviate substantially from the actual social costs of their use. This comes about in two main ways.

First, the extraction and processing of extractive resource commodities involves particularly heavy use of environmental resources. Strip mining, the processing of copper, the conversion of coal, the making of steel, the refining of oil, and many others, are obvious examples. In the ordinary course of market exchange the social costs associated with any damage to these environmental resources are not reflected in the private costs incurred by the producers of resource commodities and by the ultimate users of the products produced from them.

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Secondly, when such commodities are devoted to their end uses they further generate social costs which the market does not reflect. Junk yards, litter in the country side, the combustion of fuel in automobile engines, and the time bomb of polychlorinated biphenyls in the capacitors of flourescent lights are random but obvious examples.

Thus the market generates a *systematic bias*, the result of which is to essentially subsidize the production of extractive resource commodities. The larger the impact on environmental resources in the extraction, processing and use of resource commodities, the larger the subsidy. Furthermore, as environmental resources become increasingly scarce and valued, and as the production of environmentally destructive resource commodities increases, the societal subsidy to such production correspondingly increases. Perversity compounded!

The natural tendency of markets to work in this unfortunate manner is bad enough. But policies formed to stimulate the production of resource commodities during the euphoria of extreme abundance, and in the interest of rapid economic growth, aggrevate the situation. Special tax treatment of extractive industries vis-a-vis ordinary industries abounds. Depletion allowances, capital gains treatment and expensing of various kinds of capital investments and operating expenditures are obvious examples. Superimposed on all this are policies which discriminate in favor of production from virgin materials in contrast to the use of secondary materials. Railroad rate discrimination and discriminatory labeling requirements are often cited examples.

The ultimate result of market malfunctioning and the biases of policy is excessive use of materials and energy in general, excessive use of virgin material in particular, too little recovery and reuse of materials and energy, and excessive environmental deterioration. The miscarriages are not isolated and random events. They are a systematic result of the way our market and governmental institutions have operated.

Within the context of the conceptual framework just developed, I will now proceed to discuss a number of the next decade's natural resources policy problems. I will begin with those associated with the quality degradation of common property resources and then proceed to consider a number of related specific problems associated with resource commodities that are traded in markets. As the discussion proceeds it will be useful to point to additional ways in which the performance of resource industries diverges from the idealized market model outlined earlier.

Throughout, however, three main policy prescriptions will dominate—change the structure of economic incentives, improve competition, reduce direct regulation.

In the concluding sections I will assess how well the set of specific policy recommendations developed in the paper squares with the goals of the Employment Act and the resulting implications for institutional change.

Environmental Policy

Over the post World War II period, at all levels of government in the United States, numerous laws have been passed attempting to come to grips with environmental quality degradation. The rationale for such laws has been totally unrelated to the concepts developed in previous sections. Gradually in this process of policy formation, the role of the central government has become increasingly dominant. It is worth reviewing the history of federal legislation in this area in a little detail because it clearly highlights the pitfall of exclusive reliance on efforts to impose direct regulations and on subsidy approaches. Direct regulations and subsidies are elements which, as I have already indicated, are deeply embedded in most areas of our natural resources policy. Environmental pollution legislation is also worth reviewing because it is in this area of natural resources concerns where policy making has been the most active in recent years.

With respect to both air and water, the early federal legislation (in the 1950s) established enforcement action against individual sources of residuals discharge as the principle policy tool for controlling such discharges. These actions could be brought by the federal authorities against residuals dischargers if specific interstate damage could be demonstrated to have resulted directly from discharges at a particular source. Early on in the post-war legislation, modest federal subsidies for municipal wastewater treatment plant construction and for certain water quality planning activities were also introduced. It is now generally agreed that these first federal legislative enactments had little or no positive effect on the quality of the nation's environment.

Succeeding legislation was passed in an effort to strengthen enforcement provisions of earlier laws and, in a series of steps, the amount of federal subsidies authorized for municipal wastewater treatment plant construction was increased. Beginning in the mid-1960s, an effort was undertaken by the Congress to circumvent the necessity for showing actual interstate damage in federal enforcement actions in the water quality area. This was to be accomplished by requiring the states to set water quality standards for interstate and boundary waters and to develop plans for attaining these standards. With many delays, the states finally complied in the late sixties. Watercourse standards were set by the state agencies on the basis of more or less—usually less—informed consideration of potential water uses. The idea embodied by the law was that violations of water quality standards as a result of failure by a discharger to conform to the plan were to be regarded as prima facie evidence of interstate impact, without the necessity to show that direct damage had resulted in one state from a specific discharge in another.

A similar approach was legislated a few years later for air quality. But, in this case, nationally uniform ambient standards were set which were supposed to represent a threshold below which no health damage was deemed to occur—a politically convenient fiction. In addition, new sources of atmospheric emissions were supposed to be equipped with "best available control technology," and federal law, following the lead of California, began to specify stringent effluent limitations for automobile emissions.

The ambient standards implementation plan approach to the water quality problem worked little or no better than the previous law had done. By the end of the sixties, it became apparent that nearly all the implementation plans were so loosely related to the water quality standards that the law would be unenforceable. Furthermore, the subsidy programs for wastewater treatment plant construction had not only been relatively ineffective but induced serious inefficiencies of various sorts. I will return to this point a bit later. At about the same time, an ancient piece of water legislation, the 1899 Refuse Act, was rediscovered. This law required that all industrial waste dischargers have permits from the U.S. Army Corps of Engineers. The provision was clearly intended to protect navigation, but was now interpreted to extend to all forms of residuals discharged to watercourses. Enforcement of the law started, and the Corps of Engineers received a large number of applications and began to issue some permits. But shortly before the process of issuing permits began, the Congress passed another environmental law, the National Environmental Protection Act (NEPA). This law, among its various provisions, required that all federal, and federally supported, actions having a potentially significant impact on the environment must be preceded by an "environmental impact statement." The courts ruled that permit-issuing activities of the Corps fell under the provisions of the Act. Consequently, the Corps abandoned the hopeless task of issuing permits for which tens of thousands of environmental impact statements would be needed.

Following these events, the Congress (in 1972) passed a new water quality law. Among its provisions was the requirement of permits for all point source waste discharges to watercourses. This time the permit issuing was to be exempt from NEPA and was to be done by the Environmental Protection Agency and the states. Although the current law is notoriously ambiguous, the intent of its supporters seems to have been that of making uniform across the nation the permit requirements for particular industries and municipalities. These requirements are to be based primarily on consideration of technical feasibility rather than the uses to which receiving waters are to be put. However, stream standards established under the 1965 Act were still to be controlling if discharges under the permit system should result in a poorer water quality than they required (it appears that ¼ to ½ of the stream miles in the country may fall into this category). The permit stipulations are also intended to become stricter in a succession of steps until a national goal of "zero discharge" is achieved in 1985. Subsidies for municipal wastewater treatment plant construction were increased mightily and, under other laws, industries can benefit from rapid write-off of pollution control equipment against taxes and from low-interest municipal bond funding of facilities.

The pattern then, applying to both air and water, culminating in the most recent water quality legislation, has been toward increasingly heavy federal subsidization of certain kinds of pollution control facilities, greater and greater centralization of control efforts increasingly based on emission standards which are in turn based on some sort of concept of technical feasibility, and an effort to make emission standards as uniform nationally as possible.

There are several reasons for having deep reservations about the pollution control program which has evolved in the United States. The federal subsidies which have been provided bias the choice of control technologies toward end-of-the-pipe treatment rather than the use of processes which reduce the generation of waste in the first place. In practice, the municipal subsidies have tended to slow down construction as municipalities queued up to await federal funds whose availability was always less than authorized, or more recently as municipalities strove to meet the letter of the law in planning requirements.

Uniform standards, as among waste dischargers (the objective of the federal legislation), implies that sources where control costs are high have to control discharges as much as sources where control costs are low. Accordingly, any level of ambient environmental quality attained is accompanied by higher costs, research suggests higher by a multiple, than would be associated with a least-cost set of control efforts. Specifications of particular "best available" technologies to be used in pollution control may have a serious dampening effect on the development of new pollution control technology. It puts firms in the quandary that if they innovate, they hand the regulatory authorities the means of imposing on them new and more stringent standards of pollution control.

With respect to automobile emissions, present control efforts appear to have locked us into a technology (reliance on modification of the internal combustion engine) which many scientific reports conclude is a very poor long-run approach to the problem.

Finally, the history of efforts to enforce the Federal Government's pollution laws, together with the vast near term cost implications of recent legislation should it be successfully implemented, elicit deep doubts about whether the federal program can ever be effectively enforced—much less whether it can produce efficient results. Granted that an objective of recent legislation, especially the Water Quality Act, was to make enforcement easier and more effective, there is room in the actual statutes for staggering amounts of litigation and all the attendant delays. Large-scale litigation has already begun. Many informed students of the permit-issuing process believe that the result will be to force permit requirements, for those permits that are issued, down to the lowest level of minimally accepted practice and that substantial environmental improvement will not be the result. Legislation for stationary sources air pollution control is still largely untested, but there are some major cases in the courts, and what reductions in emissions have occurred by means of fuel substitution show signs of disappearing in the wake of the energy crisis as the nation shifts to greater emphasis on the utilization of coal.

A basic problem with the present program is that enforcement, especially since it involves criminal penalties, must leave ample room for due process, which means many possibilities for delays or variances while the free-of-charge use of common property resources continues. The economic incentive is to hire lawyers rather than to get on with discharge control. The recent report of the National Commission on Water Quality is implicitly a devastating indictment of the regulatory approach by a commission and commission staff basically sympathetic to that approach. Before the 1972 Water Quality Amendments some proponents of regulation claimed it had not been given a fair trial because of the weakness of previous laws. Now it has been tried.

A Positive Program

One may generalize by saying that national environmental policy in the United States has never recognized the economic sources of, and remedies for, the problem nor its relationship to the broader range of natural resources issues. Clearly, it has not recognized the problem for what it is—a massive failure of the economic incentive system resulting from the fact that the large natural systems—watercourses, the air mantle, large ecological systems—are by nature common property unpriced by the market and, as explained earlier, subject to systematic progressive degradation as economic development proceeds. The basic failure in the system of economic incentives requires rectification if common property resources are to be protected, allocated to their best uses, and used efficiently. Moreover, despite the nation's addition to direct controls experience shows that economic incentives like effluent charges work more effectively where they can be applied. Further evidence of the power of market price incentives is derived from the rapid response of industrial activities to the recent increases in energy prices.

There is then, despite more than twenty years of federal legislation, still a clear need to develop a positive program for turning the system of economic incentives around. It must be rearranged to make it work for the environment rather than against it while at the same time helping to curb the excessive flow of materials and energy through the economy and thereby reducing the rate of depletion of our basic resources. I think the following are some of the main elements of an effective strategy for doing this. Other elements of a policy program will be developed when the matter of resource commodities is considered more explicitly.

(*a*) *Inventory of Discharges.*—As complete an inventory as practical of possibly deleterious substances in effluents going to all of the environmental media should be assembled. All dischargers of substantial size should be required to sample their effluents and report them. This step is in theory substantially underway under present legislation. How adequate the sampling and coverage will be is not known and there is no central repository with an efficient retrieval system.

(*b*) *Highly Toxic Substances.*—A list of substances should be developed, for which the presumption is that discharge to the environment will be substantially forbidden on the grounds that the overall deleterious effects clearly outweigh any benefits (cost saving) associated with the discharge. Numerous toxic persistent organics (like PCBs) would be candidates, as would all of the heavy metals. In these cases the burden of proof should be entirely on the discharger to show that there is no feasible alternative and that external costs are absent or reasonable. Again there has been some progress on developing such lists of hazardous substances but the burden of proof issue has not been definitively settled.

(*c*) *Effluent Charges.*—For those substances, the discharge of which is not entirely forbidden, national effluent or emission charges should be levied at such a level as to provide a substantial incentive for control. The national effluent charges would be a first move in the direction of reversing the economic incentives adverse to the environment. They would not be as efficient as charges tailored specifically to environmental and specific source situations, but they would have several desirable properties. First, they could be set at a level that would stimulate rapid progress on environmental pollution problems. Second, they would establish the principle of payment for the use of common property resources everywhere. Third, they would be much more efficient than uniform standards, because the economic incentive would be to exercise most control of discharges at these sources where costs per unit of control are lowest. Finally, and perhaps most important, they would avoid most of the enforcement problems associated with the permit approach since their collection would be legally and administratively similar to the ordinary collection of taxes. They would permit the needed flexibility of response while continuously exerting pressure to act—energy crisis or no.

(*d*) *Burden of Proof.*—The burden of proof should be put on producers of *new* products or processes to identify and report any substances associated with them that might have adverse ecological or health effects, and such producers should be required to bear any environmental costs which might in due course result. The Price-Anderson Act which provides publicly subsidized insurance for nuclear powerplants in the United States, and other "bail out" types of legislation, should be phased out and avoided in the future. These policy changes could have important effects on the nature and direction of technological change.

(*e*) *Regional Environmental Management Agencies.*—The proceeds of the effluent charges and, if needed, other appropriated government funds should be used to encourage the establishment of regional environmental quality management agencies. Requirements should be laid down to assure that interdependencies among airborne, waterborne, and solid wastes are appropriately recognized and that efficient regional programs of control can be pursued. As earlier discussion has implied, both policymaking and administrative practice in the U.S. have completely neglected these interdependencies. In heavily developed areas, integrated environmental pollution management agencies should be strongly encouraged. Research has conclusively shown that such regional management agencies can implement technologies and influence the location of activities such that environmental management costs can be reduced greatly from what is possible if control efforts are limited to the traditional approach of implementing controls at existing point sources. Once regional agencies are duly established, the task of collecting effluent charges would be turned over to them, and the proceeds would be available to them for their use. They would be permitted to raise some or all of the effluent charges, to tailor them to specific purposes, but not to reduce them below the national level.

(*f*) *Eliminate Special Advantage to Virgin Materials.*—To attack the incentives problem at the other end, so to speak, depletion allowances and other special and discriminatory tax treatment of virgin materials should be repealed. A further step would be to encourage the institution of substantial severance taxes on materials extraction to encourage improved durability, maintenance, and recycling of materials and energy (by higher recovery of useful energy). This would contribute not only to conservation, by countering tendencies which the market may have to discount the future at too high a rate, (further explanation is found further on), but would also discourage the generation of waste materials which damage the environment.

(*g*) *Charge on Packaging Materials.*—The effluent charge concept is beautifully applicable to solid waste problems. A charge equal to the average cost of environmentally benign disposal should be levied on packaging materials. The charge should be refunded to the extent materials are recycled. The proceeds of the charge not refunded should be made available to cities for their solid waste programs. Practical proposals for such a system have been developed and are under consideration in the Congress. The path breaking Oregon bottle bill works essentially this way. A charge is levied on beverage containers and refunded if the container is returned. Thus the consumer pays the charge, an effluent charge, if he disposes of the container into the environment. By all accounts this law has been extremely successful in achieving its objectives and serves to protect the environment and reduce material and energy use.

A program with these general features would make the economic incentive system a powerful and all-pervasive force for environmental improvement. It would go a long way toward making the previously external costs of using the common property resources internal and help to make growth benign rather dangerous. It would lead toward achieving environmental goals efficiently as well as effectively both in the application of present technology and in the development of new technology. I can only regard it as astounding that our government would hope to accomplish these ends, involving literally millions of decisions by individuals, firms, and small units of government by issuing largely unenforceable orders.

Energy Policy

Space does not permit, nor is there a need to recount the shattering series of events in regard to energy which have happened over the last few years. The story of the embargo, the sudden widespread realization of our degree of dependence on foreign supplies and drastic downward revisions of estimates of domestic supplies, the environmental degradation and hazards which may follow from our efforts to limit foreign dependency, these are all things of which current headlines are made. These problems which have rushed upon us are complex and many faceted. But it is possible to see them in a slightly larger perspective by referring back to the conceptual discussion of the opening section.

While the section on environmental issues did not single out energy as such, it is true that the energy industries have been unusually heavy users of common property resources, as have the end users of energy. Historically the whole energy conversion process has been far from meeting the full social costs of production. This tendency to undershoot social costs has been significantly aided by a number of different types of special tax treatment. In general, it is well known that the extractive sector of the economy is one of the most lightly taxed ones. In part this is a result of special provisions for extractive industries, such as depletion allowances and capital gains for timber, coal, and iron, and expensing of exploration and development expenditures. But it is also partly due to the special ability of the extractive industries to take advantage of uniform provisions in the tax code, for example, the foreign tax credit and capital gains. It is now generally agreed by students of the matter that investment in extractive industries has been at least fifty percent greater (and possibly much greater than that) than it would have been if taxation of these industries had been on the same basis as other industries.

A combination of unpriced use of common property resources and light taxes has made energy artificially cheap and stimulated the development and use of energy hungry technologies throughout our economy. As already indicated, this has led to excessive rates of materials use, in this case energy materials, excessively rapid rates of resources depletion, and as was emphasized in the previous section, environmental pollution on an enormous scale. Approximately 60% of the total weight of materials flow in the United States consists of mineral fuels.[2] A much higher proportion of the total weight of residuals consists of combustion products because of the addition of oxygen and nitrogen from the atmosphere. A positive program for environmental improvement and reduced materials flow as presented at the end of the last section would largely come to grips with the social cost—private cost divergence aspect of the problem insofar as they pertain to current uses. But there are additional pertinent aspects of market failure in the energy industries which must now be raised.

In considering environmental problems I have stressed market failures resulting from the presence of common property resources. The existence of such resources violates one of the basic requirements needed for a market to produce an optimal allocation of resources. As additional background for considering policy issues with respect to energy, and the extractive industries more generally, it is necessary to point out that this industry violates the conditions for a perfect market in several additional ways. Establishing what these are will enrich the conceptual framework we can use for policy analysis.

First, the energy industry violates, and increasingly violates, the basic condition that competition must exist. While blatant monopolistic behavior has not characterized the basic energy commodities industry in recent decades there can be no doubt that elements of monopoly exist in it (I here exclude the electricity industry which, of course, consists of regulated monopolies). These manifest themselves in vertical integration and concentrated ownership of multiple sources of primary energy and in control of energy transportation facilities. As in the case of environmental market failure, our approach has been to institute direct regulations in an attempt to control monopolistic behavior, especially price behavior. The effects of this regulation have not been obviously better than our experience with such controls in the environmental area. There have been dampening effects on domestic exploration and development which help to contribute to heavy import dependence, a distorted and inefficient price structure, and inefficient patterns of production, among many other ill effects. This is not to say that public policy toward the industry is not needed but, as in the case of environmental policy, direct regulation has mistakenly been chosen in preference to policies which would alter the structure of economic incentives.

Secondly, the market will not lead to an optimal response to import dependency. On initial view one might suppose that private speculators would accumulate stockpiles which would protect against disruption of supply such as an embargo by a cartel. Since the embargo a substantial amount of private petroleum stockpiling has, in fact, happened. However, it is clear upon further reflection that the market can only accomplish such national security measures imper-

[2] This calculation excludes construction materials.

fectly. Unlike the risks of adverse weather which affect the supply of flow resources, it is virtually impossible to make any assessment of the risk associated with the activities of a cartel. Thus the risks and uncertainties confronted by a private party engaging in major stockpiling would be enormous. In addition no individual consumer would be willing to alter his purchases or pay a higher price to reduce import dependence or accumulate a stockpile. This is because his individual behavior would have only a trivial effect on the whole situation. Thus a commercial enterprise could not, unless it were a monopoly, afford to increase its costs in a major way by stockpiling or not buying cheap imports for its sales could always be displaced by those of a company willing to import. Thus government policy must concern itself with matters of import dependency and stockpiling. National security is a *public good* with characteristics similar to those of common property resources. Public goods cannot be properly produced and allocated by the market system.

Finally, as noted at the outset, one of the characteristics of the "ideal" market model is that markets for all goods and services in fact exists. So far, we have considered this requirement in a static context and found that the condition is violated. But in a dynamic context there is the further implication that a full set of futures markets must exist if the market system is to have the desired normative properties of Pareto-optimal allocation over time as well as at a given time. This means that it should be possible today to make contracts about deliveries of goods and services in the future. For example, an owner of a nonrenewable resource should be able to sell a claim today on one unit of the resource to be delivered 15 years from now. This is a requirement for ideal markets of profound importance with respect to extractive resources because they are depleting resources and such a full set of futures markets does not exist. If there were no uncertainty about future prices and availability of the resource, a perfect capital market without futures markets would achieve the same allocation as a perfect futures market. But all estimates of future demand and supply of the resource will in reality be quite uncertain. The resulting distribution of risk among the entities in the economy will not be optimal, unless they have the possibility of insuring themselves against every possible state of the world that might occur. This could be done, for example, if a full set of markets for claims contingent on the occurrence of states of the world could be established. However, the costs and difficulties of organizing such a market, and the problems connected with moral hazard, effectively rule out such a full set of markets. Therefore, the existing distribution of risk will be non-optimal and this may have some profound implications on the rate at which non-renewable resources are extracted.

The profit maximizing rate of extraction depends on the expected future prices of the resources and the interest rate. If the future prices are expected to rise at a faster rate than the interest rate, it would be profitable to reduce the present rate of extraction, and if the future prices are expected to increase at a slower rate than the interest rate, it would be profitable to increase the present rate of extraction. This is, however, only true if the expectations on future prices are held with certainty or if any risk can be insured. If that is not the case, a risk averse producer of the resource would systematically produce more today and less in the future to reduce the losses that may occur because prices rise more slowly than expected.

Consequently, the absence of futures markets and the lack of complete set of markets for contingent claims introduces a systematic incentive to produce too much of a non-renewable resource in the present at the expense of the production in the future. This is perhaps the most fundamental rationale for levying severance taxes and undertaking other conservation measures with respect to extractive industries.

I turn now to specific policies especially pertinent to the energy sector which have not yet been treated in other connections.

Since 80 percent of our national energy supply comes from oil and gas, any successful effort to limit import dependency over the *next decade* must rest on some combination of conservation and enhanced production of domestic oil and gas as its primary pillars, with heavy emphasis on the former. Fortunately a positive program for achieving this end can be devised which is also consistent with the objective of improving the efficiency of the industry. Two central elements of this program are deregulation of prices and a variety of measures to improve the performance and competitiveness of the industry.

A Positive Program for Gas and Oil

GAS

The diminishing supply of natural gas over the next decade is perhaps our most urgent resource commodity problem. The Federal Government should take the following steps:

(*a*) *Gas Price Deregulation.*—All gas prices, or at least those for gas from new sources, should be deregulated. The desirable effects would be about the same either way but would come sooner if the former course was adopted. As old gas is exhausted, a single price system would gradually come into effect under the latter policy. The purposes of decontrol are:

(i) Stimulate production in the short run. There is no doubt that we have used up our gas supplies too rapidly in the past but in the immediate future we have few alternatives to stimulating production. It is widely agreed among scholars of the situation that regulation has held down exploration for new supplies of gas. In addition public utility type regulation does not seem appropriate for an industry as risky as natural gas production.

(ii) Rationalize the national pattern of production. The present system of interstate gas price regulation discriminates against high production cost, low transportation cost sources near markets. The potential for producing natural gas from wells in coal and shale formations appears to be large but the cost is considerably above conventional wells. Since in many cases these sources could be developed close to markets, the regulations discriminating against such sources could be quite serious.

(iii) Stimulate conservation in both the short and long run. In the short term this would occur primarily by the substitution of other fuels for gas used as boiler fuel. It is in this end use where a substitution of other fuels is easiest and where the use of a highly desirable fuel like natural gas appears unjustified. Price deregulation, unlike forbidding the use of gas for this purpose, as those who are addicted to direct regulation suggest, would provide a measure of flexibility in those cases where substitutes are very costly and difficult to obtain. Furthermore, higher gas prices would stimulate more conservative use in space heating by means of temperature reductions, insulation and fuel substitution. We now have the anomalous situation where natural gas, which is perhaps the most desirable of all fuels, costs much less on a BTU basis than coal or oil.

(iv) Obviate the need for direct allocations. Rationing would surely have to come if present gas prices are maintained. Experience with regulations in many spheres does not make one optimistic that Washington is wise enough or has enough information to ration gas to its best uses.

(v) Eliminate price and allocation distortions. Clearly the existing two price system introduces significant distortion into this market. Interstate gas carries a maximum wellhead price of 52 cents per MCF while recent intrastate contracts have in some states been at a price of $2.00 per MCF or more at the wellhead. As a result to this pricing system, the major share of "new gas" is being absorbed in the intrastate markets. Gas producing states are seeking to take advantage of this distortion as means of attracting new industry and new jobs. The anomalous fact that gas is cheap, but new supplies are unavailable, in New England and relatively expensive, but available, in Texas is bound to distort all types of decisions into inefficient directions.

(*b*) *Grants to Home Owners.*—In connection with deregulation, a one time only system of direct grants for home insulation and fuel reconversion processes should be undertaken. The main reason for this is to blunt the effects of a sudden increase in gas prices on poor people who live in the poorly insulated and energy intensive houses which are one of the heritages of the age of excessively cheap energy. Direct grants should be favored over tax deductions which, while politically appealing, are usually a sham since they help those most who need it least. One reason why home owners do not insulate even where it would be to their economic benefit is that they are not informed about the pertinent benefits and costs (as the reader will recall the model of ideal markets assumes all participants are fully informed). A national information and demonstration program is needed to provide such information to owners of existing homes and new home buyers. The FEA is experimenting with such educational activities but at a totally inadequate level.

(*c*) *Emissions Control.*—Price deregulation lends added importance to the implementation of a system of effluent charges to provide a strong economic incentive to control emissions as fuel reconversion is implemented. Since substitutes for gas will come mainly from direct or indirect use of coal, there is a great danger that a reconversion program, whether stimulated by prices or other means, could have very destructive consequences for the environment. Direct regulation of emissions is a very undesirable policy strategy under present circumstances. Once a variance is granted the emitter is "home free" so to speak and may once again regard the environment as valueless since he pays nothing for its use.

(*d*) *Performance and Competitiveness of the Industry.*—Finally, because of monopoly elements in the industry, price deregulation should be considered in the context of measures to improve the performance and competitiveness of the industry, some of which I will suggest after presenting a policy program for oil.

OIL

Liquid petroleum is our basic fuel and recent estimates have greatly reduced the supply thought to be available. The following steps should be taken by the Federal Government:

(*a*) *Price Decontrol.*—A program of phased decontrol of old oil prices and elimination of import fees should be pursued. The purposes for this action are mostly analogous to the reasons for favoring the deregulation of gas:

(i) To stimulate production in the short run. This is especially important for old oil since normally around 70 percent or so of oil is left in the deposit for economic reasons. Therefore, not only does the present price control system limit production from additional recovery from established wells but it is highly inefficient because it stimulates the production of high extraction cost new oil over the production of lower cost old oil.

(ii) To foster conservation in both the short and long run. Numerous official and unofficial studies have shown that the demand for petroleum does display some price elasticity. Price rises are to be favored over direct regulation of petroleum use since the latter could never achieve the same broad across the board incentive to conserve.

(*b*) Energy Use in Transportation.—In view of the enormous consumption of energy in transportation in the United States (about one quarter of total energy consumption) special measures are needed to serve both the tightly interrelated interests of conservation and environmental improvement, and to blunt the impact of energy cost increases on low income persons:

(i) Tax on low gasoline mileage automobiles and on gasoline. Partly because of the excessively low energy prices which have historically prevailed in the United States, Detroit has been able to produce enormous gas guzzlers with small uncomfortable passenger compartments and persuade the American consumer that they are automobiles. Unfortunately, while consumers for a time after the dramatic increase in the cost of fuel turned heavily to the purchase of smaller cars that tendency is now reversing itself. A heavy tax, implemented in a time phased manner, should be levied on low gasoline mileage automobiles. Again this is much to be preferred to a direct regulation approach such as requiring a specific mileage performance. Congress is hardly the proper place to design automobile engines as our experience with legislated emissions controls has most clearly shown. The proposed tax on automobiles would stimulate production of cars with improved gasoline mileage but it would not influence driver behavior once the automobiles are bought. To reduce driving and to stimulate performance maintenance through tuneups the federal tax on gasoline should be increased substantially. The linked problems of conservation and environmental improvement would, once again, both be helped by such a tax.

(ii) Alternative transportation systems. The Federal Government should further assist in the upgrading of intracity and intercity transport systems. Proceeds from the tax on low mileage automobiles could be one possible source of finance for such a program. Again this is a program element which could serve both the interests of environmental management and conservation of resource commodities. It should be developed on the basis of a careful assessment of both types of effects.

(iii) Measures to blunt the income redistributive effects of petroleum price increases. A system of special vouchers for engine tuneups and overhauls might serve to counter adverse distributive effects in the short run. In the long run our society must come to grips with the income distribution problem in a more fundamental manner. This is essential if efficiency-improving measures are not to be frustrated or encumbered with administratively difficult (and therefore probably inequitable) and costly special provisions to try to offset distributional effects of public policies designed to promote conservation and protect the environment. Some form of income maintenance is required.

Measures to Improve the Performance and Competitiveness of the Oil and Gas Industry

To help come to grips with the non-competitive aspects of the oil and gas industry a number of policy initiatives are needed.

(*a*) *Excess Profits Tax.*—An excess profits tax is needed to avoid enormous windfall profits especially on old oil and gas, if prices are deregulated.

(*b*) *Foreign Tax Credit.*—The foreign tax credit should be repealed. This is to eliminate whatever preferential incentive for foreign operations the tax provides.

(*c*) *Protection of Smaller Producers.*—Various measures should be taken to help protect smaller producers in the interest of preserving or enhancing competition. These include:

(i) Larger advance payments by pipelines to producers.

(ii) Reduced fixed lease bonuses on outer continental shelf leases and making percentage royalty the variable on such leases.

(iii) A heavy burden of proof on joint ventures to publicly show that the scale of needed activities requires such joint and potentially anti-competitive action.

(iv) Amended anti-trust laws to require integrated companies to conduct each functionally separate segment of their business without subsidy from other segments. This is to keep the integrated companies from squeezing the independent refinery industry when deregulation occurs and entitlements are ended.

(*d*) *Anti-trust Activities.*—Anti-trust investigation of the oil and gas industry should be expanded. This is especially important with respect to the vertical integration of the industry giants which can be used as an effective tool for monopolization. Surveillance and investigation to disclose and deal with possible monopolistic activity is especially important once price controls are lifted.

Western Coal

Table 1 shows, that even with decontrol of oil and gas prices, national dependence on imported energy promises to grow enormously unless other actions are taken as well. Oil imports grow continuously over the period until the year 2000 and by about 1990 become more than one-half of total energy demand. Of course other policy measures suggested in this paper would tend to have a substantial dampening effect on demand growth. Nevertheless in the absence of strong efforts to develop alternatives, import dependency will grow mightily in the longer run and it will grow somewhat in the short run almost no matter what is done. Since the Yom Kippur War our dependency on foreign oil has grown from about 35 percent, most of which was supplied by Canada and Venezuela, to about 50 percent and there has been a drastic shift toward less dependable middle eastern supplies. An embargo now would have much more serious consequences than it did in 1973.

TABLE 1.—PROJECTIONS OF U.S. FOSSIL FUEL PRICES, PRODUCTION AND TOTAL CONSUMPTION UNDER DECONTROL

[Constant 1974 dollars, energy in quads, 1976 decontrol] [1]

Year	Field price (Dollar per 10^6 Btu)				Fossil fuel demand (10^{15} Btu)						Reserves (10^{15} Btu)			Discovery (10^{15} Btu)	
	Crude oil	Natural gas	Deep-mined coal	Strip-mined coal	Total oil	Oil imports	Natural gas	Deep-mined coal	Strip-mined coal	Total demand	Oil	Natural gas	Coal	Oil	Natural gas
1975	1.30	0.20	0.44	0.30	26.56	8.07	20.60	8.78	5.58	61.52	182.75	252.79	18,659.67	33.10	9.30
1976	1.78	.61	.45	.31	31.90	11.55	20.46	9.32	6.09	67.78	199.18	241.48	18,645.32	23.64	7.09
1977	1.78	.66	.48	.33	33.73	12.64	20.09	9.47	6.23	69.31	204.33	227.98	18,629.91	26.17	6.25
1978	1.78	.72	.49	.33	35.44	13.53	19.59	9.26	6.38	70.67	210.14	213.77	18,614.41	22.86	8.29
1979	1.78	.78	.50	.33	37.14	14.83	19.24	9.26	6.55	72.19	211.92	201.97	18,598.76	19.20	7.08
1980	1.78	.86	.52	.34	39.02	16.77	18.77	9.26	6.72	73.77	209.22	189.46	18,582.95	16.92	6.24
1981	1.78	.94	.53	.34	41.01	19.13	18.18	9.27	6.90	75.37	203.83	176.46	18,566.97	15.88	5.41
1982	1.78	1.03	.55	.35	43.15	21.74	17.47	9.29	7.09	77.01	197.46	163.10	18,550.79	15.50	4.67
1983	1.78	1.13	.56	.35	45.44	24.52	16.66	9.32	7.29	78.71	191.08	149.58	18,534.41	15.36	3.99
1984	1.78	1.24	.58	.36	47.90	27.44	15.77	9.35	7.50	80.51	185.02	136.10	18,517.80	15.19	3.38
1985	1.78	1.36	.59	.37	50.54	30.52	14.80	9.39	7.71	82.44	179.29	122.82	18,500.95	14.90	2.85
1986	1.78	1.49	.61	.37	53.38	33.79	13.77	9.43	7.93	84.52	173.73	109.90	18,483.86	14.48	2.37
1987	1.78	1.63	.63	.38	56.44	37.28	12.70	9.49	8.16	86.79	168.19	97.48	18,466.49	13.97	1.96
1988	1.78	1.79	.65	.39	59.74	41.04	11.60	9.54	8.40	89.29	162.56	85.67	18,448.84	13.41	1.61
1989	1.78	1.96	.67	.40	63.29	45.07	10.51	9.60	8.65	92.05	156.81	74.58	18,430.90	12.85	1.31
1990	1.78	2.15	.69	.41	67.12	49.41	9.42	9.67	8.91	95.12	150.96	64.29	18,412.64	12.31	1.05
1991	1.78	2.36	.72	.42	71.25	54.06	8.35	9.75	9.18	98.53	145.05	54.83	18,394.05	11.78	0.84
1992	1.78	2.59	.74	.43	75.70	59.05	7.33	9.82	9.46	102.31	139.11	46.26	18,375.12	11.27	0.67
1993	1.78	2.84	.77	.44	80.59	64.39	6.35	9.91	9.75	106.50	133.19	38.58	18,355.83	10.76	0.52
1994	1.78	3.11	.79	.45	85.64	70.11	5.44	9.99	10.05	111.13	127.31	31.77	18,336.18	10.27	0.41
1995	1.78	3.40	.82	.46	91.18	76.20	4.60	10.08	10.36	116.22	121.48	25.83	18,316.13	9.79	0.32
1996	1.78	3.72	.85	.47	97.10	82.69	3.83	10.18	10.68	121.79	115.73	20.70	18,295.69	9.31	0.24
1997	1.78	4.06	.88	.49	103.42	89.58	3.15	10.28	11.01	127.86	110.06	16.34	18,274.83	8.84	0.18
1998	1.78	4.43	.91	.50	110.14	96.88	2.54	10.38	11.35	134.42	104.49	12.69	18,253.53	8.38	0.14
1999	1.78	4.82	.94	.52	117.26	104.56	2.02	10.48	11.70	141.46	99.04	9.68	18,231.81	7.94	0.10
2000	1.78	5.23	.97	.53	124.73	112.60	1.57	10.59	12.07	148.96	93.71	7.24	18,209.62	7.50	0.08

[1] Based on an econometric projections model developed by Prof. William Schulze and the resource economics group at the University of New Mexico.

Another feature of the situation highlighted by the table is that, recognizing the uncertainties involved, by the end of this century our supplies of oil and gas will have been virtually depleted despite the rate of new discoveries projected in the analysis. At the same time regardless of a near doubling in the projected annual rate of demand the effect of use on the nation's enormous coal reserves is close to imperceptible. In addition there is good reason to believe that, especially in the west, coal reserves are greatly underestimated. The key to controlled import dependency toward the end of the century appears to be coal and a strong push for conservation. Lead times are such that the development of a full scale liquefaction and gasification industry will take about 25 years so the policy issues are immediate even if the effects are not. Recognition of these facts has caused the executive branch to press hard for programs to develop western coal on a massive scale. The problem is to structure economic incentives so as to use this resource, both directly for electrical energy generation and for the production of synthetics, without large scale environmental destruction and general reduction in the quality of life in the producing areas. Again resources and environmental considerations must be combined in fashioning a coherent program to come to grips with these problems. Before proceeding to the presentation of a positive program it must be underlined that limiting import dependence by the development of synthetic oil and gas from coal is a very costly proposition. The price of OPEC oil is currently about $12 per barrel. The minimum price of synthetic oil would be $17 per barrel. Assume imports would otherwise grow at a rate of about 8 percent a year (which they would easily do if not countered by various policies) and a national policy is established to completely offset this increase by the production of synthetic fuels. Then, at a 6 percent discount rate, the present value of the cost of energy independence to the year 2000 would be approximately $285 billion. Clearly such a course would not be followed but this calculation does indicate the important role which energy conservation must play in our national future. But even with the large cost effective investments in conservation that are possible, and which should be undertaken, substantial development of western coal is likely.

A POSITIVE PROGRAM

The situation with respect to the development of western coal is complex and calls for several policy initiatives at the federal level.

(*a*) *Measures to Reduce Economic Uncertainty.*—To provide a more secure base for the large investments which would be needed, a variable tariff should be imposed on imported fuels which would put a floor on the price of imported oil. The present price of OPEC oil is not high enough to make synthetics competitive using existing technologies to produce them. The Federal Government should provide capital subsidies to a limited number of full scale synthetic fuel operations to test alternative technologies and to begin to develop synthetic fuel capacity in anticipation of reduced availability of domestic oil and gas. In addition a stockpile and reserve production capacity should be developed to provide some buffer against a renewed boycott.

(*b*) *State Level Effluent Charges.*—The federal taxes on atmospheric emissions recommended in an earlier section should be framed

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in such a manner that their administration and revenue from them is turned over to the energy producing states and Indian Tribes. These charges could be increased at the discretion of the state but not set below the federally established level. The purpose of the taxes would be to provide a strong economic incentive to exercise strict control over emissions and to help compensate the people in the producing regions for the environmental degradation which will nevertheless inevitably occur.

(*c*) *Protection of Clean Air Areas.*—The "non-degradation" provision of present air pollution legislation should be reframed. "Clean air preserves" should be designated and an especially high emissions charge levied on any residuals discharging activities located in them. This would not prohibit development as would a literal reading of non-degradation (and if it is not read literally what can it possibly mean?) but it would make it economically worthwhile to exercise especially stringent emissions control and would assure that the activity locating in the preserve is of outstanding economic value.

(*d*) *Long Term Planning and Severance Taxation.*—The Federal Government should encourage the states and Indian Tribes to establish long run plans for dealing with the situation which will occur when the economic base provided by depleting energy resources will diminish. Severance taxes are an appropriate way of providing a financial basis for coming to grips with this problem and to combat the varous tendencies for the market to discount the future at too high a rate. By providing an additional incentive for conservation they also help to reduce resource depletion and serve environmental preservation. The Federal Government should encourage and protect the states in efforts to establish significant severance taxes (the present effective severance tax rates are in many cases very low at the present time, for example, the effective rate on uranium is one quarter of one precent in New Mexico).

(*e*) *The Leasing System on Federal Lands.*—Much of western coal is on public land where it is subject to the federal leasing system. Some reforms are needed to simplify this system as it exists, make it more competitive, and to make sure that the public receives proper reimbursement for the valuable right to mine the public lands:

(i) Avoid overlap, waste, duplication and needless delay by consolidating all leasing activities includng those on Indan lands in one mineral development agency.

(ii) Grant exclusive exploration permits for specific time periods with an exclusive right to develop for the mineral discoverer; abolish preference right leasing.

(iii) Provide for reasonable revenues to the public from mineral production based on the value of the mineral product and not the amount of production.

Additional Issues for Public Policy in the Energy Area

There are two additional issues for national energy public policy which need attention. The one because of its great important and knotty difficulty. The other because, while small in terms of the total national interest, it is very important to those regions and persons affected and because it has been totally neglected in all efforts to develop a national energy policy. I will turn to the latter first.

Boomtown Problems

The energy producing states may see the growth of many boomtowns as a result of rapid development. This is so also of some coastal areas where major import and refining facilities will be created. Boomtowns in the producing regions of the west are likely to have many more problems because of their remoteness from population centers and, in some cases the harshness of their natural environment. Experience and logic tells us that such towns are ordinarily undesirable if not disastrous places in which to live. They usually impose large social costs on the areas where they develop. The problem for public policy is once again to bring private cost into alignment with social cost and to improve our institutional capabilities for resources management. The following are the main elements of this situation and some things which could be done about them through federal initiative.

The need for basic public services, sewers, roads, utility lines, school facilities, arises before there is anything like adequate public funding available at the local level to provide them. In addition normally little or no advance planning occurs. "Front end" money and advance planning are needed to come to grips with this situation.

What might be called public environmental services are frequently even more neglected. As a result the usual appearance of the towns is ghastly and urban recreational and cultural opportunities outside the home are virtually nonexistent. A suitable urban environment requires landscaping, parks, playgrounds and community centers. Again these are matters which require planning and timely money.

The worst quality of life is frequently experienced by the women in boomtowns. They usually must live in manufactured houses the keeping of which does not occupy much of their time and which are physically very confining. They suffer most from the poor utility and amenity services in such towns. In addition these towns, since they are based on a heavy extractive industry or construction, usually provide very few opportunities for women to work outside the home.

It is now well documented that the unwholesomeness of boomtown environment contributes to alcoholism, divorce, and substantially reduced economic productivity.

Clearly, mitigating the adverse effects of boomtown development involves advanced planning, proper institutional arrangements for the implementation of plans and, certainly not least, a large amount of front end money. These are the essential ingredients which have been lacking in virtually every boomtown development in the nation's history. In my opinion, the Federal Government, in cooperation with the states, must take a leading role in coming to grips with this situation. It appears to be beyond the means or at least beyond the will of the states to deal with it by themselves, or to successfully impose it on the industries exploiting the resources and therefore causing the problems. Moreover the costs and benefits of the developments giving rise to boomtowns usualy extend beyond the state or even the region in which they occur.

A POSITIVE PROGRAM

As part of the nations resources and particularly as part of its energy policy, the Federal Government should take the lead in addressing the boomtown problem.

(*a*) *Loans to States.*—The Federal Government should make available to the states planning grants and loans at moderate interest rates to provide the front end money required where large natural resources developments giving rise to a boom situation are contemplated. These loans could be used to provide the funding for basic public services, environmental public services, and useful and satisfying activities for women and young people.

(*b*) *Repayment and Internalizing Social Costs.*—The loan would be repaid in two ways. First, for the basic public services, the schools, the public utilities, the electric lines, and the sewers, the money would be repaid from user charges or normal taxes on the people using these public services. The part of the loan going for environmental services, for setting up activities for women, and for manpower training, would be repaid by severance type levies on the extraction of the mineral. This not only would provide a repayment mechanism for the loan but would do so in a manner which causes at least some of the social costs of the minerals extraction to be reflected in the private costs of development companies and in product prices.

Nuclear Energy

There is currently a deep debate about the role nuclear power should play in our energy future. Here, once again, environmental and resource commodity issues are tightly interlaced.

Clearly, there are some major benefits from using nuclear fission technology, else it would not have so many well-intentioned and intelligent advocates. Residual heat is produced to a greater extent by current nuclear generating plants than from any fossil-fuel-fired ones and they require more cooling water. But otherwise the environmental impact of routine operation of the nuclear fuel cycle, including burning the fuel in the reactor, can very likely be brought to a lower level than will be possible with fossil-fuel-fired plants. In general, the costs of nuclear and fossil fuel energy, with the latter having a fuel cycle in which residuals generation is controlled to a high degree, do not seem to be so greatly different, although this varies regionally and the cost of nuclear plants has been rising more rapidly than those of fossil plants. This has been largely due to interest during construction (to build a nuclear plant takes about a decade) and increasingly stringent safety standards. If this tendency continues nuclear will soon be clearly non-competitive with coal in most areas. This is one reason for large scale cancellations of orders for nuclear plants. Also, there still remain major subsidies to this industry in the form of subsidized insurance and enrichment facilities not to mention the enormous costs of research and development.

Unfortunately, the advantages of fission are much more readily quantified in the format of a benefit-cost analysis than are the associated hazards. Therefore there exists the danger that the benefits may seem more real. The social cost issues are subtle and difficult to deal with.

To use fission technology safely, society must exercise great vigilance and the highest levels of quality control, continuously and indefinitely. In part this is because of the great hazards associated with imperfect operation of reactors and the nuclear fuel cycle. Especially the breeder reactor involves the use of large quantities of plutonium which is one of the most toxic substances known to man and which could be used to fabricate nuclear weapons. As the fission energy economy grows, many plants will be built and operated in countries with comparatively low levels of technological competence, a greater propensity to take risks, and a strong desire to reduce their dependency on foreign oil which proved so disastrous to them in the middle seventies. An increasingly large transportation of hazardous materials will probably occur.

But equally disturbing questions surround the storage of high-level radioactive wastes. Estimates of how long these materials must be isolated from the biosphere apparently contain major elements of uncertainty, but current ones seem to agree on "at least two hundred thousand years."

In the United States, heavy emphasis has been given to the storage of these wastes in salt formations, and a site for experimental storage was selected at Lyons, Kansas. This particular site proved to be defective. Oil companies had drilled the area full of holes, and there had also been solution mining in the area which left behind an unknown residue of water. But comments of the Kansas Geological Survey raised far deeper and more general questions about the behavior of the pertinent formations under stress and the operations of geological forces on them. The ability of solid earth geophysics to predict for the time scales required proves very limited. Furthermore, there is the political factor. An increasingly informed and environmentally aware public is likely to resist the location of a permanent storage facility anywhere.

Because the site selected proved defective, and possibly in anticipation of political problems, emphasis is now being placed in the United States upon the design of surface storage facilities intended to last a hundred years or so, while the search for a permanent site continues. The surface storage sites would require continuous monitoring and management of a most sophisticated kind. A complete cooling system breakdown would soon prove disastrous and even greater tragedies can be imagained should such facilities prove to be the victims of violence.

A POSITIVE PROGRAM

In view of the possible hazards of nuclear energy and in view of the deep ethical nature of some of the problems they present, there is an urgent need to decide whether policy action is needed while the nuclear energy economy could still be kept within some bounds. Crucial issues like plutonium recycle nad development of the fast breeder reactor are yet to be finally decided as is the growth and scale of nuclear energy in general. The following actions are therefore urgently needed:

(*a*) *Congressional Hearings.*—Either a special committee of Congress or one with broad policy responsibilities, such as the Joint Economic Committee, should hold carefully planned and executed hearings on the value choices which must be made in regard to nuclear energy and develop a policy program with respect to them. The Joint Atomic Energy Committee with its long history of advocacy for nuclear technology would not be suitable for this purpose.

(*b*) *The Price Anderson Act.*—By limiting liability in case of nuclear accidents, and by subsidizing what insurance is available, the

Price Anderson Act provides an artificial stimulus for the development of nuclear energy. It should be repealed, at least for new facilities.

(*c*) *Alternative Technologies.*—An all out effort should be made to develop promising technologies which could be large-scale long-term alternatives to nuclear energy and synthetic fuel production. Solar and geothermal energy have signifiant economical applications now but may be seriously held up by institutional obstacles of various sorts. Public policy needs to give attention to clearing out institutional obstacles such as property rights ambiguities, and building codes and zoning provisions which inhibit the use of solar energy. Solar heating and cooling of new buildings and provisions of industrial process heat are good investments now vis-a-vis electricity or synthetic fuel. The research program to tap the deep heat of the earth should be greatly accelerated.

Non-Fuel Minerals

Consideration of non-fuel minerals policy is not as yet surrounded by the crisis atmosphere which prevails in regard to energy. We have not had the equivalent of OPEC events with respect to non-fuel minerals imports and in general the reliance of the economy on any specific minerals is much less critical than its dependency upon petroleum. Nevertheless, non-fuel minerals invite serious attention from policy makers for three reasons.

First, in some respects our dependency on foreign sources of these minerals is even greater than for fuel minerals.

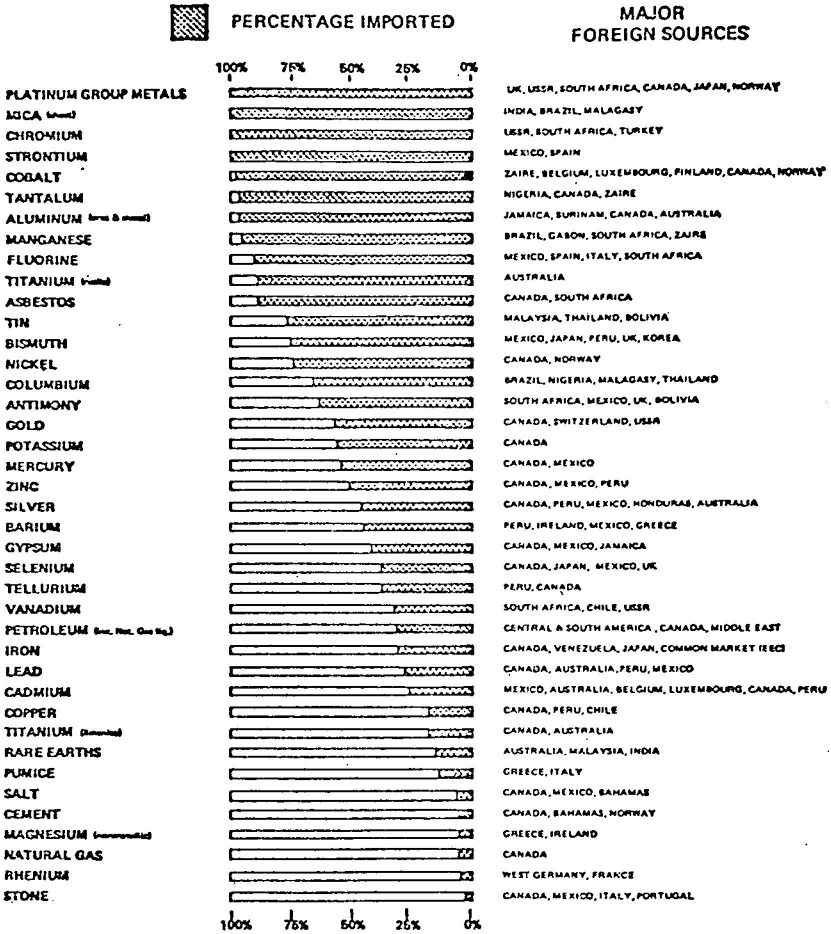
Second, domestic production, especially if some effort is made to reduce import dependency, will have to call upon progressively lower grades of ore. This means much increased threats of environmental impact and ever higher energy inputs for every unit of useful material recovered.

Third, the remaining non-fuel minerals in the United States are found largely on federal land and are exploited under an archaic mining law.

Figure 1 indicates the percentage of U.S. mineral requirements imported during 1972. The dependency on foreign supplies ranges from virtually zero, in the case of stone, to 100 percent in the case of a number of important metals. A study done by Resources for the Future for the President's Commission on Population Growth and the American Future found that for 18 minerals studied (these were the principal metals and key inorganics needed for fertilizer production) in the case of only three are our domestic reserves in excess of projected cumulative demand through the year 2000. These are phosphorus, potassium, and magnesium from the sea, and in addition iron and nickel reserves in Canada and the U.S. combined exceed projected combined production. Thus it is clear that if our economy continues to look anything like it does now, and continues to grow, our import dependency will show a strong tendency to rise. Since reserves as usually defined are an economic magnitude as well as a physical one, the rate of increase of imports will depend upon domestic prices and technology, as well as the degree of recycling achieved. Nevertheless, our dependency on the outside world will be large.

FIGURE 1

PERCENTAGE OF U.S. MINERAL REQUIREMENTS IMPORTED DURING 1972



THE INTERNATIONAL SCOPE OF THE MATERIALS SYSTEM

The United States imported varying amounts of metal, nonmetallic, and fuel minerals from more than 40 countries or areas of the world in 1972. No major nation of the world is completely self-sufficient in all minerals required to sustain an industrialized economy. Source: Bureau of Mines, U.S. Department of the Interior, 1973.

The Bureau of Mines has made some estimates of world reserves and consumption over the next few decades. Two general classes of minerals which present problems emerge from this investigation.

The first is a set of minerals where there is not so much a supply problem as that the United States is heavily dependent on foreign sources of uncertain dependability. Chromium is an excellent example of this class. We are 100 percent dependent on imports which originate entirely in the USSR, South Africa and Turkey. In a situation such as this a well thought out and systematic program of stockpiling is indicated. We do not have such a program.

The second class of minerals that may present a problem is where presently known world resources are inadequate to meet world demand and we must either out trade other countries for the limited supplies or find substitutes for these materials. A number of important minerals fall into this category including zinc, lead, copper and magnesium. In some cases, for example, copper and magnesium, it is possible to extend available supplies enormously by going to much lower quality sources. For magnesium, sea water is an exhaustible low grade "ore". In the case of copper, already the U.S. mines some of the lowest grade ores used anywhere. In both instances extraction processes are costly and very energy intensive. In these cases we may look to increasing costs, more complete recycling and substitutions of other non-fuel minerals for the ones increasing in relative cost. We most likely face a future of rising or at best stable relative prices of most important non-fuel minerals rather than the decline we have seen historically.

The second set of problems surrounding non-fuel minerals pertains to the environmental impacts of mining and processing minerals. Again the inseparability of environmental and resource commodity issues is demonstrated. Failure to internalize external costs results in the siamese twin problem of environmental damage and excessive resources depletion. In this connection, it is pertinent to note that the remaining supplies of non-fuel minerals are almost entirely found in the southwestern United States. This is the same highly mineralized area to which the nation is looking for solutions to the energy problem. The combination of massive energy development plus sharply increased mining activities for other minerals, while having to process progressively lower grade ores, points to strongly adverse effects on the environment of this area of the country.

The Southwest is at the same time highly valued for its recreational and aesthetic appeal and the environment-development conflict will take a particularly stark form there unless highly effective environmental policies are fashioned or new and less destructive mining and processing techniques are developed. The situation is well exemplified by copper. Ores as low as one-half percent (or even 0.3 percent) copper content are now being processed. Should we begin to use one-quarter percent ores, the amount of material that has to be mined and processed will double and energy requirements will probably more than double. With respect to the latter, there are already indications that copper smelters will switch from increasingly scarce oil and gas to coal for their energy inputs thus exacerbating the tendency to adverse environmental impacts. The heritage of all this may be enormous holes in the ground, great tailings piles, large emissions of sulfur compounds and particulate matter to the atmosphere—and all this in combination with increasing environmental disruption resulting from the exploitation of fuel minerals.

The third category of non-fuel minerals problems that need policy attention arise from the location system under which most non-fuel minerals are found and exploited on public lands. These activities are governed by the general mining law of 1872. There are some major problems with this law, and with administrative actions and judicial decisions flowing from it, as perceived by the mining industry, the administrative agencies and the concerned public. Changes leading to the more efficient discovery and exploitation of non-fuel minerals and to improved environmental protection are indicated.

From the point of view of the mining industry, the "marketability" test required of both prospectors and patent applicants threaten security and prediscovery tenure. The size of mining claims and mineral patents is also totally inadequate for modern mining operations necessitating expensive trades and acquisitions. The law contains vaguely defined concepts like "extralateral rights," "common variety," and even "locate" and "discover." These create legal uncertainty and much administrative red tape. It appears that the mining industry would like to retain the location patent system while updating, simplifying, and streamlining the 1872 law.

In regard to public land management agencies, they have been in the situation of having responsibility but no authority. Mining has occupied a privileged status. It is not subject to the same rules that apply to all other uses of the public lands. Furthermore, although this problem is now decreasing, the "priority" position of mining over most other uses has invited fraudulent entries on the public lands. Many second homes and recreational developments are occurring on public land with very little outside control by making use of patented mining claims. Furthermore, under the law, mining claims are recorded with local government rather than with the landlord agencies. This not only presents the agency with problems but makes it a difficult and expensive job to discover which lands actually have claims on them.

Other public problems are associated with requirements for "discovery" and "assessment" work which result in needless destruction of landscape, often to no purpose except to meet legal requirements.

A General Accounting Office study in 1974 reported visits to 240 mining claims and 93 patents issued within the last 25 years. In 239 of the 240 claims no mining was taking place and in 237 there was no evidence that it ever had. There was no evidence of any mining having occurred on 74 of the 93 patents.

A Positive Program

These major policy problems with respect to non-fuel minerals require a coordinated policy program dealing with the numerous but frequently interconnected facets of the problem.

(*a*) *Stockpiling Policy.*—For important minerals for which we are heavily reliant on foreign supplies of dubious dependability a systematic and well thought out stockpiling program should be instituted. As indicated earlier the private sector cannot be relied upon to stockpile optimally. We have had stockpiles in the past but they have usually been the result of short term security considerations or the incidental artifact of programs to help ailing industries. The stockpiling program should be reasonably related to the economy's future need for the mineral.

(*b*) *Excessive Materials Flow and Landscape Disruption.*—Most policies needed to deal with the twin problems of excessive materials flow and environmental disruption, resulting from failure to internalize social costs, have already been suggested. Effluent charges (including materials disposal charges), severance taxes, elimination of many tax advantages going to extractive industries are main elements of the needed policy program. Such policies would lead to a restructuring of relative prices in such a way that the goals of mineral conservation, recycling, and environmental protection would be served. Given such a policy program, no special privileges or benefits should be provided for recycling except to eliminate discrimination which may exist in the structure of freight rates and in labeling requirements. Subsidies for recycling should be considered only as a very poor second best if it should prove politically impossible to implement programs which successfully internalize the social costs of minerals use.

One environmental problem which is common to fuel and non-fuel minerals mining and processing is the disruption of the landscape resulting from strip mining and the generation of enormous piles of tailings. There is some state activity which attempts to come to grips with these problems but federal legislation is needed which requires land restoration and tailings disposal. The operation of such a policy should be secured by requiring the posting of a bond by the mining activity or by a special severance type levy on the sale of the mineral. This would also have the desirable effect of reflecting an important social cost in the current price structure.

(*c*) *The 1872 Mining Act.*—Ultimately the location system for non-fuel minerals should be replaced by a leasing system which could, in principle, provide much more positive public control of the external cost aspects of mining activity. Some lesser changes in the 1872 Law could, however, be very constructive in improving its performance and should be implemented promptly:

(i) Protect rediscovery rights by granting exclusive exploration privileges under permit and by establishing a new statutory base for "marketability" which recognizes reserves for the future.

(ii) Provide for reasonable revenues to the public from minerals production based on the value of the mineral product and not on the amount of production.

(iii) Permit the use of whatever supportable area of surface is needed to develop a mineral claim and for as long as may be necessary to extract the mineral without issuing a patent in federal public lands.

(iv) Dispense entirely with the requirements for minimal dollar amounts of "discovery" and "assessment" work as being a nuisance to the locator and an unreasonable and unnecessary disturbance of the surface.

(v) Develop an easily accessible central registry of all mining claims.

Macro-Economic Issues

In addition to the need for rethinking and reform of many traditional, obsolete, or misdirected policies aimed at influencing specific activities with natural resources implications, there is a need to reconsider some policies at the macro-economic level as well. Again the point is to correct misdirected economic incentives. One such policy area is corporation income taxation. At the margin corporate activities must yield at least the same rate of return to their stockholders as if the latter had invested in noncorporate entities or in federal securities. Since the corporation income tax is levied at a rate of approximately 50 percent this would mean that the before tax marginal rate of return in the corporate sector would have to be approximately twice the rate paid on long term government bonds, even neglecting risk factors. The long term government bond rate can be taken as some sort of an indication of the public's time preference at the margin. If this is accepted then the corporate sector will need to use approximately double the rate of time discount in evaluating its projects as would be indicated by the social rate of time discount. This means not only a general discrimination against conducting economic activities through the corporate sector but, reinforcing the absence of futures markets, a tendency to favor projects with large immediate payoffs over those of a longer term nature. Among other things, this results in a tendency to exploit natural resources at too rapid a rate vis-a-vis the time preferences of society and to recover less than the socially optimal amount of a mineral from known deposits. Of course, these effects are considerably attenuated in the mineral industry under present circumstances because of its unusual ability to avoid the corporation income tax by using other features of the tax law. Nevertheless there is a high degree of arbitrariness in the situation and if earlier recommendations to amend the tax law were to be accepted the situation would become more severe.

The second set of macro-economic issues surrounds the national need for heavy capital investment over the coming decade. The needs of defense, of investment for environmental improvement, for resource development. and for replacement of obsolete facilities in many industrial sectors will be large and, if they are to be successfully met, will require an increased rate of real saving and investment in the economy over the next decade. The chief macro-economic tools available to the Federal Government to influence (private and public) saving and investment behavior are taxation and public spending and the monetary operations of the Federal Reserve System. To have the effect of increasing investment and savings simultaneously the structure of macro-economic policy should be such as to yield a substantial full employment surplus in the federal budget while at the same time holding interest rates well below their present levels. The Congress's tendency to emphasize federal expenditures and its reluctance to impose taxes plus the Federal Reserve's self-prescribed mission of protecting the economy against inflation have led to a policy situation which is almost exactly the reverse of that which will be needed.

A Positive Program

The macro-economic situation requires the following policy initiatives:

(*a*) *Corporation Income Tax.*—As part of the general tax reform vis-a-vis the mineral industries urged in this paper, and only as part of such a program, the corporation income tax should be repealed.

(*b*) *Monetary and Fiscal Policy.*—There is an urgent need for the Congress and the Federal Reserve to come to agreement on an integrated macro-economic policy which will combine a large full employment surplus with low interest rates.

Recommended Resource Policies and Employment Act Goals

A question of foremost interest to the Joint Economic Committee is the likely effect of the proposed policy changes on the major goals of the Employment Act—employment, economic growth, and price stability. Table 2 summarizes my estimation of the direction these influences will take. It also is a convenient, albeit very brief, restatement of the major policy recommendations put forward.

TABLE 2.—ESTIMATED EFFECTS OF RECOMMENDED POLICIES ON OBJECTIVES OF THE FULL EMPLOYMENT ACT

[ST=short term (75–85), LT=long term (85–2020), +=positive, −=negative, 0=no effect]

	Employment		Economic growth		Price stability	
	ST	LT	ST	LT	ST	LT
1. Deregulation of oil and gas	+	+	+	+	−	+
2. Measures to increase competition	+	+	+	+	+	+
3. Severance taxes	−	−	−	−	−	−
4. Tax on large automobiles and gasoline	−	0	−	0	−	0
5. Cost-effective energy conservation	+	+	+	+	+	+
6. Alternatives to nuclear	−	0	−	0	−	0
7. Changes in minerals leasing and location systems	+	+	+	+	+	+
8. Effective land restoration	−	−	−	−	−	−
9. Measures to limit foreign dependency:						
(a) If foreign supplies continue and would otherwise be available at present cost	−	0	−	0	−	0
(b) If foreign suppliers engage in restrictive activities	+	+	+	+	+	+
10. Controlling boomtown social costs	−	+	−	+	−	+
11. Effluent charges:						
(a) Vis-a-vis emission standards providing equal environmental quality	+	+	+	+	+	+
(b) Vis-a-vis probable effectiveness of present policies	−	−	−	−	−	−
12. Regional management agencies	0	+	0	+	0	+
13. Control of toxins	−	(?)	−	(?)	−	(?)
14. Repeal corporate income tax	+	+	+	+	+	+
15. Fiscal and monetary measures to generate capital investment	+	+	+	+	+	+
16. More equitable income distribution	0	+	0	+	0	+

With respect to economic growth I am assuming for purposes of the table that it is measured in the usual way—price corrected GNP. This measure, of course, leaves out many dimensions of human welfare, including the quality of the natural and social environment. If these could be included in the measure many more pluses would appear in the economic growth column.

In general the pluses greatly outnumber the minuses (56 to 34) but this is not a very useful measure because quite different weights would have to be attached to the different recommendations. The heaviest influence is likely to come from 1, 2, 9, 14, 15, and 16. Nearly all of the effects of these recommendations appear to be positive in terms of the objectives of the Act. Thus, if I am correct, a set of recommendations developed solely from the viewpoint of improving policy in the area of natural resources, taken all together, appear to be strongly reinforcing to the goals set out in the Employment Act 30 years ago.

My assignment of directions of influence and weight to the various recommendations could no doubt be debated, but in many respects number 9 (measures to reduce dependency on foreign sources) presents the most complex issues in regard to Employment Act objectives. Its implications are large and it therefore merits a little further consideration. I will discuss it in terms of the energy situation.

If OPEC were to break up, the price of oil could once more fall to quite low levels. The production cost in some areas of the Middle East is still less than twenty-five cents a barrel. Such a dramatic price reduction would no doubt be an enormous stimulant to economies around the world including our own and should contribute to price stability, in the short run. It would no doubt overwhelm the influence of all the other policy recommendations. In the long run, however, it might not be such a favorable turn of events if it once more led to a cheap energy syndrome and delayed needed adjustments until petroleum has become quite scarce.

But assuming that we have a policy of maintaining current high prices on oil in order to stimulate domestic production, to develop substitute sources, and to foster energy conservation, what should be our policy posture toward OPEC? There are, as always, two broad options (1) do nothing special and (2) do something special.

Those who would support the view that no action is needed could argue that, in contrast to earlier cartels such as those in tin and rubber, OPEC is stable (within limits) but pretty clearly circumscribed with respect to the range of actions it can take. Saudi Arabia is the balance wheel. It has enormous supplies of oil and no great need for current revenues. It can therefore adjust production in such a way as to allocate production to those OPEC countries most in need of current revenues. There is evidence that this has been done with respect to Iran and Venezuela. Still, since the oil is distributed via international oil companies substantially controlled by U.S. interests, it is necessary for these companies to go along with such arrangements if they are to work. Thus U.S. influence could jeopardize the viability of the cartel should it threaten to push up prices much more. Furthermore, it can be argued that additional price increases will be limited by consideration of demand elasticities including the possibility of the development of large scale substitutes in the United States.

Another factor which might add to the long run stability of the cartel is the plans which are now being considered by OPEC for blunting the oil price impact on developing countries. Two schemes have been mentioned:

(i) Sell oil to developing countries at discount prices.

(ii) Convert the enormous amounts of gas now being flared in the OPEC countries to low cost fertilizer for developing countries.

Again, at least the first of these would require cooperation from the international oil companies.

Finally, it could be argued that stresses and strains already visible in the cartel are such as to circumscribe any short term strategic moves it might wish to undertake for economic or diplomatic reasons. It might be impossible to raise prices again once they were lowered (say to knock out a substitute energy source in a consumer country) since this requires agreement on much more radical redistribution of production and revenues than the marginal adjustments recently undertaken.

The case for a positive policy rests on the thought that despite speculation about the stability of the cartel there is enough residual risk to create reluctance to make large investments in substitutes for foreign oil.

Two alternatives might be contemplated:

(i) A stabilized high U.S. price brought about by quotas and a variable tariff or an auctioning system for foreign oil to be operated by the U.S. government. Either could be used to provide a stable price base for both the planning and development of U.S. energy capacity and for the implementation of conservation measures.

(ii) A variant of this approach would extend it by adding vigorous efforts to break the power of the cartel.

The most available instrument for the latter would seem to be via the operations of the international oil companies, as already indicated. There would be hazards in such an effort for should it not work the world might be faced with another oil embargo system the effects of which would not be much more serious than they were in 1973. Also the present redistribution of wealth to the OPEC countries is serving valuable development purposes for them and therefore, at least in a distorted way, contributing to the objective of aiding developing economies which some of the developed countries share. But it could be argued that, everything considered, the present situation is highly adverse to the developing world in general as well as to many developed countries. The matter is quite complex since it depends heavily on what sort of position OPEC eventually establishes with respect to other developing countries.

If the cartel were broken and a successful quota system established in the U.S. it would result in a large reduction in the loss of real income to the producing nations which exists under present conditions. The distinction here is between internal transfers and external obligations.

In this case the influence of the combined policies of price stabilization internally, and breaking the cartel, on real growth in the U.S. would be favorable. It goes without saying that there are, however, many other considerations involved. The best current course for the U.S. would seem to be to set a floor under petroleum prices and not to try to influence the cartel. This is the policy underlying (9) in the table.

Institutional Issues

As I look back over the main elements of what I see as the coherent and integrated policy program which I feel is urgently needed to come to grips successfully with our natural resources problems, I am inclined to be filled with a sense of hopelessness. The ability of the legislative and executive branches of our government to actually design and execute such a program seems entirely lacking. There is a scatteration of missions among numerous agencies many of which are inconsistent with one another. The committee structure of Congress is a straitjacket which inhibits the legislation writing committees from seeing anything in a large perspective. Nowhere in the government is there a policy planning function which could forsee problems and work on policy programs to deal with them.

Nevertheless the gravity of the problems we face calls for an effort to improve natural resources policy. It is possible that some institutional reforms within the Federal Government could be of help in this connection. The history of federal efforts in such areas as the environment do not lend much force to the view that reorganization solves problems. Still I think the matter of developing a coherent policy program for natural resources is sufficiently urgent that the time has come to try to build an administrative structure and an analytic capability which matches the dimensions of the job and hope that the Congress can find its way toward mechanisms for considering policy issues in an appropriately large context. A reformed committee structure with respect to natural resources and the new Congressional budget office appear to be the best hopes in this connection.

It is time also, I think, to create the much discussed Department of Natural Resources.

The largest function in terms of money and personnel of the Department of Natural Resources would, of course, be to execute whatever natural resources policy is in existence. But there are two other very important roles which such an agency should fulfill and I wish to comment briefly on them.

In the longer view, perhaps the most important function of a Department of Natural Resources would be policy planning in conjunction with an appropriately structured committee of Congress. The intent would be to try to define the interconnections among problems, to look at the natural resources situation in the large, to define policy options and to anticipate the implications of adopting one or another of them. This would be a difficult and delicate function and great care would have to be given to its design and protection. The latter requires particular comment because the history of efforts to sustain research-evaluation-planning enterprises within government agencies is bleak. Matters such as how this function would be treated in budget making, where it would be located both physically and in the departmental structure, and what its relationship would be to outside research institutions, are of great significance. What I have in mind is a group comparable in scope and capability to the Economic Research Service when that agency was at its peak. In general, analytical capabilities in the Federal Government in the areas of agriculture, monetary and fiscal policies and international trade are much superior to that in natural resources.

Another function of the Department should be to develop and sustain a systematic analytical program for anticipating future resource problems in a coherent framework of economic and demographic projections. The nation has never had such a program. Private efforts (Resources for the Future, for example) and government efforts (Strategic Environmental Assessment Systems, SEAS, in EPA for example) have been sporadic and partial. Moreover, the projections of particular missions oriented agencies are subject to question in terms of their disinterestedness. The development of SEAS was built on a firm methodological foundation, although it badly needs improvement and extensions, and it is capable of being expanded to address aspects of a broader range of natural resources problems than just environmental ones. SEAS should be expanded and moved out of EPA to the newly created Department of Natural Resources where it could serve as the core of a quantitative device for projecting future tendencies and doing policy analyses.

The Joint Economic Committee is one of the few instruments Congress has for taking large looks at complex questions and for achieving improved perspectives on them. I hope the Committee will be able to define for itself, and carry out, a leadership role in the critical area of natural resources policy where perspective and coherence are so badly needed.

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