Materials Aspects of World Energy Needs

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Materials Aspects of World Energy Needs

National Materials Advisory Board
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1980

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The report is a compilation of the presentations and comments of the individual participants in the International Materials Congress. The views and interpretations are those of the individuals concerned and are not necessarily those of either the supporting agencies and organizations or the National Research Council.

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ABSTRACT

The International Materials Congress: Materials Aspects of World Energy Needs assembled a group of materials and energy scientists and engineers, managers, economists, administrators, and educators to consider several broad aspects of the materials-energy interface.

Plenary session papers presented by participants from both developed and developing countries contributed to the information base on materials and energy outlook, international cooperation, economic aspects, and environmental considerations and established the theme for the subsequent workshop sessions.

Workshops on ten major aspects of materials-energy interrelationships provided the opportunity for open and informal discussion of critical issues in each area and the development of reasonable consensus on problems and potential solutions. Summaries of the workshop discussions and closing plenary papers were presented on the final day of the Congress.

At a meeting on the morning following the Congress the International Advisory Committee reviewed the accomplishments of the Congress and took action to prepare for a second International Materials Congress in 1981 or 1982.

These proceedings contain the plenary papers, the workshop reports, the issue summaries prepared as preprints, some selected papers used in the workshops, and a summary of the meeting of the International Advisory Committee.

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PREFACE

New and improved materials and innovative applications of present materials are essential to advances in many key areas of energy development and cost reduction. However, most materials technologies have been developed in a time of relatively inexpensive fuels and raw materials; therefore they are not necessarily appropriate for a world of high-cost energy and for many nations aspiring to rapid development and a higher standard of living.

To respond to the world's energy problems, materials science and technology must contribute to more efficient generation and use of energy and also must provide more energy-efficient ways to produce, process, and fabricate materials, all with minimum or no sacrifice of environmental quality.

The International Materials Congress: Materials Aspects of World Energy Needs was planned and conducted to address this important materials-energy interface in a forum with broad international representation that included nations at all stages of development.

The Congress was sponsored jointly by the U.S. National Academy of Sciences and National Academy of Engineering and was supported by several government and private agencies.

The four-day schedule of the Congress included opening and closing plenary sessions and two days of workshop sessions. The opening-day plenary papers provided background and set the theme for the meeting.

The ten full-day workshop sessions, five on each of the two days, were concerned with the materials-energy aspects of mining, processing, and recycling; buildings; fossil, geothermal, and solar energy; economics of production; education; manufacturing; renewable resources; transportation; nuclear energy; and institutional and organizational patterns. Reports of the workshops were presented on the final day, followed by open discussion and closing plenary papers.

On the morning after the Congress, the International Advisory Committee, consisting of members from 30 different countries, met to evaluate this Congress and to initiate action to provide for future international materials congresses.

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ACKNOWLEDGEMENTS

This Congress was planned, organized, and conducted by a Steering Committee under the chairmanship of Dr. John B. Wachtman, Jr., Director, Center for Materials Science, National Bureau of Standards, Washington, D.C., and by a Program Committee under the chairmanship of Dr. Richard S. Claassen, Director, Materials and Processes, Sandia Laboratories, Albuquerque, New Mexico. The chairmen and all of the members of the committees gave generously of their time from important professional positions to bring about this Congress. The high level of foreign participation in the formulation and conduct of the Congress was due in large measure to the cooperation and assistance of the International Advisory Committee headed by Dr. N. Bruce Hannay, Vice President, Research and Patents, Bell Laboratories, Murray Hill, New Jersey, and Foreign Secretary of the National Academy of Engineering. Dr. Nathan E. Promisel, consultant, Washington, D.C., was largely responsible for the organizing and guidance of the International Advisory Committee. The plenary speakers, session chairmen, workshop chairmen, rapporteurs, and issue presenters contributed immeasurably to the technical and socio-technical content of the program and to the smooth running of the Congress. Grateful acknowledgement is given to all of those men and women, with special thanks to the representatives of countries outside the United States.

Gratitude and acknowledgement is also given to the federal agencies and private organizations that provided the necessary financial support for the Congress: the Forestry Service of the Department of Agriculture; the National Bureau of Standards of the Department of Commerce; the Department of Energy; the Geological Survey and Bureau of Mines of the Department of the Interior; the National Science Foundation; the Ford Foundation, and the Electric Power Research Institute.

Also acknowledged is the effort of Dr. Robert V. Hemm, Executive Secretary of the National Materials Advisory Board, who handled the arrangements and the administrative management of the Congress, and the dedicated effort of the secretarial and clerical staff of the NMAB in the preparation and conduct of the Congress.

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PROGRAM

MARCH 26, MONDAY

PLENARY SESSION
Chairman: John B. Wachtman (U.S.)

OPENING REMARKS
Dr. Courtland D. Perkins, President, National Academy of Engineering (U.S.)

Perspective from a Developing Nation: Overview of the Materials-Energy Issue
Luiz C. Correa da Silva (Brazil)

Perspective from a Developed Nation: Overview of the Materials-Energy Issue
Lord Ritchie-Calder (U.K.)

Multinational and Bilateral Cooperation in Energy Research and Development Between CMEA Countries
George Koranyi (Hungary)

A View on Strategies for International Cooperation
Umberto Colombo (Italy)

PLENARY SESSION
Chairman: Richard S. Claassen (U.S.)

Environmental Constraint and Energy Conservation in the Japanese Iron and Steel Industry
Toshiharu Uchida (Japan)

Materials and Energy in the Economy: Comparisons and Interrelationships
S. Victor Radcliffe (U.S.)

Energy Sources Available in This Century
S.W. Gouse, Jr. (U.S.)

MARCH 27, TUESDAY

WORKSHOP SESSIONS

Workshop 1: Materials Science and Technology for More Energy-Efficient Mining, Processing, and Recycling

Chairman: Dieter Altenpohl (Switzerland)
Organizer: Carl Rampacek (U.S.)
Rapporteur: Ralph C. Kirby (U.S.)

Issues:

Mining of Hard Rock
Thomas Howard (U.S.)

Beneficiation
Gudmar Kihlstedt (Sweden)

Unconventional Resources
R.C. Kirby (U.S.)

Metal Production Processes
Gabriel Torres Villasenor (Mexico)

Recycling
A. Bonfiglioli (Argentina)

Workshop 2: Materials Science and Technology for More Energy-Efficient Buildings

Chairman: Larry W. Masters (U.S.)
Organizer: Elio Passaglia (U.S.)

Issues:

Building Envelopes
Don Hipchen (U.S.)

Workshop 2: *(continued)*

Building Systems
Gerald Groff (U.S.)

Integrated Utility
Rutger Roseen (Sweden)

Solar Heating and Cooling
Barry Butler (U.S.)

Workshop 3: Materials Science and Technology for New Energy Sources and More Efficient Energy Conservation--Fossil Fuels, Geothermal, and Solar

Chairman: Robert I. Jaffee (U.S.)
Organizer: Robert I. Jaffee (U.S.)

Issues:

Plant Performance and Reliability
L. Hagn (Fed. Rep. Germany)
Rapporteur: Robert Bates (U.S.)

Materials for Coal Conversion Plants
W.T. Bakker (U.S.)
Rapporteur: Jerry Sorell (U.S.)

Materials for Combined Cycle Power Plants
Bernard Ilschner (Fed. Rep. Germany)
Rapporteur: Chester T. Sims (U.S.)

Materials for Geothermal Fluid Handling
D.W. Shannon (U.S.)
Rapporteur: Phillip Lamori (U.S.)

Materials for Fluid Bed Combustion
John Stringer (U.S.)
Rapporteur: S.J. Dapkunas (U.S.)

Workshop 4: The Economics of Materials Use Under Conditions of Rising Energy Costs

Chairman: Dieter Kamphausen (Fed. Rep. Germany)
Organizer: Anne Carter (U.S.)

Issues:

Changing Importance of Materials and Materials Costs in the World Economy
Wassily Leontief (U.S.)

Materials Economics and Technological Adaptation
Baruch Raz (Israel)

Investment Requirements and the Changing Role of Materials in the International Economy
Shamsher Singh (India)

The Political Economy of Materials Policy
William Vogely (U.S.)

The Materials Markets, International Institutions, and Materials Policies
Robert N. Pryor (U.K.)

Workshop 5: Materials Education for the Interrelated Energy and Materials World
Chairman: Anthony Kelly (U.K.)
Organizer: Daniel Drucker (U.S.)
Rapporteur: Charles A. Wert (U.S.)

Issues:

Response of Materials Education to the Changing Materials and Energy Situation

Workshop 5: *(continued)*

Materials Education Provided by and Needed by Developing Countries

Continuing Education to Meet the Changing Energy and Materials Situation

Presenters:

Adeniyi A. Afonja (Nigeria)
Heraldo Biloni (Argentina)
David G. Brandon (Israel)
Ahmed E. El-Mehairy (Egypt)
Fritz Hinzner (Chile)
Gunnar M. Idorn (Denmark)
E. C. Subbarao (India)
Charles A. Wert (U.S.)
Robert L. Youngs (U.S.)

MARCH 28, WEDNESDAY

WORKSHOP SESSIONS

Workshop 6: Materials Science and Technology for More Energy-Efficient Manufacturing

Chairman: James Mattice (U.S.)
Organizer: Charles Berg (U.S.)
Rapporteur: Mario Cellarosi (U.S.)

Issues

Problems of Materials, Energy, and Logistics
T.R. Santelli (U.S.)

Future Manufacturing Processes
Jaedish C. Agarwal (U.S.)

Energy Implications in Aerospace Manufacturing
Richard Leonard (U.S.)

Energy Implications in Automobile Manufacturing
Neil DeKoker (U.S.)

Manufacturing Techniques and Materials for Heavy Construction
Thomas E. O'Hare (U.S.)

Future Directions for Metal Treating
Beresford N. Clarke (U.S.)

Laser Processing of Materials
Bernard Kear (U.S.)

Manufacturing with Polymers
Nam P. Suh (U.S.)

Workshop 7: Science and Technology for Energy-Efficient Materials from Renewable Resources
Chairman: Robert Youngs (U.S.)
Organizer: James Bethed (U.S.)
Rapporteur: Marco A. Flores-Rodas (Honduras)

Issues:

Energy from Biomass
Kyosti V. Sarkanen (U.S.)

Supply of Renewable Materials
Robert Stone (U.S.)

Resource Renewability
Bruce Zobel (U.S.)

Energy Conservation Through Improved Design
John Haygreen (U.S.)

Recycling Primary and Secondary
Rodney Edwards (U.S.)

Energy Conservation Through Conversion
Robert Jamison (U.S.)

Workshop 8: Materials Science and Technology for More Energy-Efficient Transportation

Chairman: I.C.G. Ogle (Canada)
Organizer: Morris A. Steinberg (U.S.)
Rapporteur: Salomon Wald (France)

Aircraft Structures and Propulsion
Leonard A. Harris (U.S.)

Automobile and Bus Design
Nils C. Tømmeraas (Norway)

Railroad Vehicles and Powerplants
William J. Harris (U.S.)

Ship Materials and Design
Kiyohide Terai (Japan)

Unconventional Systems
David L. Douglas (U.S.)

Road and Highway Construction and Maintenance
William B. Ledbetter (U.S.)

Workshop 9: Materials Science and Technology for New Energy Sources and More Efficient Energy Conversion --Nuclear

Chairman: J. Philippe Berge (France)
Organizer: Robert I. Jaffee (U.S.)

Issues:

Materials in Light Water Reactors
G. Ostberg (Sweden)
Rapporteur: R. Smith (U.S.)

Materials in Gas-Cooled Reactors
J. Barford (U.K.)
Rapporteur: Per K. Kofstad (Norway)

Materials in Breeder Reactors
Michael Weisz (France)
Rapporteur: J.E. Cunningham (U.S.)

Materials in Fusion Reactors
R.R. Hasiguti (Japan)

New Materials for the Nuclear Industry
S. Bush (U.S.)
Rapporteur: A. Bement (U.S.)

Workshop 10: Institutional and Organizational Patterns and Strategies for Interrelation of Materials and Energy Research and Development, Technology, Production, Coordination, and Planning

Chairman: Rune Lagneborg (Sweden)
Organizer: Franklin P. Huddle (U.S.)
Rapporteur: Harold Bullis (U.S.)
Michael Matheson (Sweden)

Issues:

Beneficial Institutional Functions

Linkage of Materials Issues with Those of Energy and Environment

Scope of Possible International Institution for Materials

Possible Aegis for an International Materials Institution

Functions of an International Materials Institution

Presenters:

Adeniyi A. Afonja (Nigeria)
Edward L. Brady (U.S.)
Luiz Correa da Silva (Brazil)
Gyorgy Dobos (Hungary)
George Koranyi (Hungary)
Eliane Morin (France)
Albert Paladino (U.S.)
Harry Tollerton (U.S.)

MARCH 29, THURSDAY

PLENARY SESSION
Chairman: Robert H. Bragg (U.S.)

WORKSHOP REPORTS AND DISCUSSION

PLENARY SESSION
Chairman: Gunnar Hambraeus (Sweden)

WORKSHOP REPORTS AND DISCUSSION

Lessons from the Congress: Conceptual and Technical
Morris Cohen (U.S.)

Lessons from the Congress: Emphasis on Societal Issues
Hans L. Landsberg (U.S.)

Future International Activities in the Materials Field
N. Bruce Hannay (U.S.)

MARCH 30, FRIDAY (Post Congress)

Meeting of the International Advisory Committee

Chairman: N. Bruce Hannay (U.S.)

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CONTENTS

SUMMARY

Franklin Pierce Huddle

A lengthy prehistory anticipated the formulation of the meeting of a significant part of the world materials community, March 26-29, 1979, on the outskirts of Washington, D.C. For some five years recognition had been growing of the vital shared interests of the world's nations in the evolution of a rational global policy for materials.

By the time the conference was convened, it was readily apparent that a considerable consensus existed. Much of the time of the conference was expended in an effort to define and measure the boundaries of that consensus. The primary element of consensus is indicated by the title of the conference: International Materials Congress. Its aim was to identify common interests, and to exchange views on these interests, in the field of materials. A subset of this scope was that energy aspects of materials and materials aspects of energy be addressed. Among the further points of evident agreement were the following:

(1) An organization of the world materials community is a desired goal, but it should be functional and flexible rather than institutional and rigid.

(2) With materials as focus, the relationship of energy and environment to materials is very important.

(3) The management of materials information and the training of materials technologists are of global concern and invite international cooperation.

(4) Irrespective of the question of depletion of exhaustible resources in the global lithosphere, there is undeniably a waning of the richest deposits of materials and of the most accessible resources of energy. Scientific research and development could extend and enhance the usefulness of less rich minerals, find uses for renewable organic resources, design engineering structures for more frugal usage of materials, and facilitate more efficient recycling of materials.

(5) Similar effects could be achieved with respect to the generation, use, and conservation of energy: research and development are revealing more efficient means of discovering resources, employing unconventional generation technologies, reducing losses of energy and heat, and more efficiently storing and transporting energy.

(6) Through international cooperation, education and professional development of materials scientists and engineers should be promoted in individual nations to address more capably both national and international problems to which materials science and engineering could provide assistance.

(7) Opportunities are evident for the wider sharing of technological skills in the management of materials and energy, particularly in the face of the growing need to attend to environmental considerations--the preservation of the quality of global space.

In his welcoming address to the Congress, Courtland Perkins, President of the National Academy of Engineering, expressed his hope that the meeting would be truly international and explained that increasing the number of participating countries might have delayed the Congress by a year. He hoped, however, that international participation would be even greater in the future.

In the opening day's plenary sessions there were seven substantive papers. The first speaker, Luiz C. Correa da Silva, from Brazil, attributed contemporary concern for energy unbalances to a broad global failure in resource management. He called for better planning and management, more imagination, and more vigorous international cooperation, organization, and activities. An area of particular promise, he suggested, was renewable resources--and within that area of interest, genetic manipulation of species to increase the range and rate of useful yields.

Second on the program was Lord Ritchie-Calder from the United Kingdom, who reviewed the history of materials with particular attention to the lost opportunities of the past quarter-century. A major cause of such lost opportunities, he suggested, was their assessment as unjustified in terms of short-range economic cost-effectiveness. However, in the future, elements other than monetary cost might well predominate. Alluding to Dean Swift's parody of Francis Bacon's New Atlantis, he proposed a new energy currency, reminiscent of Howard Scott's "technocracy" movement of the early 1930s, based in its turn on the intellectual ratiocinations of Thorstein Veblen. The implication was that the economics of the postwar period, in the new currency, would turn out to be dys-economic.

George Koranyi of Hungary, the third speaker, proposed a concept of international organization in the field of global materials and energy policy based on the concept of regional "expert groups," to address special problems of regional concern. These groups would be located in a regional center, drawing upon one or two members of associated states. In this way it would be possible for small and large states to work together with problems appropriately assigned within each. The obstacles to greater East-West cooperation in such a scheme, he suggested, could be readily overcome.

Umberto Colombo, from Italy, speaking fourth, called for "technological pluralism." The threefold factors of materials, energy, and environment are central to the management of global resources. Trade-offs between conventional and novel sources of materials and energy, and generally between established practice and new approaches, should be sought. Such a pluralistic approach, he said, would take much effort and needs firm international cooperation but would be rewarding in terms of both freedom of action and technological competence.

The three afternoon plenary speakers were Toshiharu Uchida of Japan and S. Victor Radcliffe and S.W. Gouse, Jr., of the United States. Uchida, who reported impressive achievements in both energy conservation and environmental restoration in his country's steel industry, spoke of the need for global standards of behavior and achievement in these endeavors and the general sharing of knowledge required for the skills on which such performance was based.

Radcliffe addressed the global need for improved quality, quantity, detail, and time-trends of global data concerning materials and energy supplies and demands.

Gouse presented an optimistic view of the remaining resources of materials and energy in the lithosphere. However, he warned, despite this apparent abundance, "the time constant gets in the way." In other words, there is a great potential in global resources, but their exploitation might take too long and cost too much to prevent shortages.

In the colloquy that followed, Wassily Leontief explained that adaptation to changed energy circumstances would be most difficult, involving great unemployment, capital investment (presumably at marginal levels of return), and many challenges to equity. Such adjustment, he noted, involved both physical and social change and was always easier in an expanding (developing) economy than in a stable (developed) economy.

The next two days were occupied with workshop discussions. In the workshops, issues were introduced in summary form and were discussed in detail. The results were reported in the plenary sessions on Thursday, March 29. The reporting sequence was chosen to juxtapose related topics.

Workshop 1 addressed energy aspects of mineral mining, processing, and recycling. From its report, six points emerged: comminution (ore grinding) is wastefully inefficient in energy use but no remedy appears available; some novel sources of minerals--e.g., manganese nodules and Red Sea sludges--are about to be tapped; exploitation of nonbauxitic alumina continues controversial; the undeniable energy advantages of recycling energy-intensive metals needs attention; reduction in needless variety of engineering alloys would facilitate recycling; and systematic recording of energy requirements in metals production and fabrication could point the way to greater efficiencies.

Workshop 2 addressed materials science and technology for more energy-efficient buildings. It is clear that for selection of building materials, energy flow and energy capital costs are now to be added to other criteria such as strength, durability, availability, utility, design, appearance, and cost. Moreover, there is also opportunity for economy in existing structures: one-quarter to one-third of energy losses could be prevented by fitting old buildings with thermal insulation, reducing air leakage, and other measures. The group arrived at four proposed courses of action: research into future needs for performance of construction materials; reform of building codes; international collection of data on these subjects; and education of designers, builders, and the public on construction materials and their performance considerations.

Both workshops 3 and 9 dealt with materials science and technology for new energy sources and conversion--nonnuclear and nuclear respectively.

With respect to the nonnuclear area, the workshop addressed mainly technical problems associated with fossil-fueled stream and gas turbine generators, fluidized bed combustion, and geothermal energy utilization. It was noted that large units posed special problems of unreliability and that design faults are a foremost (two-thirds) source of failure.

With respect to the nuclear domain, fusion was dismissed as not yet susceptible to technical problem definition. Throughout the discussion of other applications (gas-cooled and light-water fission reactors and fast breeder reactors), the need for closer international cooperation was frequently cited. Materials technology offers opportunities for improved efficiency (higher temperature operation) in gas-cooled reactors; it contributes to safety and economics of light-water reactors. Safety and reliability are the main criteria of concern, and international cooperation is needed in such areas as cooperative planning, research, information management, and such technical areas as corrosion, fuel behavior, materials degradation, repair welding, and inspection.

Workshop 4, on economics of materials production and use, addressed the problem of future supply and demand in materials. To some extent the question of rising costs of energy entered discussion of this issue, however, the main point seemed to be that supply is determined by long-time-frame considerations while prices are responsive to short-time-frame considerations of the supply and demand relationship, material by material and even country by country. Both materials and purchasing power are unevenly distributed. Accordingly there is a need for international institutions in materials resources to gather and analyze information and to formulate options for national and international policy makers. Among specifics, the group suggested expanded technical options through research, improved exploration, better information management, and more efficient markets.

Workshop 6 addressed materials science and technology for more energy-efficient manufacturing. The participants reviewed the many options for energy economics in the plant and concluded that there is an embarassment of opportunities; there are literally countless measures available. Historically, the goal of manufacturing has been to produce an item for sale at least cost. In the face of the new realities of energy and materials supply, new approaches are needed. It is time to take a "truly disciplined approach," in other words, a systematic approach, to maximize the total performance of the entire manufacturing process with materials and energy properly taken into account.

Workshop 7 addressed science and technology for energy-efficient materials from renewable resources. Various renewable materials were discussed, but the concentration was on wood. Two items were central to the findings of this workshop: inventory and combustion technology. Under the first item the group stressed remote sensing technology, periodic updating of information, standardization of inventory methods, international cooperation in inventory designs, and acceptance of the "whole tree" inventory concept. Under the second item, they urged total tree use, improved combustion technology, and attention to the environmental effects of wood combustion. Wood as a structural material also received attention, as the participants called for research to improve its service life. The technology of wood harvesting and transportation also requires improvement.

Workshop 8 examined materials science and technology for more energy-efficient transportation. The scope of this workshop was impressive: materials and energy interactions relevant to all present and prospective transportation modes and general problems of transportation. It included construction and operation of vehicles and systems, the highly visible public-private interface, and the profound effects of rising costs of energy on the future mix of transport systems. In each transportation mode there was a clear interaction between energy efficiency and use of materials, particularly in weight saving to reduce fuel consumption. The concept of total energy balance of the system should be examined. During the discussion the needs for international cooperation and government wupport for new materials characterization were cited.

Workshop 5 (Education) and Workshop 10 (Institutional Patterns) were considered in sequence at the close of the workshop presentations. Workshop 5 addressed materials education for the interrelated energy and materials world. The objective of education in the present context was defined as the production of skilled problem-solving technologists. The panel suggested that more emphasis is needed on the materials-energy interface in engineering curricula and that research programs and graduate school curricula would offer preferred points of entry for these matters. The panel then called for interaction among educational institutions transnationally because the social impact of changing conditions of energy supply is a matter of global concern.

Workshop 10 was essentially commissioned to consider what steps ought to be taken following the close of the four-day Congress. To this end, it recommended that a small, internationally representative working group be formed to formulate an "evolutionary and progressive plan for a nongovernmental materials organization of international scope and membership", plan and organize a further international conference, and drawing upon developed, newly industralized, and developing country representatives, assign and plan papers for that conference bearing on the scope, objectives, functions, structures, mode of operations, funding, and support of the proposed organization so that definitive action may be taken at that meeting toward establishment of an appropriate organization.

In developing this recommendation, the group considered in sequence the questions of need for an organization, its objectives, some possible models, functions, and dimensions. None of these were completely resolved, although there was good input and clarification of issues and there was apparent consensus among the 64 participants from 19 countries who joined in the discussions. Among the points of guidance agreed upon were that any new organization start in a modest way, select feasible tasks, motivate existing organizations, maintain a technical rather than a political orientation, maintain a long-range perspective, operate informally, and rely heavily on face-to-face contact.

Three speakers closed the final plenary session of the Congress. The first of these, Morris Cohen, of MIT, identified knowledge as the one resource not limited in scope, content, or opportunity for growth. Even though materials supply constitutes a potential limiting factor, shared knowledge developed at the present Congress has shown many ways to alleviate future materials constraints. And he predicted that future materials congresses would continue to address the subject of education in materials science and technology.

Hans L. Landsberg, from Resources for the Future, the second closing speaker, praised the concept of the Congress in bringing together engineers, scientists, and economists. What is technically feasible is not always economically affordable; economic incentives are necessary. But these, in turn, must be politically acceptable both in themselves and in their expected results. Criteria of acceptability include such matters as environmental preservation, regional balance, balance among producers and consumers, amicable international relations, the national security, and balance between the present and the future. An institution for global planning in the materials area would be concerned with all of these.

The closing speaker, N. Bruce Hannay, Foreign Secretary of the U.S. National Academy of Engineering and Vice President of Bell Telephone Laboratories, concluded the proceedings with the questions:

Should there be a second conference?
How should it be instituted?
What should be its theme?
What about the format?
Who will fund the arrangements?
Who will convene it?

It would be a significant accomplishment if the International Advisory Committee appointed for this Congress could come to grips with these questions and in a modest way provide for continuity and communication to keep alive and expand the international relationships the Congress has achieved.

The speaker acknowledged that international representation has been signally incomplete--even though it has been fairly extensive. One problem is that there has been no truly international organization available and appropriate to convene such a conference. The organizers had to make do with what was at hand and they were reasonably successful as a first endeavor. But, he concluded: "I myself feel that this provides ample reason for us to attempt the next step to use this conference as a starting point on which to build a mechanism and a plan for continuing international communication in materials-related subjects along the lines that we have begun here."

At the post-Congress meeting of the International Advisory Committee the committee took positive action to prepare for the next International Materials Congress in 1981 or 1982.

PERSPECTIVE FROM A DEVELOPING NATION:
OVERVIEW OF THE MATERIALS-ENERGY ISSUE

Luiz C. Correa da Silva

Some of the following may appear to overlap with views which might be expressed looking at the problem from the vantage point of developed countries. This is because:

- Developing countries do have some "developed problems."
- The topic refers to the perspective as seen <u>from</u> a developing country. That includes, of course, parts of the broad panorama.
- Developing countries are quite concerned with strategies for handling medium- and long-term problems and opportunities. Differently from developed countries, they still have to build practically all of their "machine à vivre," to borrow from Le Corbusier. Ours can only be the future, since at present we have about 3 billion people producing only some 10 percent of the world's industrial output. That means roughly one thirtieth of the output of developed countries on a per capita basis.

THE PROBLEM

The theme of this Congress is the study of the energy-materials interface, as it appears to us at the temperature of 1979 degrees A.D.

Crucial to such study is the understanding of the ternary system Ma-Sc-Tc (masurium, scandium, technetium) as modified by the introduction of En, S, P, and F (einsteinium, sulfur, phosphorus, and fluorine).[1]

Figure 1 shows a simplified sketch of the ternary Ma-Sc-Tc, a very complex system with thousands of characteristic intermetallic phases and compounds of great importance to humankind. Yet, it is still largely unknown and certainly contains thousands of other interesting phases to be discovered.

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[1]Heuristic *ad hoc* designations. In reality: materials, science, technology, energy; plus societal, political, and financial constraints.

Please note the important area of solid solutions called steels, which have been the backbone of our civilization. Another, and perhaps the most extraordinary intermediate compound discovered until now, is the semiconductor phase, of which the ordered state known generally as MOS-LSI structure is revolutionizing our lives.

Until recently the ternary system Ma-Sc-Tc could be studied almost in isolation. The materials scientist or engineer could develop, produce, and apply its intermediate compounds without or with only minor consideration of the all-pervading presence of the components En-S-P-F (energy; and societal, political, and financial factors). They could generally treat the whole complex thing as a "quasi-ternary," except for more or less routine costing and pricing.

Not anymore. The continuous sophistication of the production-consumption system imposes increasing constraints and ever narrower specifications relating to En, S, P, and F.

It is, then, this almost hopelessly complex quaternary system Ma-Sc-Tc-En, modified by S, P, and F (Figure 2), that constitutes the "space" whose exploration we must discuss. I would like to suggest that we should not refrain from a bit of "wildcatting."

THE SETTING

Before examinating general or specific action we must consider the setting (the panorama, the perspective) in which our exploration of the seven-dimensional system Ma, Sc, Tc, En, S, P, F has to take place. Let us consider some of the relevant aspects relating to the new pattern of supply and demand, and availability and cost of energy and materials, since a number of changes took place or became clearer in that pattern during the decade just ending.

Limitations or Exhaustion of Natural Resources

After about a century of intensive use of natural nonrenewable resources by developed countries the problems relating to exhaustion, limitations in volume or quality, increasing costs of exploration, unbalanced geographic distribution, access or availability, etc., began to seriously hinder economic growth in those countries and economic development in developing countries. As an example, it can be very roughly estimated that 1 billion people in developed countries have used a cumulated 30-50 Gt of iron so far, against only 0.5-1 Gt used by the 3 billion people in developing countries--a ratio of some 100 times per capita! Not that iron ore is, in particular, in tight supply but it is true that some of the best placed or best quality deposits have neared exhaustion. The discovery of an exceptional deposit like the one at Carajás (Amazon Valley, Brazil) is a rare occurrence.

The situation is quite serious with hydrocarbons, even though it is not as bleak as it is painted by those looking only at the problem of overall global reserves. However, the energy situation is a very serious one for reasons quite independent from petroleum availability and price in the international market. If petroleum suddenly became abundant we would still be faced with problems relating to ability of some countries to pay for imports, environmental considerations, accelerated exhaustion of other raw materials, etc.

Ecological Disruption and Urban Deterioration

New demands and new constraints of various types are arising from an increasing preoccupation with the quality of life both in developed and in developing countries. The consumer who used to be essentially a Pavlovian creature is becoming increasingly aware of "quality" in all respects--manufactures, services (including government), environment, and "life." New and better intermediate phases in the Ma-Sc-Tc-En system will have to be identified, produced, and applied.

The "Phase Transformation" of Developing Countries

In developing countries, in the decade just ending, a number of changes took place that will have a decisive impact on materials availability, cost, and technology. In the 1970s developing countries as a group moved clearly from a position that could be described as ideological and dogmatic to one described as pragmatic and developmental. By and large, they became essentially aware of their true problems and opportunities. One could say that, as a community, a "conglomerate," they acquired 51 percent control of their own stock. I feel that, when the dust settles, this will come to be recognized as the most important political and economic event of the decade.

Evidence of their awareness and pragmatism can be found in various events and occasions, for instance, the U.N. Industrial and Development Organization's Second Conference on Industrialization (Lima, 1974), during which they set for themselves the target of 25 percent of world industrial output in the year 2000. They have since decisively increased their efforts towards this goal and are increasingly proficient in the analysis and decisions regarding options for economic, industrial, technological, and scientific development. Recognizedly, developing countries form a heterogenous group, a pluralistic community, a fact which may be an advantage, since it reflects ab initio a situation which seems increasingly desirable in developed countries.

We may say, I think, that in the 1970s the Group of 77[2] attained adulthood. They successfully defied developed countries in the political, economic, and even the military plane.

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[2]The Group of 77 represents the position of Third World countries at the United Nations; it has grown to include about 120 countries.

As a consequence, developing countries will increasingly require raw materials, energy, equipment, and manufactures of all types. These will have to be mainly locally produced, of course, according to local resources, capabilities, and conditions.

The Energy Crisis

The OPEC decision of 1973 was an instance of the newly found autonomy of decision in the economic and political areas. Dispassionate and fair analysis will show that the decision had an overall positive effect, in spite of the initial concussion and the waves and ripples that followed.

An energy-materials emergency was in incubation long before 1973. OPEC did nothing but force or accelerate international recognition of a serious problem. OPEC forced us to recognize that the first and second principles of thermodynamics are "fallacies," since energy is not conserved; and since certain systems evolve spontaneously towards more unstable energy situations!

The "oil shock" of 1973 brought with it a worldwide awareness of the imperative to deal with the whole system Ma-Sc-Tc-En as modified by S, P, and F. OPEC's decisons has originated a period of readjustment of the world production-consumption pattern which will last for a generation and which will have the following effects:

- A new technological leap forward without precedent in peace time.

- A better distribution of world income between developed and developing countries, through the petrodollar flow and through a new spectrum of comparative advantages, more favorable to developing countries in general.

- Greater preoccupation with efficiency and economy in the use of natural resources, especially the nonrenewable type.

- Greater preoccupation with economic planning, with particular attention to international cooperation.

- General awareness of the need to safeguard the national autonomy of decision in the economic and political areas through appropriate materials and energy management.

There has been much distortion in the treatment of the energy problem. In many cases developed and developing countries have used petroleum and OPEC as scapegoats for troubles of other origin.

Figure 3 shows the actual evolution of prices of imported petroleum, CIF Brazilian ports. The data are expressed in constant U.S. dollars of

1977 (US_{77}). The price of oil (CIF) suffered a threefold increase in 1973-1974 but became significantly cheaper in 1978, in real terms.

Figure 4 shows the evolution of the specific price (US_{77}/t) of general imports (all imports excluding oil) for Brazil, in constant 1977 dollars. It can be seen that the specific price of our import "basket" has been increasing exponentially since 1968. The Figure also shows the specific prices for general exports, i.e., all exports excluding coffee and iron ore (two traditional, "old colonial-type outflows," which together came close to paying for oil in 1976-1977; not anymore, however!). Please note the conspicuous gap between the two prices, due to the great difference in "technological content" per ton. Also note that after 1974 the average specific price fell.

Figure 5 shows in more detail the behavior of specific import prices (oil excluded) in the period 1973-1975. It indicates that prices of Brazilian imports (oil excluded) were increasing at the rate of 12 percent per year since 1969 (in real terms) and would have reached 470 US_{77}/t in 1974. Comparing this figure with the 1968 figure of 273 US_{77}/t and the actual price of 563 US_{77}/t paid in 1974, one can assign to OPEC an additional price increase of only 20 percent over the 1974 projected price.

I have no request or mandate to defend OPEC; in fact, Brazil has been strongly and adversely affected by the oil price increase of 1973. However, this should not deter us from looking at the problem realistically, so as to plan effective action to solve it and, perhaps, to transform it into an opportunity.

Instability of the International Monetary, Finance and Trade System

For about three decades after the Second World War there were two very strong currencies: the dollar and gold. It is by now clear that the international monetary, financial, and trade structure has reached a crisis that will only be effectively dealt with after general and full recognition that two new strong "currencies" have taken the place of the dollar/gold binomium, namely, energy and technology. The consequent and imperative restructuring in depth will unavoidably lead to a new economic order based on the energy-dollar or petrodollar (\$) and on the techno-dollar (₮).

Pluralism and Complexity

Most of us here would probably prefer to stick to the "nuts and bolts" of science and technology for the industrial development, production, and application of materials. Most of us would prefer to keep our attention strictly focused in the quaternary Ma-Sc-Tc-En, without allowing such impurities as S, P, and F to disturb the beauty of our work, in the peace of our ivory towers!

Yet, even within the basic ternary system, complexity has long been a fact of life. As early as 1962, Dr. Cyril Stanley Smith was pointing this out. In that year the Comision Nacional de Energia Atomica of Argentina or, more precisely, that extraordinary group of metallurgists which we could, in friendship, designate as "Sabato and his boys," organized the Coloquio de Bariloche to discuss the impact of science on technology. A lively discussion took place during which Dr. Cyril Smith made keen epistemological observations regarding the increasing complexity and interdisciplinary character of the problems that materials scientists had to deal with. There was consensus, and somebody suggested, as an example, that the typical expert on plastic deformation ought to have "one foot on a rolling mill and another on a dislocation." Complexity is indeed a feature, and the need for a pluralistic approach is imperative in this space-time-energy-information universe of ours. It is time to complete Clausius' famous double statement of about a century ago:

> Die Energie de Welt ist eine Konstante.
> Die Entropie der Welt strebt einem Maximum zu.

I feel that we may now state with confidence:

> Die Komplexitat der Welt nihmt stets zu.

Complexity here is not meant only in the dictionary sense but also in the mathematical sense, along the lines proposed by Chaitin and others (e.g., Chaitin, 1975) and relating to algorithms.

THE ISSUES, THE ACTION

Coping with the energy-materials emergency means moving away from the Ma-En side toward the Sc-Tc side of the basic quaternary system previously mentioned; always taking into account the effect of the "impurities" S, P, F.

One could say, then, that the issue is the decrease of energy and materials "cost, content, and claim" of processes, products, and services. To achieve this there is a variety of options which I group, somewhat arbitrarily, into three broad avenues of action:

<u>The tautological or conventional way</u>. This includes use of the following verbs: save (not "conserve" please!),[3] abstain, prevent, increase efficiency, substitute, expand supply, diversity sources, recycle, optimize systems, miniaturize, disperse, stimulate, coerce, persuade, tax, etc. All of these can be broadly described as better management of materials and energy flows.

[3]All energy is "conserved," even when wasted (first principle of thermodynamics).

The imaginative or LSI way. The intensive development and application of "genetically encoded microstructures" of the LSI type have in the 1970s and will continue in the 1980s to revolutionize information processing and systems control to an extent that will multiply our capability for creation of new materials, structures, systems, processes, and services. And I would include, of course, the creation of LSI-type materials for structural purposes.

The revolutionary or renewable way. Renewables will be the solution or, at least, an essential part of the solution of the energy-materials problem of developing countries. The full development of renewable options (for energy and materials) would decrease the pressure to move away from the Ma-En side of the quaternary and, in certain cases even allow us to reverse the direction of our efforts and to move again toward greater use of materials and energy.

Let us remember that the most advanced computers on earth are renewables. The HOMO-Mark VII, of the Sapiens type, has been employed in the most advanced scientific, industrial, artistic, and military work. The competing brand, the FEMINA-Mark VII, also having the Sapiens type of neuronic LSI circuitry, is even more remarkable and is being increasingly employed after it broke the near monopoly kept by HOMO Inc.

Table 1 shows the energy input economically processed or incorporated in Brazil in 1974. It is a rough estimate ($\pm$ 10 percent) but it shows that Brazil is a photon-dependent country for the hydrologic cycle and for the photosynthesis of saleable products, or of inputs that go into saleable products. No Amazon forest growth and similar photon-absorbing processes outside the economic cycle are included in the table.

Under the impact of the "oil shock," and faced with mounting expenditures for imported oil (some 4.1 $G.US_{78}$ FOB, in 1978),[4] Brazil has stepped up the development of alternative energy sources. Itaipu, the largest hydroelectric plant in the world, is now being built jointly with Paraguay, with a capacity of 12 M.kW, but we have a further 20 M.kW plant under construction elsewhere. The nuclear program aiming at the exploitation of some 120,000 tons of uranium reserves is also under way in spite of strong opposition from certain quarters outside the country. The great hope, and unavoidable solution for the hydrocarbon problem will be photosynthesis. The 1978-1979 sugar cane crop, now being processed, should produce some 2 M.t of ethanol for automotive purposes. The plan is to produce at least 10 M.t by 1985 and over 20 M.t by 1990. But that is only scratching the surface of photosynthesis. Determined visionaries like me will argue for a total photosynthesis contribution by 2000, of some 100 M.TEP (100 million tons of petroleum equivalent) by photosynthesis. That would also include charcoal, fuel oils, methanol, etc. Table 2 is one possible scenario illustrative of the type of energy supply pattern which might result.

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[4] 1 $G.US_{78}$ = 1 billion 1978 dollars.

Photosynthesis and genesynthesis will be the great challenges of the next 20 years and, together, they could help solve (or salve) the energy problem of developing countries while, at the same time, increasing extraordinarily the volume and variety of renewable inputs for the production of materials and structures. Apart from more or less obvious possibilities such as the production of fuels, feed-stock for polymers, greatly improved cellulosic materials, etc., we can conceive of the day when we can freely design genes to produce biogenetically encoded microstructures with specifically desired characteristics.

Figure 6 diagrams one example of the marvelously complex single crystals obtainable by genetic encoding (skeletal spicules of $CaCO_3$ in the larva of the sea urchin). This is, I think, food for thought. We already produce genetically encoded, extremely sophisticated microstructures of the MOS-LSI kind, by the use of algorithms and computers. Why not use DNA?

Twenty years after Fermi and coworkers achieved the first nuclear chain reaction (December 2, 1942), nuclear energy was industrial. Twenty years after Shockley, Bardeen, and Brattain developed the transistor (1947), microelectronics was fully industrial. It is almost a certainty that recombinant DNA will make genesynthesis fully "industrial" (I should say "agricultural") within 20 years. The resulting genetic revolution will have an even greater impact than the nuclear or the electronic revolutions.

Developed countries have, in the last 100 years, constructed a civilization based on nonrenewables. It is a thought, a hope, that in the next 20 years developing countries might lead the way toward a civilization based on renewables.

THE METHODOLOGY

Faced with the need to take action "against a sea of troubles," as the Bard might put it if we showed him the seven-dimensional phase diagram Ma-En-Sc-Tc-S-P-F, it seems necessary to consider methodology. Apart from other possibilities the following "tools" seem essential.

Increased Use of Science and Technology

In the seven-element system of interest the inputs of Sc and Tc are "renewables" and their use can be increased much beyond present levels. They afford the most effective way of dealing with the limitations or constraints connected with the other components of the system--Ma, En, S, P, F. Technology, in particular, being the transducer between science and industry,[5] is a basic intangible input which developing countries

[5] The word is here used <u>lato sensu</u> to include agriculture, services, etc.

must produce and use intensively. In this context I would like to mention what I call the four Carel Sadiarov's heuristic equations:

$$S_{P,M} = f\ (V, P, Q, D)$$

$$V, P, Q, D = \Phi_i\ (T)$$

$$T = \psi\ (H)$$

$$H = \zeta\ (E)$$

They read as follows, from the producer's point of view:

- The success of product P in market M is a function of volume, productivity, quality, and distribution (a buyer will read P as price and D as delivery).
- The four variables V, P, Q, D are themselves functions of technology T.[6]
- Technology is essentially a function of the human factor H.
- The human factor H is essentially a function of education E.

Development of Quantitative Methods to Evaluate Energy/Technology Input/Output of Processes, Products, and Services

As of today we, materials scientists or technologists, have a good capability to handle the substantive aspects of materials development, production, and application. It seems, however, that we are weak in the analytical and conceptual bases necessary to deal effectively in a quantitative manner with the planning of materials development and production in a broad context, i.e., with due consideration of the Ma-En-Sc-Tc-S-P-F system, as a whole.

We have today ample machinery to deal quantitatively with the problem of economic value or with the problem of physical quantities; we are used to dealing with certain quantitative aspects of energy use in microsystems such as industrial plants and equipment. Consider, however, the following question: what is the total energy cost (in kcal of kWh) of a car, starting with raw materials *in situ* and primary energy? What is its energy "content" (supposing we oxidize it completely in a calorimeter)? What is its energy "claim" during its lifetime? What would be its energy "credit," as scrapped? It is not that these questions are difficult ones; they are just unfamiliar.

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[6] Technology is here understood in the broad sense, including planning, industrial design, marketing, management, etc.

In the case of technology the problem is much more difficult because, in the end, the matter boils down to the evaluation of quality and volume of neuronic computers' input and output. What was the value of the transistor as "just born" in 1947?

It would be interesting to discuss, in the course of the workshops planned, what is the real need, stage of development, and improvement required in the methodology to handle quantitatively energy and technology "cost, content, claim, and credit" of processes, products, and services. This is essential to increase the effectiveness of our efforts in the exploration and exploitation of the seven-dimensional space Ma, En, Sc, Tc, S, P, F.

Maybe we need an "energomics" (based on kWh) and a "technomics" (based on brain-hours).

It would seem that there is room and need for new or intensified educational, professional, and institutional activities. These would tackle systematically areas such as: full exploration of the quaternary Ma-En-Sc-Tc system, in the presence of S, P, and F constraints; broad evaluation and development of the potential of photosynthesis and genesynthesis for materials-energy purposes; and development and application of the conceptual basis and detailed methodology for quantitative treatment of energy-technology input-output.

New lines would have to be opened in universities (new disciplines), in professional societies (new types of meetings), and in institutions (new projects, programs and, perhaps, new specialized institutions).

International Cooperation for Joint Study of the Quaternary MA-En-Sc-Tc

It is by now clear that modern economies are almost completely dependent on the exploration and exploitation of the materials-energy-science and technology "space." Heads of state meet, great military forces are deployed, currencies loose or gain value, trade is distorted, etc., according to variations in the international pattern of Ma, En, Tc, and Sc capabilities.

International cooperation is imperative, more than at any time before, at government, enterprise, academic, and professional levels. It would be highly desirable to have some guidelines and action originating in this Congress and contributing toward increased international cooperation, since problems in the basic quaternary system of interest to us have by now become "world size."

In the quest for new solutions and in the exploitation of new opportunities, can developing countries contribute significantly? Can they be effective partners? At the end of the 1970s all indications are that they can, they must, and they will. Besides, they are in a hurry.

They must, as the French say, bruler les etapes. The long forgotten law of ontogenetic recapitulation, proposed by Haeckel will not apply to countries, either.

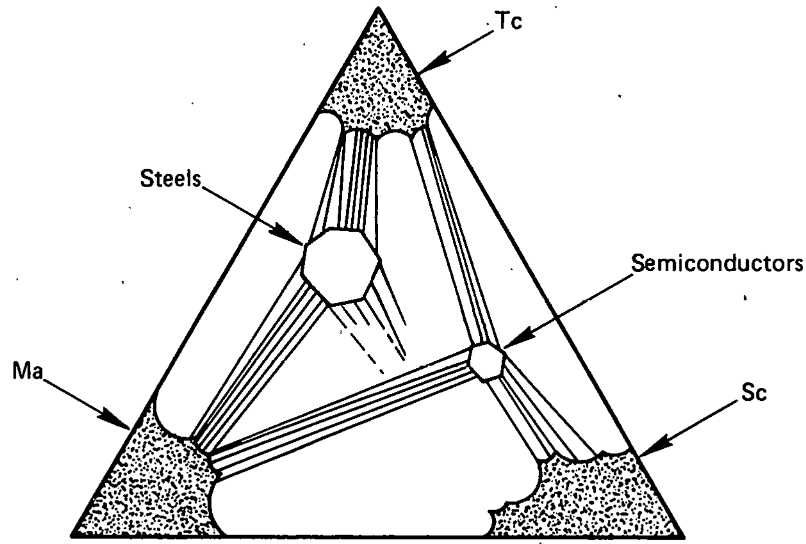
It should be appreciated that for developed countries the energy-materials problem is essentially one of maintenance; for developing countries it is essentially a problem of investment and secondarily one of maintenance. Practically all of the needed infrastructure--housing, industry, etc.--are still to be built.

Can developed countries help developing countries in the exploration of the Ma-Sc-Tc-En system? Of course, and very much. In my own experience, I was fortunate enough to attend Robert F. Mehl's lectures in early 1944, in São Paulo, which changed decisively the whole pattern of Brazilian metallurgical development. He was followed by other distinguished metallurgists from the United States, France, the United Kingdom, and elsewhere.

Another striking example are the activities of the Department of metallurgy of the Comision Nacional de Energia Atomica of Argentina. Through its intensive program of international cooperation the pattern of metallurgical development in Latin America has been decisively and positively changed. Many verterans of this effort are present here today.

Those are additional reasons why this Congress and its results are of particular interest to developing countries. The initiative of the National Academy of Sciences and the National Academy of Engineering is timely and appropriate. I feel that the participants from developing countries would join me in expressing thanks for the Congress and for the invitation to share in the work planned.

Figure 1. THE Ma-Sc-Tc TERNARY SYSTEM (MATERIALS, SCIENCE, AND TECHNOLOGY)*



*This is a fictitious diagram. It should not be examined for thermodynamic accuracy.

Figure 2. THE Ma-Sc-Tc-En QUATERNARY SYSTEM (MATERIALS, SCIENCE, TECHNOLOGY, ENERGY, PLUS SOCIETAL, POLITICAL, AND FINANCIAL CONSTRAINTS)

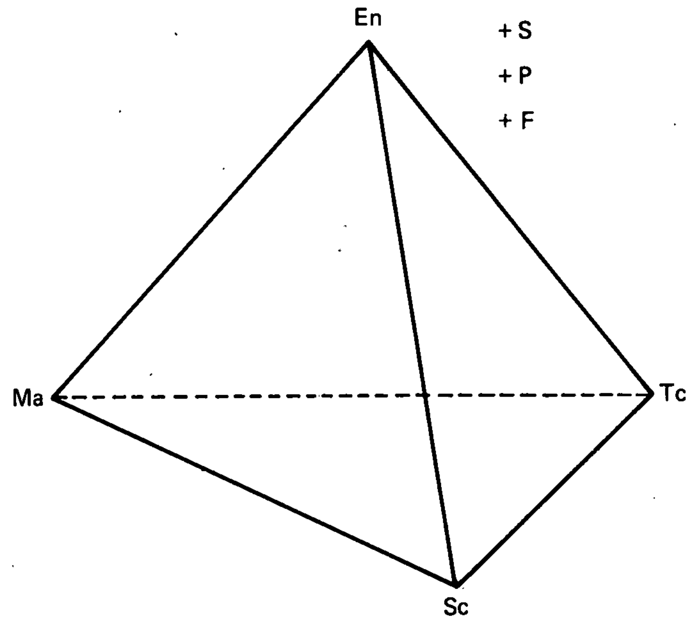


Figure 3. OIL PRICES CIF BRAZILIAN PORTS: EVOLUTION IN CONSTANT 1977 DOLLARS PER BARREL

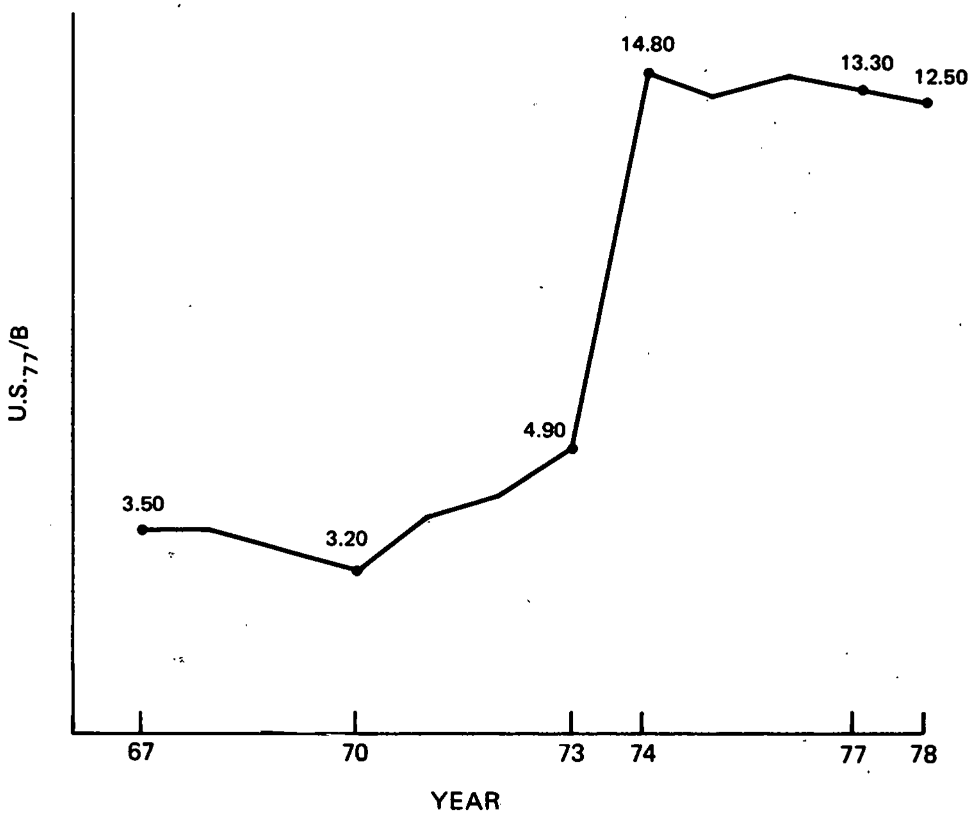


Figure 4. SPECIFIC PRICES OF BRAZILIAN IMPORTS, EXCLUDING OIL; AND OF EXPORTS, EXCLUDING COFFEE AND IRON ORE: EVOLUTION, IN CONSTANT 1977 DOLLARS PER AVERAGE TON, FOB. IN CONSTANT 1977 DOLLARS

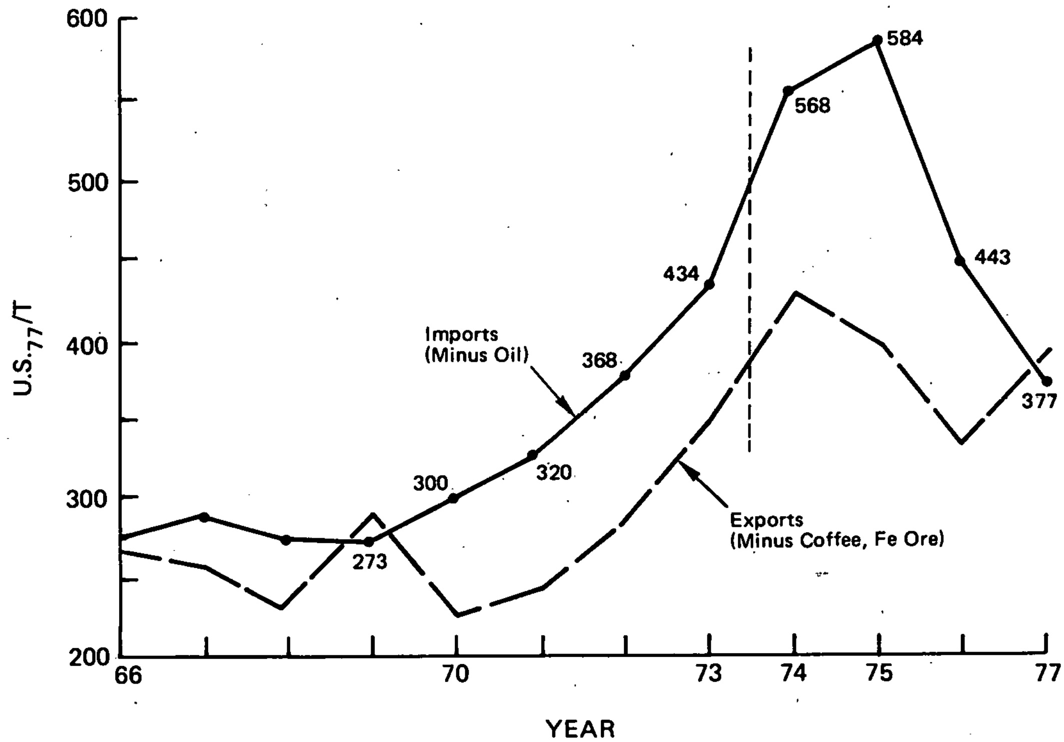


Figure 5. SPECIFIC PRICES PER TON OF IMPORTS, OIL EXCLUDED: DETAIL OF EVOLUTION, IN CONSTANT 1977 DOLLARS

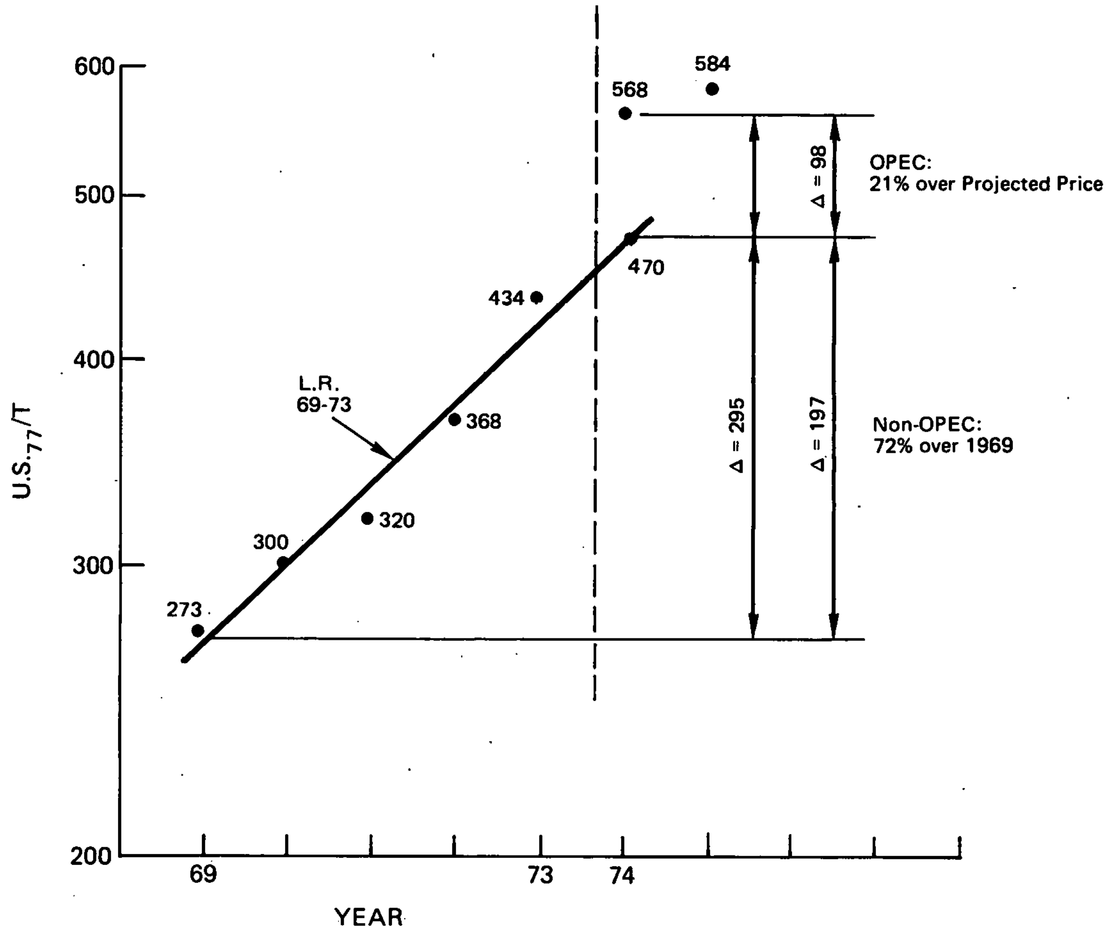


TABLE 1. Total Energy Inputs into the Brazilian Economy (1974)

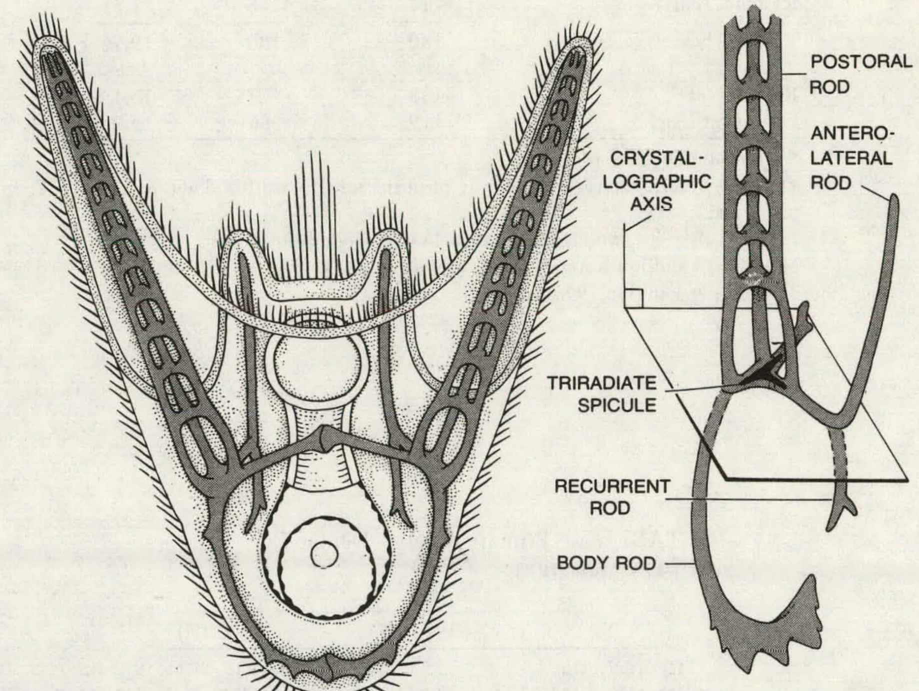
	M.TEP	%	$G.US_{77}$
Fossil	42	23	4.6
Hydroelectric	19	10	2.1
Agricult (crops)	33	19	3.6
Silvicult (wood, charcoal)	32	18	3.5
Grazing	40	22	4.4
Residues (part)	14	8	1.5
Total*	180	100	19.7
Renewables	138	77	15.1
Photosynthesis†	119	66	13.0

*All productive activities.
†Photosynthetic inputs include only photons actually captured and used or processed.
Includes all crops, wood, cattle raising, etc. Rough estimate.
M.TEP = million tons of oil equivalent.
$1G.US_{77}$ = 1 billion 1977 dollars.

TABLE 2. Primary Energy Demand: 1977 and 2000

	1977 (%)	2000 (%)
Hydroelectric	25	~38
Petroleum (&LPG)	44	23-33
Photosynthesis	27	23-16
Misc., Mineral	4	14-11
Other (renews.)	–	~2
Total M.TEP	100	400
	(6.2%/yr)	

Figure 6. SINGLE CRYSTALS OF $CaCO_3$ OF ELABORATE SHAPE CONSISTENTLY REPRODUCED BY GENETIC ENCODING



(Apud Inoue, Okazaki. Biocrystals, SCIENTIFIC AMERICAN, April 1977, p. 83)

SUNSHINE OUT OF CUCUMBERS

The Lord Ritchie-Calder

Those of you who know more about Gulliver's Travels than Walt Disney's version of them may recall his visit to the Grand Academy of Lagado and his encounter with one of the fellows. I quote his account, as reported by Jonathan Swift:

> He had been eight years upon a project for extracting sunbeams out of cucumbers, which were to be put in vials, hermetically sealed, and let out to warm the air in inclement summers. He told me, he did not doubt that in eight years more he would be able to supply the governor's gardens with sunshine at a reasonable rate, but he complained that his stock was low and entreated me to give him something as an encouragement to ingenuity, especially since this had been a very dear season for cucumbers. I made him a small present, for my lord had furnished me with money on purpose because he knew their practice of begging from all who go to see them.

That was written 250 years ago as Swift's satire on the Royal Society of London (or so it is alleged) but you may agree that it has a familiar ring of present day grant applications: an ongoing energy project; the long lead-time of R&D ("just eight years more") on top of the eight-year feasibility study; and the effects of inflation on research materials.

Maybe, in the present energy crisis, we should look again at the possibilities of extracting sunbeams out of cucumbers--if we could get enough cucumbers. The cucumbers are what we are here to discuss. Let us, with the arrogance of Homo faber, postulate that human ingenuity can artefact anything provided that the energy and the basic elements are available and that we have got our priorities right. I remember an occasion when Alvin Weinberg, questioned on the availability of uranium, said, "If it comes to the bit we could burn rocks." On another occasion Harrison Brown, contemplating (certainly with distaste) a possible world population of 50,000,000,000 said, "Then they will be eating rocks." As I understood them they were saying that we could extract the 10^{14} tons of uranium in the lithosphere or that we could recover the basic organic elements and make all the molecules of carbohydrates and amino acids and proteins. (We can recall that the Germans did rather well on ersatz margarine from the carboniferous deposits, and in November 1944 Albert Speer was lamenting to Hitler that the margarine factories had closed down because of the bombing of the coal mines of the Ruhr.)

As in the case of cucumbers, much depends on the availability of the starting materials. Thirty years ago, the first acrylic fiber was produced by Dupont. In Britain, a brash copywriter described it as "wool from peanuts." This was ill-advised and decidedly tactless because there happened to be a glut of wool and such a shortage of peanuts for oleomargarine that the British government was embarking on an expensive and ill-starred scheme to massproduce peanuts in Tanganyika. I asked whether it would not be better to produce peanuts out of wool. On another occasion a newspaper editor asked me with some excitement whether I had heard of a process for making milk out of grass. I said, "Yes, it is called a cow." He was, in fact, talking about leaf protein.

We put a price tag on a conversion process but, of course, the unit cost ought to be expressed not in terms of money but of energy. In the case of cucumbers, one would have to reckon whether the bottled sunbeams would justify the energy consumed by the fellow of the Grand Academy in the 16 years of feasibility study and R&D; and in the cropping of cucumbers, how much energy would go into the manufacture of artificial fertilizers, pesticides, weed-killers, and the pumping of irrigation water.

Energy expenditure itself is relative to need. The bookkeeping becomes unimportant, for example, in wartime. At the present time, in response to the oil shortage, interest in oil from coal has been vigorously revived and the several processes are being subjected to cost-benefit analyses. Judging by the current literature on this subject, it might almost seem that we were starting de novo. It seems to be forgotten that Friedrich Bergius got the Nobel Prize for work he had started in 1914, converting coal dust into gasoline and lubricating oils. The Fischer-Tropsch reaction was developed to convert coal gas to hydrocarbons and to snythesize pertoleum-like substances. In a recent debate in the House of Lords, their Lordships had to be reminded, to their incredulous surprise, that essentially, the German war machine in World War II ran on oil-from-coal processes. Hitler depended on them for most of his motor and aviation fuel and for ammonia for explosives. He did not launch his Blitzkreig until he could rely on his synthetic oil supplies. His only source of natural oil was the Romanian oil field, and a main objective of his attack on the Soviet Union was to gain the possession of the Baku oil field. At the peak of wartime production, Germany's oil-from-coal plants were supplying 6,000,000 metric tons per annum. The main center was Leuna in the brown coal region of East Germany. The Germans failed in their thrust to the Caucasus. In May 1944, the American Fifteenth Air Force wrecked the principal natural oil refineries at Ploesti in Romania. Simultaneously the Eighth U.S. Air Force attacked the synthetic oil plants in Germany. Albert Speer, German Armaments Minister, has written, "On May 4th 1944 the technological war was decided. With the attack of 935 daylight bombers of the American Eighth Air Force upon several fuel plants in central and eastern Germany, a new era in the air war began. It meant the end of German armaments production." For lack of oil from coal, the German tanks were to grind to a standstill in the Battle of the Bulge and the German Air Force was to be grounded. But, for six years, the German war machine had been fueled from coal. To cost the project would be meaningless because one would be putting price tags on death and destruction, but what about energy-in and energy-out? And whatever happened to oil from coal in the intervening 30 years?

The answer to the latter is obvious: oil, apart from its intrinsic chemical values, was conveniently liquid and, in money terms, cheap. Its cheapness doomed Britain's well-advanced oil-from-coal program in the 1930s. Britain has been described as "a lump of coal entirely surrounded by fish." We fueled the Industrial Revolution. We blackened out cities with millions of tons of soot from combustion which was less than 10 percent efficient. We still have an estimated 15,500,000,000 tons in reserve. In the 1930s there was no premonition of North Sea oil and we were entirely dependent on oil imports. It behooved us therefore to make the most of our coal. And in the 1930s we were proceeding to do so.

There were other compelling reasons. Britain then had a mining work force of over a million. In some of the minefields, unemployment was over 80 percent, considerably because ships' bunker-coal, was so hard to handle, was being replaced by oil. Work for miners was therefore a consideration. Another was the belated recognition of the health hazards of coal. The notorious pea-soup fogs (the coal smogs) were thickening and the sulfur from British chimney stacks was wafting northward to destroy the Scandinavian forests. There was a public health demand for smokeless fuel. In the early 1930s work on low-temperature carbonization to produce smoke-free fuel for the domestic open fires was well-advanced. It was reckoned that if the 120 million tons of coal being consumed in Britain were treated they would yield, apart from smokeless fuel, 440 million gallons of motor spirit (nearly half Britain's import requirements); 750 million gallons of diesel oil; and 560 million gallons of tar acids. The process produced a rich gas. The approach here was the Fischer-Tropsch reaction. There was also the Bergius approach--pulverizing the coal and pumping in hydrogen at high pressure and high temperature. The Imperial Chemical Industry with a promise of government tax protection went ahead with a plant capable of producing 100,000 tons of petrol a year using 350,000 tons of coal (or half of one day's national production). The plant was to cost the equivalent of $10,000,000 at the then exchange rate. There were plans to salvage the depressed mining areas by establishing carbonization plants and oil distilleries at the pithead, establishing gas grids, and erecting chemical plants and factories for plastics, derived from coal.

What went wrong with those rational ideas for oil from coal? Quite simply, in commercial terms, the availability of cheap oil. And that consideration persisted after the War, until OPEC served notice that oil would never again be cheap.

For the past 30 years, the chemical industry has moved its source of feed-stock for bulk chemical production from coal to oil. In Britain, the workforce in the mines declined to about a quarter of a million and the consumption of coal declined from 5 x 10^{18} Joules per year in 1920 to 3 x 10^{18} at the present time. Solid fuel consumption has been dominated by blast-furnace coke for iron and steel. The chemical industry is the largest industrial consumer of primary energy, of gas and petroleum, and is second to the engineering and metal trades in the consumption of electricity.

Thirty years ago, I went back to my home district in Scotland. Its industry was traditionally weaving--wool, linen, cotton and, predominantly, jute. A hundred and fifty years ago, still in the days of handlooms, an East Indiaman, under sail, had arrived in the Tay, on the east coast of Scotland. It had on board a coarse fiber--jute. The cottage weavers could weave anything so they produce a tough textile which could be used for sacking and baling and tarpaulin. Then they combined the linen trade and the jute trade by using linseed oil from the flax to make linoleum with jute backing, and jute also became the basis for carpets. With mass-production factories, the jute trade boomed. The jute was hauled 10,000 miles from the Ganges Delta. Then the jute manufacturers of Dundee found that they could use cheap Indian labor and set up weaving plants on the Hoogly in competition with the Scottish production. And still the jute industry on the Tay boomed until the middle 1930s when it began to suffer from the jute manufactured on the spot in India and what is now Bangladesh. After the War, I suggested that Dundee should forget the long sea haul. Across the River Tay, in Fife, was a coal field. Why not take advantage of oil from coal and go over to manmade fibers? Today in my home town there is a polypropylene plant working 24 hours a day producing manmade fibers for the local weaving mills--but from oil, not coal. True, it will now come from the North Sea but I still think that an opportunity of oil from coal was missed 30 years ago.

It is coming in Britain: It is recognized that the oil and natural gas from the North Sea, so convenient to the British economy at the moment, will be depleted within 25 years, while the coal reserves can be reckoned in centuries. We talk about "the second coal era." It is current U.K. government policy not to approve any more oil- and gas-fired power stations. Environmental regulations will force the production of a clean low--Btu coal-gas to be piped to industry. The United Kingdom has a natural gas grid but the British Gas Corporation is developing the technology that will provide methane synthesized from coal.

With the statutory imposition of smokeless zones, we in Britain and Europe are now beginning to clean up the soot-blackened buildings. In Edinburgh which used to be called "Auld Reekie" because of its smoke pollution, and in London, which was already smothered by soot from "sea coal" in the 17th century, and in Paris, we can now have our architectural heritage, the stonework, restored and flood-lit in all its pristine beauty. We are not likely to tolerate the abuses of crudely burning coal as a fuel, especially since we can now treat coal as what it really is--a storehouse of essential chemicals. In it we have the feedstocks of the materials of the present and the future--pharmaceuticals, dyes, and paints to brighten our lives, plastics, manmade fibers, even (it seems) fossilized antibiotics, single-cell proteins, fertilizers, herbicides, and pesticides. Almost as a belated compensation for our past burden of soot, we have the carbon for carbon fibers and their composites as structural materials. And, since we are committed to the internal combustion engine for a long time to come, we can have fluid hydrocarbons as well. With the development of magnetohydrodynamic (MHD) generators it may be possible to get electricity directly from coal, instead of using it to generate steam for turbines. MHD is, of course, a major preoccupation of plasma physics with profound implications for fusion reactors. A very hot gas when in motion conducts an electric current. When it passes through a vertical magnetic field the ions are moved horizontally and can be collected by electrodes. Hence, if coal can be used to generate a very hot flame, electricity might be extracted.

Although there is a great deal of interest in the production of oil from coal, there are really only two centers of significant commercial production--East Germany, the major scene of German wartime hydrogenation activities, and South Africa. South Africa is entirely dependent for its natural oil on imports and, with recurring threats of sanctions, has reconciled itself to a siege economy. As early as 1955 a plant to produce liquid hydrocarbons was brought into operation. It combined the LURGI pressure gasification process with conversion through the Fischer-Tropsch process. In 1974 a new large plant was undertaken, sited in a coal field of 30,000 hectares with sufficient coal for more than 60 years. The target was motor fuels (gasoline plus diesel oil) of the order of 1,500,000 metric tons per year.

In Britain, the National Coal Board is developing two processes for converting coal to synthetic crude oil, with a special concern about aviation fuel. The present U.K. aviation kerosene requirements of 4 million metric tons per year is equivalent to 7 million tons of coal. However, aviation kerosene is not the only product, and energy is required to carry out the conversion. Estimates show that to meet present avaiation requirements would mean liquefaction of 2.5 million tons of coal a year, and the market is expected to double by 1995. One process is liquid solvent extraction in which coal is digested in an oil of high boiling point recycled from the process itself. The filtered coal solution is pumped to a hydrocracker where it is catalytically treated with hydrogen under pressure and coverted into "syncrude" and hydrocarbon gases. The syncrude is distilled to separate light, middle and heavy fractions. The light oil can be processed into transport fuels, chemicals, and plastics; the middle oil can be further hydrogenated to provide aviation fuel; the heavy oil is recycled as a solvent for the early stages of the process or converted into coke. The other process is gas extraction, using the solvent power of a gas at high pressure and temperature. When the coal is mixed with a suitable hydrocarbon gas, as much as 40 percent of the coal dissolves; the undissolved residue can be used to produce hydrogen or gaseous fuels. When the dissolved coal is transferred to another vessel at low pressure, the gas and the extract separate cleanly. The extract can be reacted with hydrogen to produce light oil and the heavier fraction can be further processed to give aviation fuels.

I have labored the point about coal because in addressing myself to materials and energy, I have been impressed (or depressed) by the way in which get-rich-quick considerations have diverted us from the effective use of our resources of which coal is conspicuously one. Coal was a bit of rock which you burned very inefficiently in domestic grates and boiler furnaces. And as long as there was cheap muscle energy in the form of badly paid miners, it did not matter. In 1792 William Murdock first lit his house in Redruth, Cornwall, with gas from coal but was derided as the "madman who is proposing to light London with smoke." Around the same time, Thomas Cochran, Earl of Dundonald (who, incidentally, as a volunteer admiral in the Chilean navy contributed to the defeat of the Spaniards and the liberation of Chile and Peru), invented a smokeless fuel process and explored the potentialities of coal tar. From that coal tar, William Perkin of London, trying to make a synthetic quinine, discovered the first aniline dye, but it was left to the Germans with their greater regard for chemical engineering to exploit it and develop the dyestuff and pharmaceutical industry. Kerosene was manufactured from coal for lighting lamps in 1850 but within 10 years was overtaken by E.L. Drake's petroleum well. The internal combustion engine became a competitor with steam. The oil refineries as by-products produced the feed-stocks of the chemical industry which might otherwise have come from coal or coal tar distillation. And oil, until recently, was abundant and cheap.

One salutary effect of the modern environment movement will be to remind us of the real cost. "The quality of life" is difficult to quantify but we now take some notice of the environmental impact, the social cost so long ignored. In industrial England in the 19th century the gloat was "where there is muck there is brass" (where there is filth, there is money). The gracious countryside of the Midlands became "The Black Country." The Welsh living in the coal fields and working in the steel mills lamented "how green was my valley." The lowlands of Scotland became a blighted landscape of slag heaps, acid-poisoned lakes and streams, and industrial slums--the hallmark of prosperity. "Lancashire cough" was the chronic bronchitis of helpless millions. And so it was in the industrial areas of the United States and Europe. The present generation is now having to foot the bill for reclamation.

Concern with the environment is also reminding us that all life and not just our livelihood depends on energy and that energy derives from that fusion reactor, the sun. It is the sun that drives the weather machine, the winds, the waves, and the clouds which replenish our hydroelectricity. From it, through photosynthesis, we derive the food calories which sustain life and the coal and oil hydrocarbons. More and more, we are turning to sun-derived organic materials, and when we achieve nuclear fusion as our source of energy, we will be imitating, on earth, the processes of the sun. When we are talking about the environment, our main concern is with the sun-created biosphere which sustains all life--the trees, the vegetation, the sea-plankton, the food crops, the creatures, including man himself. We exist because of sun-generated molecules.

In our awareness of environmental problems, we are being reminded of the wealth we are squandering because pollution is, in the final analysis, the discarding of unwanted products. Eutrophication, which is bedevilling our rivers, lakes, and seas, is just too much rich nutrients, from domestic wastes and industrial effluents, in the wrong place at the wrong time. Smokey chimney stacks and automobile exhausts are venting valuable chemicals. Noise pollution is squandered energy. The British Aerospace Corporation has estimated that the engine--combustion system of a jet aircraft releases enough energy to heat 17,000 four-bedroom houses. That expresses itself in decibels.

We mine and quarry the rocks of the lithosphere to extract metal, which we process and presently discard, with inadequate provision for recovery and recycling. Product manufacturers go for the end result and jettison as waste what they do not want. One recalls that the uranium for the first atom bombs came from the spoil heaps of Katanga, in the Congo. When radium was the premium product, Union Miniere had created the uranium as waste. One also recalls that deep-culture of pencillin became possible when it was recognized that corn-steep liquor, an embarrassing waste of the distilleries and starch manufacturers, was an admirable nutrient for Penicillin notatum mold which secretes the antibiotic.

I once made a film for Imperial Chemical Industries (I.C.I.) on environmental pollution. With great indulgence, they accepted my condition that all the examples of pollution should be from their own plants. As a practical illustration of "repentance" we filmed the treatment of sludge from one of their processes and followed through the extraction from it of rare metals and fine chemicals. Directors of I.C.I. who saw the film were piqued when they recognized that, for other purposes of the combine, they had been buying them at premium prices from competitors.

We are a long way past the time when we despised "ersatz." The feudal hierarchy of traditional materials has now given way to an aristocracy of manmade alternatives. Or maybe one should say that materials have been democratized. I am old enough to remember when rayon was disparaged as artificial silk but no one would so derogate present manmade fibers. Polymer chemistry has produced a social revolution. It was summed up in a university debate, apropos of a famous British department store where royalty and commoners shop for "ersatz." The motion was, "This house agrees that Marks and Spencers have had more social influence than either Karl Marx or Herbert Spencer."

Apart from wood, structural materials were always inorganic. We even define our epochs as the Old Stone Age, the New Stone Age, the Bronze Age, and the Iron Age--the materials by which cultures were determined. Surely ours must be the Plastic Age, even if in terms of end results the products may be, in many cases, rigid and unyielding. We might agree that for a material to qualify as a plastic or synthetic material, it must at some stage of its history, possess plasticity, that is the capacity to flow and take a desired shape. The foundations of the present synthetic plastics industry were truly laid by Dr. Leo H. Baekerland when he produced the first manmade resin, phenoformaldehyde, in the presence of an acid catalyst.

Synthetic material, to match specific needs and process engineering requirements, challenged the metallurgists to make unmanageable metals manageable. Electrolysis had already transformed aluminum from an intractable laboratory curiosity, tantailizingly described by Humphrey Davy at the beginning of the last century, into a cheap universal light metal. Magnesium, lighter still, had been mass-extracted from sea water. But, came the day when high temperatures, high speeds, and the new requirements of atomic energy and electronics called for the handling of unfamiliar metals such as uranium, beryllium, zirconium, titanium, germanium, idium, tantalum, niobium, molybdenum, and--how important now--a new look at silicon.

Inside-out smelting, which uses ultrashort waves to agitate molecules and generate heat from inside a metal, made still rarer refinements possible. Powdered metallurgy, which involved compressing rather than smelting, produced combinations that could not be achieved by alloys. Ceramic metals, or metallic ceramics, a long way from potters' clay, exploited oxides, borides, carbides, and nitrides to make materials that were strong, corrosion-resistant, and able to endure high temperatures. Combinations of plastics with metals or glass (e.g., fiberglass) opened even wider possibilities.

he development of "tailor-made molecules" or, in the language of the chemist, long-chain polymers, was, indubitably, one of the most important points of departure in the history of technology. To be able to prescribe a material for a specific purpose and give it predetermined qualities meant that invention was taking on a new dimension. It was no longer a case of, "What can we do with the metals we have?" but "What exactly do you want?"

One development that fascinates me is carbon fiber. Since the advent of stressed skin construction in the early 1930s, aluminum alloys have been the dominant structural materials. They have been improved progressively. What designers or airframes are looking for is a structural material that combines strength, stiffness, weight, ease of fabrication, and durability under service conditions. In all those requirements, carbon-fiber composite is five times more strong and four times more stiff that titanium alloy. Carbon-fiber epoxy is laminated so that the fibers are cross-plied. Substantial weight savings should result from the use of carbon-fiber composites as structural materials. Since the 1960s when they were first developed, activity has built up in the western world on their production and use not only in aircraft production but in many different ways, from self-lubricating bearings to golf clubs. Using such a material it is possible to reduce the vast number of small components that are typical of conventional metallic structures, leading to a reduction in production costs as well as weight. Laboratory tests have shown that this material does not exhibit fatigue properties analogous to those of metallic materials, but careful tests are still being carried out on the effects of temperature, moisture, and repeated loading under service conditions. The promise is that there will eventually be a weight saving of 25 percent in the wind structure compared with present materials.

There may be those who question the description the "Plastic Age" and make claims for the "Silicon Age." Identified with silicon chips and the implications that the integrated circuits they minisculize may take over the logical faculties of the human brain in a world run by computers, silicon might indeed qualify. Silicon stands next to carbon in the fourth group of the periodic chart and it is the second most abundant element in the earth's crust, surpassed only by oxygen. It is nonmetallic in character. It is present in practically every rock. If we think about the creation of the world, the respective roles of carbon and silicon are interesting. The carbon series build up their complexities by conjunction of carbon atom to carbon atom while the silicon series build up their complexities through the intermediary of oxygen atoms. In the beginning, at temperatures of -50° to $+100^{\circ}$ C, carbon had within itself the capacity of evolving life while silicon was a parent of cold rocks. The energy we get through the carbon route, like oil and coal, has come to us through the organic chemicals. Silicon long the inert material which as Sio (silica) fashioned glass and ceramics, was electrified by the solid state physicists. Not only is silicon likely to run our businesses for us but, with silicon cells already proven as the source of energy for the radiotransmitters and telemetering equipment of space satellites and probes, we can get direct conversion of sunbeams into electricity.

We are discussing materials and energy. The prevailing paradigm is that it all began with the Big Bang. Time began with a primeval atom which exploded and released the energy and particles, the matter and anti-matter, which formed the expanding universe, and all the galaxies and the stars and the planets and created the elements which congealed to form earth. Energy into matter; matter into energy--when you are thinking about materials it does not matter whether you start with the energy within the nucleus or with hydrogen with its proton and orbiting electron. To have the elements which form any of the materials you are going to manipulate, or the molecules you are going to fabricate, you have to account for energy. You can do your accountancy in gigajoules or you can express it as money and "added value." But you have to do the sums properly and what we call cost is not a reliable indicator. It all depends on energy-in and energy-out. For example, the food calories of a crop may be much less than the energy put into the artificial fertilizers. Or another example, the European Economic Community produced an energy plan that aimed at 200 gigawatts from nuclear reactors by 1990 (to help fill the predicted energy gap). One of my colleagues, an eminent scientist, in a select committee of the House of Lords, without bothering about the huge cost in money terms, demolished the argument by demonstrating on a sheet of notepaper that the energy used in the materials for constructing and equipping the many installations would exceed Europe's interim capacity and precipitate the energy shortage which the program was planned to correct.

Perhaps if we really started accounting in energy terms instead of money symbols we might get the energy problem straight and get the real value of our materials and commodities. I ought to admit, and my banker will confirm, that I know little about finance but I know that money has little relation to real wealth. It did at one time when the tillers produced the food calories and sustained the artisans who made better tools or better pots or better textiles than they could. The tiller bartered food for the products into which the artisan put his muscle-energy. And presently both the tillers and the artisans produced surpluses, which went onto barter between individuals and with other communities. Individuals could justify their efforts to each other--so much stoop-labor was worth so much bench-labor. But it was clumsy, so coins were invented and there was buying and selling. When goods were exported to other communities, there were further difficulties, so Darius II of Persia invented the check or money order which said "This barley is worth so much in Babylon and should be worth so many hides in Ispahan." Then money became itself a commodity. Bankers started in Babylon as early as 500 B.C. They grub-staked the artisans. They paid people to dig irrigation canals and sold the water to the farmers. They discounted the checks of the merchants on the caravan routes. There was a trade in money itself. It was not a question of the energy put into the product but of how much the market would bear.

Now, baffled by the apparent meaninglessness of money in real terms, by the wild excesses of inflation, and by the contortions of the financiers and economists to control, I have decided to go back to first principles--to the Big Bang, to $E = mc^2$--and invent my own currency, not based on the inert metal gold dug out of one hole and stored in another, but on energy.

I follow the conventions of currency. It has to be something difficult to obtain; it has to be durable; and, by my specification, it has to be redeemable as energy. And it has to be calibrated. I decided on Uranium-235. (Natural uranium is too accessible and plutonium is a second-stage product. I wanted a primary.) U-235 can be calibrated to other forms of energy, e.g., coal and oil calories or food calories. It can be related in work terms to gigajoules. It can scarcely be carried around in the pocket but it can be banked like the gold in Fort Knox, as the backing for notes. And it fulfills my last requirements; it can, in the ultimate, be put in reactors to produce energy. I have called my new currency the Utope. You can derive it as you wish from "Uranium sotope" or from "Utopia."

And it has as much promise of success as sunbeams out of cucumbers.

MULTILATERAL AND BILATERAL COOPERATION IN ENERGY RESEARCH AND DEVELOPMENT BETWEEN CMEA COUNTRIES

George Korányi

In the framework of the Council for Mutual Economic Assistance (CMEA) between the participating countries (Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Poland, Rumania, USSR) bilateral and multilateral cooperation exists in several important R&D fields. One of these is energy.

International cooperation has different forms and methods and to reach satisfactory results from this activity, forms and methods have to be selected carefully. The experiences of the CMEA countries prove that the adoption of adequate organizational forms may give support to increase the effectivity of common efforts. In the past years, the Permanent Committees for coal mining, oil and gas electric energy, and atomic energy created subordinate bodies to study and to develop cooperation. In several cases expert groups elaborate common projects which are then approved by the competent authorities of the participant states.

MULTILATERAL COOPERATION

The projects are assessed by the Permanent Committees and working parties are invited to submit programs including the participants and their particular tasks. A leading institution is designated by one of the countries for collecting and synthetizing reports and presenting them to the expert group. If the consolidated report is accepted by the group, it is submitted to the Permanent Committee with a recommendation to introduce the results of the work done in practice. Some examples of the most important multilateral projects in the energy R&D field:

- Utilization of intersystem effects in electric energy networks.
- Development of advanced telecommunication systems for electric energy transport and distribution networks.
- Mechanization and automation of work in open cast collieries.

- Development of new techniques for entirely mechanized mining in great depths.

An important development in multilateral cooperation was the organization of Coordination Centers. In one of the member countries, in the framework of an appropriate institute (research, or development, or documentation), a small group has been formed from representatives of the member countries. This kind of an international team gives effective support not only to synthetize reports but to maintain a permanent contact between institutions participating in the elaboration of the project. The most important projects steered by Coordination Centers are:

- Advanced utilization methods for coal (e.g., gasifying, liquefaction).

- New technologies for processing and utilizing natural gas.

- Development of new catalysts for hydrocarbon processing.

The Geophysical Coordination Center is steering quite a number of projects, like: development of new methods for computing data on geophysical exploration and drilling, or, research on well geophysics.

To demonstrate particular advantages of multilateral efforts, some examples are quoted.

Hungary has been invited to investigate geophysical instrumentation for deep wells because in Hungary the geothermal gradient strongly differs from other countries.

While in Europe generally the gradient is 30 meters/1^{o} Centigrade increase of rock temperature in wells, in Hungary it only amounts to 18-20 meters. This way in depths of 4200-5400 meters, conditions entirely correspond to depths of 7000-9000 meters elsewhere. Instruments and processes for very great depths can so be tested in Hungary at convenient circumstances.

Research and development work is going on for the recuperation of residual oil in exhausted fields by secondary and tertiary methods. Here again the projects are divided among the member countries of CMEA. Hungary for instance developed a new method of recuperation by inserting CO_2 pressure to oil bearing zones. As in Hungary important reserves of natural carbon dioxide are available in the region of the potential fields, costs of the experiments and tests showed a minimum in selecting Hungary for the project.

Similar advantages may be assessed in multilateral R&D work between CMEA countries.

BILATERAL COOPERATION

Numerous energy R&D fields offer possibilities to bilateral cooperation. Problems to be investigated are studied and discussed by Commissions for Economic and Technical Cooperation functioning with the participation of the two countries' competent Ministries. Once the projects are approved by the Commissions, the specialized institutes in both countries are invited to prepare and submit a program for bilateral cooperation. The program may include: exchange of information and documentation; specialization of experimental activity; organization of common teams to elaborate studies and to make experiments in one, or the other, or in both institutions; to accomplish field experiments or to erect pilc: plans.

After the approval of the program, the participating institutes may sign a contract which forsees: program of work and distribution of costs; program of mutual visits; agreement on eventual patenting and licensing of the new results.

Hungarian research and development institutions participate in the following R&D bilateral projects with different CMEA partners:

- Electronic and automatic protection of power stations and electric energy transmission systems.
- New and effective water cooling systems for power stations.
- Advanced methods for projecting and installing 750 kV overhead transport systems.
- Development of advanced hydraulic systems for mining machinery.
- Recultivation of the environment in open cast mining sites.
- Development of new hydrocarbon-drilling methods for inclined drilling.
- Utilization of foams in drilling.

International cooperation in R&D between CMEA countries prove that it can and does increase effectivity; considering the actual world-energy situation, advantages from these experiences cannot be neglected.

EDITOR'S NOTE: Because of a late cancellation, Dr. Koranyi was asked on very short notice, and graciously agreed, to present as a Plenary Session paper, the summary he had prepared for Workshop 10. His summary was selected because of its general interest to the theme of the Congress. For convenience, the summary is also included in Appendix A.

A VIEW ON STRATEGIES FOR INTERNATIONAL COOPERATION

Umberto Colombo

Energy is an essential component of almost all human activities. It is indispensable for the exploitation of raw materials, for processing materials, for obtaining food, for shelter and space heating, transportation, clothing, health and, more and more, also for the preservation and restoration of the environment. Thus, the quantity of goods and services available to man is a function of energy availability and use. Since remote times, man has tried to utilize the available energy resources through the development of exploitation and utilization technologies, and has based his life on the more abundant, easy to obtain, and cheap ones--wood, peat, coal, animal work, hydraulic energy, the sun itself, on and on to oil and natural gas, the use of which allowed the huge and rapid economical development of many countries during the last century.

In view of the perspective of depletion of the main energy source being used today, an enormous effort is required to find and develop new sources in order to assure the energy necessary for the continuation and further development of society, But, fundamental problems, such as the requirements of developing countries and the need to obtain a better international balance, must be considered.

Energy and materials are strictly correlated. In fact, practically all aspects of the energy system necessarily imply the use of materials from mining or collection of primary energy resources to consumption on utilization devices--refining and conversion into fuel; fuel storage and transportation; fuel conversion into usable energy; storage, transmission, and distribution of this energy; and final use. The development of new alternative sources of energy or of new secondary energy systems for a more rational use of energy requires the availability of new materials that can satisfy specific functions, often in severe performance conditions. Consider the formidable materials requirements of obtaining energy from nuclear fission and photovoltaic solar devices, and the even more challanging task of developing materials that will allow controlled nuclear fusion. Also the new use of carriers, such as hydrogen, presents considerable problems concerning materials, as well as the development of new, more efficient energy conversion, transmission, regulation, storage, and utilization systems.

The above considerations are enough to indicate the huge importance of materials in energy management. However, as long as we consider only the aspect of the contribution that materials can make to energy resource development and to their optimal use, we implicitly admit that the continuation of a trend typical of the last decade is almost inevitable. This trend requires a continuous increase of energy resources and materials to achieve a continuous growth of the GNP and hence to guarantee economic and social development. This growth was based on the abundance of rich, accessible, and cheap energy resources and materials. But, by this time, the "easy" coal, oil, and metal deposits have been found and exploited. Even if alternative sources of energy, metals, and raw materials are available, or imaginable, in huge quantities in the crust of the earth or on the seabottom, they are leaner, less concentrated, less accessible resources, which require enormous capital, hence, great quantities of energy and materials, besides the knowledge to exploit them.

Energy and materials, in fact, are strictly correlated, not only because energy has a "material" content in the sense mentioned above, but also for the reciprocal aspect--to be widely debated in this meeting--of "energy content" of materials, a content which accumulates during the whole life cycle of materials, until it is dissipated as materials become scrap and can no longer be used economically. In fact, between energy and materials there is a trade-off similar to that between energy and land, energy and time (that is, duration of activities), and energy and intensity of activities. For example, if fresh water for irrigation must be obtained, energy is required. The extreme example is sea-water desalting. Fresh water can be obtained by means of distillation, but the development of semi-permeable membrane processes can reduce energy requirements. This example indicates that we can trade materials off against energy and that energy itself can be considered a fundamental parameter to measure this trade-off.

Materials in the wider sense of the word are obtained from mineral ores or from biomass. The former are considered nonrenewable resources due to the very long geological time necessary for the natural formation processes; the latter are renewable. The means of obtaining both types of materials are rather inefficient, but while higher and higher yields are conceivable in the generation and use of biomasses, the exploitation of ores is limited by energy. In fact, as leaner ores are exploited, it is necessary to mine, crush, and treat greater and greater quantities of rock. These processes require energy and chemicals, besides having a huge environmental impact. The lowest usable ore concentration is determined by the cost of the required energy, chemicals (which, also, need energy), and labor, and by the availability of capital to build new plants (also needing energy).

Of course, these considerations are valid also for the exploitation of fossil fuel deposits. The North Sea fields being developed today need 100-1000 times more energy than those of the Middle East. Even so, this energy is in the order of 1 percent of that produced. But the development of oil shales requires 10-30 percent of the recovered energy, depending on the characteristics of the deposit. The exploitation limit can be fixed at five gallons of oil per ton of oil shale. For deposits of uranium to be used in burner reactors, the energy required for mining equals that obtainable from an ore content of 20 ppm of U308. However, if labor and capital costs are also considered the lower limit of the oil shales rises to 15-20 gal/t and the lower limit of the uranium to about 100 ppm of U308.

These exploitation limits of natural resources can be reduced through R&D directed at improving process yield and studying new, less energy-intensive processes, going closer and closer to the ideal limits without "energy waste." In fact, each more productive process is an entropy reduction process, which results in more orderly systems. Gibbs' free-energy function relates order to the energy (heat) required to obtain it. When this relation is satisfied--that is, in reversibility conditions and at zero rate--there is no energy waste while, in real processes, there is always waste. In any case, it is clear that the energy cost of ore and fuel mining and processing poses impassable limits.

Among industries, those of materials manufacturing are the main energy consumers (metals, chemicals, ceramics, paper, etc.). Metals particularly consumes much energy. By comparison, the engineering industries use a modest quantity of energy. But, in order to account for the total energy content of products of these industries, we must also consider the energy purchased with the supply of materials, components, capital (machinery, plants, and infrastructures), transport, and services. Through the use of input-output matrices all the energy employed indirectly in the manufacture of a good can be calculated. This is often much higher than that used directly. Therefore, from the above considerations, it follows that, if we would limit ourselves to optimizing the exploitation and use of resources, sooner or later the past, and likely the present, development trend would lead to a divergent process. In other words, for the growth of the GNP, one would require greater and greater quantities of energy resources to exploit low-grade ores under more and more complex and difficult chemical and geological conditions and to obtain water for agricultural, industrial, and civil purposes from deeper and less pure waters. Furthermore, more materials would be required for the development of energy systems. Therefore, the benefits effectively obtained would also be limited by the need of ever-increasing investments. Also the negative consequences for the environment would increase and, for their containment, further use of energy and materials would be required.

The real objective, therefore, is to overcome this divergency, through a substantial change in the manner of using resources for a different economic and social development.

For the long term, achievement of more efficient use of materials and energy resources is not so much a question of aiming toward improved ore exploitation or material processing systems, but of reducing resource dissipation, starting from an active materials conservation policy which, because of the trade-off between energy and materials, also implies an energy conservation policy. Such a policy should be aimed at reducing all forms of dissipation and waste. It must cover all phases of the cycle of materials in their production and use, must provide for recycling, avoid planned obsolescence, and substitute less energy-intensive materials.

Design is an essential element of a policy for the conservation of materials and the energy they contain. The functionality and durability of goods, the selection of materials and of their manufacturing methods, and the possibility of recycling all depend strongly on design. The choices, lacking a precise and global policy, are dictated by such factors as local availability, market price, tradition, existing infrastructures and investments, experience, knowledge, and skills. Indeed, design decisions may alter the pattern of technology and of lifestyle.

Another extremely important element for conservation is substitution. The development of technology has largely been a story of substitution: copper for stone, bronze for copper, iron for bronze, steel for iron, fiberglass for steel, plastics for metals, ceramics, and wood. Except in wartime, forced substitution due to national security and scarcity has been uncommon in the history of modern civilization.

Finally, corrosion is the principal factor of degradation of materials, representing in the industralized countries a loss of GNP on the order of 2-3 percent every year. Reduction of corrosion, obtained through R&D and the use of more suitable materials, can result in considerable savings.

The technical policies just discussed allow for structural modifications capable of contributing to the solution of the problem presented by the growing constraints to development and use of resources. It is clear that, beyond the technical and scientific aspects, such structural modifications have a deep socioeconomic connotation. It must be underlined that whenever great structural modifications in production and usage are made, the return to be expected for the long term, and therefore there is a cost to pay on the short and medium term which society must be convinced to accept. A first step in this direction is the understanding of the true role of materials and final products in relation to their characteristics and to social and individual needs.

Products of manufacturing industry include energy and processed materials and also a growing quantity of associated information directed toward obtaining given properties and capabilities to perform specific functions. In order that the end-user may benefit from the information contained in the goods produced, the goods need more and more to be offered together with an adequate service. Demand thus grows in the direction of information-rich material goods, and of nonmaterial goods such as education, health, safe environment, social security, the right to take part in decision-making. This trend toward goods and services, ever richer in information in proportion to energy and materials, is favored by the development of information technologies and of biotechnologies. The thermodynamic yields of these technologies are generally high and controllable at the biologic or electronic level. They therefore produce with low entropy, using a very limited amount of materials and energy resources.

The electronic technologies have an extraordinary capacity for influencing the efficiency of the economic activities, by reducing, for instance, energy and materials consumption and waste. And they are penetrating all sectors of economy and society.

The development of industrial applications of the biotechnologies is also destined to have a profound effect on society in a not too distant future. These technologies represent the most important instrument to achieve ever more efficient biomass exploitation processes, that is, of one of the most important renewable resources available to man. They find employment in agriculture and nutrition, in the chemical industry, in the production of energy and material resources, in the treatment of effluents, and in the beneficiation of ores.

Furthermore, the development of information technologies and of the biotechnologies does not necessarily require big production units, thus preventing some negative effects due to very large scale. In addition, those technologies--the ones with the use of microprocessor and of distributed data processing, the others with small size activities, often tied to agriculture--allow decentralization, with resulting benefits from the viewpoint of territorial balance.

I do not think it possible to continue the present development process in an extrapolative manner, even if, with corrective adjustments, the purpose were to optimize the use of resources or to reduce the most clamorous unbalances which harass our society. We cannot even think that serious policies in the various areas will be sufficient, due to the complex and manifold aspects of the problems. We need, on the contrary, a global and integrated strategy, capable of mastering the transition from the present system to one more balanced and intrinsically much less dissipating.

In fact, in the present situation of serious imbalances existing above all but not exclusively between wealthy and poor countries--that is, between industralized countries with a high consumption of material goods and energy, and countries lacking practically everything--it is necessary to design a future that will guarantee equitable and harmonious growth. If the necessary resources are to be assured, a satisfactory standard of living, preserving traditions, culture, and local ways of life, must be attained.

But at the same time more innovative thinking must be given to the future of the industrialized countries, which are showing signs of becoming saturated with material goods, while the demand for goods with a higher information content and of higher quality is increasing, together with the demand for services and more generally for culture. A society directed toward improving the quality of life, participation, decentralization, and the improvement of land, rediscovers values that the consumer society had forgotten in its quest for material well-being. Furthermore, once so many material needs are satisfied, even the superfluous, there is not point in putting the emphasis on quantity.

The effort of imagination required for this qualitative development may find the necessary support in technological innovation, for example, along the lines I have attempted to indicate. Fifty years from now, for instance, the energy needs could be much more contained than those foreseen by an extrapolated development, and not far removed from the present percapita average, but rather better distributed. A qualitative type of development in the advanced countries also calls for fewer resources (including capital) for its achievement, and hence leaves greater margin for the growth still required by the Third World, which would otherwise prove to be very difficult and unrealistic.

A long-term strategy can encounter great difficulties due to the existing, harassing short- and middle-term problems which may also drastically condition decisions and initiatives of enterprises and governments worried by the difficult contingent situations, immediate economic problems, and scarcity of capital. Therefore, it is necessary to act in such a manner that these problems may be considered consistently with the existing constraints and within the long-term strategy.

It is extremely difficult to outline a strategy and to indicate the instruments to carry it out, since they all must be created, and because today structures capable of making such a radical change do not exist. Even if market economy represents a very flexible instrument able to stimulate innovation and exchange, it suffers too much from the effects of the short-term, which strongly condition and direct it, so that it certainly is not able to lead such change in the relatively short time of decades. On the contrary, the planned economies, which would appear more qualified for the achievement of long-term strategies, are more rigid and less ready to accept the need and the opportunity for change and innovation. In fact, while we cannot imagine letting the system evolve "naturally," without giving precise directions and incentives, neither can we face such complex problems with a pre-set solution and, on the basis of the elements in our possession today, consider it as the optimal answer.

The technologies to be developed in the framework of materials and energy in the manufacturing industry and services are very numerous and often their objectives are still vague or even uncertain. The needs (economic growth and savings of energy and materials, reduction of imbalances and respect for cultural values and local traditions), even if not contradictory, are numerous and interrelated. They refer to situations that can also profoundly differ, and which certainly shall be attuned, but not obliterated. In any case, dead-end roads or even rigid and constraining paths, cannot be taken.

Therefore, the need for alternative options is indispensable. A large and articulated R&D effort is needed, so that different technologies will be available to satisfy the same needs in a sort of "technological pluralism." In fact, we shall realize that the optimal energy source does not exist, neither does the optimum material with no competitors for a particular use. Similarly, a unique way to produce a piece of goods or to supply a given service does not exist. When a society is too much conditioned by "unique" choices, considered optimal, it easily can become vulnerable and too rigid. The example of the conditioning choice of oil and natural gas as privileged and prevailing energy sources is enlightening. Technological pluralism allows us to carry into effect a strategy of decentralized activities and human settlements in such a manner that it may be compatible with the existence of more centralized systems. Decentralization, in fact, leads to a better use of most resources: energy, materials, territory, and also manpower. It allows one to utilize to the utmost advantage the energy of diffused sources, such as sun or wind, without creating environmental problems. Towns themselves can be structured, with respect to territory and its resources, in such a maner as to be more autonomous and decentralized, with regard to a whole series of functions and services, and enable the use of diffused or recovered thermal energy and of modest amounts of local material resources.

Moreover, decentralization provides the possibility of safeguarding pluralistic conditions of life, not only in the sense of culture and traditions, but also of technologies and production systems. These should, in fact, take advantage of the economies of scale, up to the point in which they are effectively convenient, as in the case of large standardized production of semi-finished articles or of mass consumption goods, while for the most sophisticated products and for those that demand a continual adjustment to market conditions, a decentralized production in medium- or small-size plants could be far more convenient. On the other hand, these plants will be capable of taking advantage of new technologies--such as the microprocessor, distributed informatics, and biotechnologies--which favor the small scale and make these plants highly flexible, automated and productive.

The coexistence of soft and hard technologies makes a more articulated society possible and allows a balanced evolution, both of the already industralized countries, where consumption must be contained, and of the developing countries, where often, the massive use of hard systems is not convenient or desirable. Therefore, a more balanced world and, after all, also a more homogeneous one, as concerns relationships between North and South or between East and West, can be attained through the achievement of a technological pluralism. Everyone is not compelled to follow a sole technological and social development pattern, or to see the rich of the world following an ever harder path, while the poor keep striving at minimal survival conditions, compelled to employ marginal technologies, unsuitable for their needs. On the contrary, technological pluralism could help create a society that permits the various countries, and various communities inside them, wide margins of choice and mix of the most apt solutions.

Of course, technological pluralism requires a great effort and firm international cooperation. The cost to be sustained for this effort would be widely repaid by the amount of freedom obtained and by the increased possibility to face and solve the complicated problems which could otherwise result in partial and contrasting solutions.

International cooperation must commence with R&D programs. Many of these require gigantic efforts and the need to examine an incredibly large and complex number of aspects. As an example, I would like to mention the tremendous problem of materials for nuclear fusion, which could be the decisive limiting factor for the development of this new energy source. This could be a real opportunity for a large common program between the East and the West. The development of decentralized energy sources (solar, wind,biomasses); the study of the related materials; of technological devices; and of the most suitable systems for production and use, including storage and distribution methods could, on the contrary, represent an opportunity for a large common R&D program between the North and the South, both having the need for these energies, in the context of a policy towards a more advantageous use of the decentralized systems.

I certainly do not take it for granted that cooperation of this kind is easy to achieve. It is well known that when international cooperation in R&D is at stake, it is easier to face basic research problems (as in the case of CERN at Geneva) rather than problems that may present important practical consequences in the medium- and short-term.

What we need, given the extreme complexity, the dimension, and the very nature of the materials issue, is a permanent forum where international strategies concerning materials, energy, and the environment could be formulated and actions at the different levels planned. Such a forum could act as a nucleus capable of catalyzing international R&D cooperation in the already existing materials and energy research centers, and of identifying unsolved problems where immediate action is needed, that could better be tackled by uniting forces at an international level.

Today, a strategic vision on materials and energy is still unclear. Too often the problem is approached in a conventional way, when what is needed are more imaginative solutions, implying, as I have tried to indicate, some notable changes in the structure of our socioeconomic system as the basic issue of decentralization would require.

This International Materials Congress is a reality where manifold aspects of materials and energy are debated and different perspectives analyzed. This Congress could perhaps be institutionalized so as to become itself, with a small permanent organization, a forum where materials and energy strategies could be studied and their consequences on the economic and social system assessed. The difficulties of such an enterprise, if we intend it to be genuinely representative of the West, East, and South, are evident and confirmed by the almost total absence, with the sole exception of two Hungarian delegates, of representatives from the Eastern Europe and China.

There is a long road ahead of us if we aim at global international cooperation. But we should not, I believe, be discouraged, since what counts now is to make a courageous first step in the right direction.

ENVIRONMENTAL CONSTRAINT AND ENERGY CONSERVATION IN THE JAPANESE IRON AND STEEL INDUSTRY

Toshiharu Uchida

ENVIRONMENTAL POLLUTION AND REGULATION

Environmental pollution became a national problem in Japan in the late 1950s when the economy entered a remarkable high-growth period. In the 1960s the economy continued its dizzying growth at a rate of about 10 percent or more a year, which brought about pollution-induced problems nationwide.

Causes of pollution in this country are manifold. The nation's land area is about 370,000 km^2, smaller than that of the state of California. Most of the more than 100 million people live on flatland that accounts for only 25 percent of the terrain. Further, nearly one-half of the population and two-thirds of industrial production concentrate in and around the major cities of Tokyo, Osaka, and Nagoya. As a result, Japan's GNP for each km^2 of habitable land is about 19 times as large as that of the United States.

In addition, the high economic growth heavily depends on petroleum for its energy source. Consequently, sulfur oxides emitted from the combustion of petroleum have caused serious air pollution in major city and industrial areas.

When ambient sulfur dioxide concentration in major cities peaked in 1967, it was 0.06-0.1 ppm annually (Figure 1). In that year, Japan imported 177 million kiloliters of petroleum with a mean sulfur content of 1.99 percent and produced 54.89 million kiloliters of heavy oil with a mean sulfur content of 2.6 percent.

As the pollution problem grew more severe and complex, the Japanese people took an increasing or even extraordinary interest in it, stirred by the heated campaigns of the news media. The literacy rate in this country is 100 percent, practically all households have television, and three daily newspapers boast circulations of 4-7 million each. Thus, the active mass media campaigns produced far-reaching effects. At the same time, the air-pollution problem offered a golden opportunity for attack on the government; it became the biggest political issue in the late 1960s.

As a consequence, conventional environmental laws were extensively amended and many new laws permitting implementation of stringent regulations formulated. Environmental regulations take two forms: those stipulated by laws passed by the central and local governments, and those specified by agreements between local governments and works. Environmental quality standards are set for many pollutants, and emission or effluent standards for individual equipment and effluent outlet have been established. In the 24 areas accounting for 56 percent of the nation's fuel consumption, a more severe emission limit is specified for the total sulfur oxides emission from each plant. For nitrogen oxides in flue gas and chemical oxygen demand (COD) in effluent, regulations of total emission from each plant are being introduced.

The regulation by agreements with local governments is more severe than that stipulated by law, and sometimes they directly make a request on kinds and capacity of pollution control facilities. In many cases, a local government does not intend to approve construction or expansion of equipment unless industry agrees to set pollution control measures on other equipment in the same plant.

Although environmental quality standards of each nation cannot be directly compared, Japan's standards are considered the most severe in the world. For instance, Japan's sulfur dioxide standard is a maximum of 0.04 ppm per day, as compared with 0.14 ppm for the United States. Until the revision of 1978, the nitrogen dioxide standard was a maximum of 0.02 ppm per day, a level comparable to the nitrogen dioxide concentration occurring naturally or close to the measurable limit. This level was 5 to 7 times more stringent than that of the United States. The limit of 0.25 g per km (or 0.4 g per mile) for nitrogen oxides emission from automobiles is less than one-tenth of that before the regulation.

The characteristic of Japanese regulations is that her regulations ignore economic consideration, though they are based on the Polluter Pays Principle (PPP), which was established by the Organization for Economic Cooperation and Development (OECD). This fact was pointed out in a 1977 OECD report, "Environmental Policies in Japan" as follows:

> The PPP immediately became very popular in Japan, and it is often referred to. But the economic objectives of the principle, and the mechanisms by which they are achieved, are not always well understood. For many, the principle just means that polluters are guilty, and must be punished. In short, it is understood as a "Punish Polluters Principle."

Several Japanese environmental laws verify this observation. Among them is a law stipulating that industries bear part of the cost of public works for pollution control, such as making green-zone and dredging. Another designates several heavily polluted areas and ascribes all respiratory diseases in those areas to air pollution. Under this law, industries again have to bear the medical and living expenses for the patients.

RAPID DEVELOPMENT OF POLLUTION CONTROL MEASURES

To comply with such severe regulations, anti-pollution control measures were rapidly developed. Between 1970 and 1975, the ratio of the nation's pollution control investment to the GNP doubled from 1 percent to 2 percent. This increase is largely due to the active investment by industry. Especially, the steel, petroleum, electricity generation, paper and pulp, and chemical industries which invested about $3300 million in 1964, or about 70 percent of the nation's total in the private sector.

Reportedly, the steel industry has spent $5 billion on pollution control measures and equipment in the eight years since 1970. This is 15 percent of all plant and equipment investments during the same period.

In the three-year period 1974-1976, the steel industry's pollution control investment was as much as about $3200 million, or about 20 percent of all investments for plant and equipment. The pollution control investment during this period can be classified as follows. About 70 percent was spent on such air-pollution control equipment as dust collectors and stack gas desulfurization equipment, 15 percent on wastewater treatment centering on the activated sludge process for effluent from coke ovens, and the remaining 15 percent on waste disposal, noise prevention, afforestation, and so on.

The amount spent annually on pollution control varies depending on how the cost is defined. It is roughly estimated that Japan's steel industry as a whole is annually spending more than $2.5 billion for pollution control in recent years. This is about $25 per ton of crude steel. Of course, depreciation and interest incurred by capital investment and repair costs constitute the majority of this. The heaviest item in the variable cost category is the cost of electricity. Until quite recently, this cost increased annually. But the present level will remain largely unchanged, with the pollution control investment substantially settled and expected to run at a low level for the time being.

POLLUTION CONTROL MEASURES AND THEIR EFFECTS

Air Pollution Control Measures

Sulfur Oxides Control (Figure 2)

To conform to the severe standards, the steel industry has sharply reduced sulfur oxides emission by using low-sulfur raw materials and fuels, desulfurizing coke oven gases, and sintering plant flue gases.

The steel industry switched to low-sulfur oil and to liquefied petroleum gas (LPG) and liquefied natural gas (LNG). As a consequence, sulfur content in the fuel used at Nippon Steel decreased to below 0.05 percent in 1977 from near 0.6 percent in 1970. The mean sulfur content in the sinter feeds used at Nippon Steel also dropped from 0.17 percent to below 0.07 percent during the same period. Today, in Japan, practically all coke oven gas is desulfurized, as is the flue gas from more than half of the sintering machines. A total of 21 sintering machines, and flue gas desulfurization equipment are in operation, 11 of which exceed 500,000 Nm^3 per hour in capacity. The 21 systems desulfurize over 12 million Nm^3 of gas per hour. Most of the systems were developed by steelmakers.

With these efforts, 1978 sulfur oxides emission from steelworks dropped to below 40 percent of the 1970 figure. The use of high collective stacks have been effective, too. Today, therefore, the contribution of steelworks to ambient sulfur dioxide concentration is practically negligible. As a result, the ambient sulfur dioxide concentration in the vicinity of the steelworks improved sharply, from about 0.04-0.06 ppm per day in 1970 to about 0.02-0.015 ppm per day in 1977.

Nitrogen Oxides Control

Nitrogen oxides emission standards set for the steel industry are very severe; e.g., for new installation, 60 ppm for gas-fired boilers, 170 ppm for coke ovens, and 220 ppm for sintering machines. Steelworks in major industrial districts are asked by local governments to reduce their nitrogen oxides emission by 70 percent. The control of nitrogen oxides emission is thus the most difficult and important environmental problem facing the Japanese steel industry.

While endeavoring individually, steel companies formed a research association to develop flue gas denitrification techniques for sintering machines. Also they furnished funds for the improvement, research, and development efforts of academic societies and machinery manufacturers concerning the low nitrogen oxides burners, combustion modification, and flue gas denitrification. The amount the industry has invested in R&D concerning nitrogen oxides emission control amounts to more than $75 million.

These technical developments and improvements in burner structure and combustion method have permitted reduction of nitrogen oxides emissions from reheating furnaces and boilers by 50 percent. Reduction from coke ovens is 30 percent, partly due to the nitrogen removal accompanying the desulfurization of coke oven gas used. Also, by improving operating conditions, a reduction of about 15 percent will be achieved in sintering plants.

But the flue gas denitrification technology for sintering machines, which is the drastic nitrogen oxides emission control measure, is still at an experimental stage, leaving many problems unsolved.

Dust and Soot Control (Figures 3, 4)

The dust and soot standards set for the exhausts of most combustion facilities fall below 100 mg/Nm^3. The sintering machine is a main emission source, and many local governments set emission standards for flue gas from sintering machines below 50 mg/Nm^3.

Disagreeable to the senses, dust and soot cause much complaint among those living in the vicinity of steelworks. Therefore, many steelworks are implementing thorough measures to attain a goal of "visible zero," going beyond satisfying the regulation standards.

Different emission sources employ different dust collecting systems depending on their characteristics. Such systems include venturi scrubbers, bag filters, and electrostatic precipitators. A high-efficiency electrostatic precipitator for sintering machines has been developed. Huge dust collectors are provided to collect dust and soot from the blast furnace cast house and other working environments. Raw materials transportation conveyors are covered, and each junction fitted with a dust collector. Sprinklers are provided across raw materials storage yards. No dust-generating spots are left unattended. Consequently, a 10-million-ton-per-year steelworks treats as much as 30,000 m^3 of air per ton of crude steel produced.

These efforts have lowered the dust and soot emission to about 20 percent of the 1970 level. Today's monthly dustfall in the vicinity of a steelworks is less than 10 tons/km^2, compared with 15-35 tons/km^2 in 1970. This level is comparable to dustfall in rural towns. Smoke from many stacks, once symbolic of the steel industry, is no longer seen, only white steam rising from quenching towers of the coke ovens remains.

Water Pollution Control Measures (Figures 5, 6)

To protect human health, severe water quality standards have been established for toxic substances and also for substances altering such conditions as pH and COD to protect fihsery resources. A very strict effluent standard is set for each effluent outlet. Most regulations specify that effluent should not contain more toxic substances than are "detectable." This is beyond the ability of standardized analysis methods. One of the severest standards not only calls for minimizing quality of effluent, but also specifies the daily mean COD at 5 ppm, suspended solids (SS) at 7 ppm, mineral oil at 1 ppm, and phenol at 0.05 ppm. To meet these standards, effluents from steelworks will have to be practically nonexistent. In addition, a law regulating total quantity of COD in effluent will be enacted in 1979.

To comply with these standards, the activated sludge process, sometimes combined with the activated carbon process, and the ammonia liquor distillation process are employed for treatment of effluent from coke ovens. Sedimentation pits are provided at effluent outlets. Facilities for treating oil in effluent, acid waste water, and alkali effluent are constructed. Further, as much water as possible is recirculated.

The steel industry's water recirculation rate averages 90 percent; more modern steelworks have achieved a higher rate of 94 percent. Considering the evaporation loss, this is nearly equal to complete recirculation.

With these efforts, the pollutants discharged from the steelworks have decreased sharply from the 1970 base figure of 100 to 18 percent for SS, 5.5 percent for mineral oil, and 17 percent for COD. The COD in adjacent sea areas has dropped from 5-8 ppm in 1970 down to 2-3 ppm. Japan's steelworks face seas that are cleaner than those bordering ordinary cities.

EFFECTS ON ENERGY CONSUMPTION

These drastic pollution control efforts have had the following effects on the energy consumption of the steel industry.

To begin with, the energy consumption pattern has changed. The severe sulfur oxides and nitrogen oxides regulations call for use of lower-sulfur fuels and introduction of such clean energy sources as LPG and LNG. This in turn requires oil suppliers to import low-sulfur crude oil and supply desulfurized fuel oil, thus raising energy costs.

Secondly, installation of dust collectors and other anti-pollution equipment has called for additional energy for their operation. Most of the pollution control equipment is electrically operated, and their power consumption--about 100 kWh per ton of crude steel--accounts for about 16 percent of the steel industry. As their energy consumption is expected to increase further, pollution control techniques consuming less energy should be developed as soon as possible.

Where fossil fuels constitute a large percentage of energy sources, increased energy consumption is generally accompanied by an increase in the generation of air-polluting substances. The increased air pollutants demand additional pollution control measures, which in turn lead to an increase in energy consumption, forming a vicious circle. Cutting energy consumption is highly desirable from the standpoint of environmental preservation. Energy-saving measures recently introduced contribute not only to efficient use of energy, but also to environmental preservation.

PROMOTION OF ENERGY CONSERVATION

Japan's Energy Situation (Figure 7)

Among the industrially advanced nations, Japan is most heavily dependent on petroleum and imports for its energy needs. Japan imported

0.65 MMBD in 1960, then 5.49 MMBD in 1973 when the oil crisis occurred. As much as 99.8 percent of oil is imported. During the same periods, the share of oil in its total energy requirements increased from 38 percent to 78 percent.

The steel industry was responsible for about 16 percent of the nation's 1977 energy consumption. The steel industry's energy sources were made up of about 60 percent coking coal, about 23 percent electricity, and about 17 percent oil in 1977. The weight of coal, which serves both as an energy source and as an iron-reducing agent, is pronounced. Therefore, lowering the blast furnace fuel rate has long been an important problem to the steel industry.

Energy Conservation Measures and their Results (Figures 8, 9)

In early 1974, Nippon Steel set out to attain by 1980 a 10 percent energy saving by cutting the 1973 energy consumption per ton of crude steel. In other words, it was to raise the energy efficiency in steel production, which was about 6000 x 10^3 kcal per ton of steel, by 10 percent. This goal was actually achieved in 1978.

The main steps thus far taken for energy saving are as follows:

- Improvement of blast furnace fuel rate.

  Nippon Steel has established many world records in this field by raising the hot-blast temperature, lowering the hot-blast humidity, and controlling furnace burden distribution. Seven blast furnaces of Nippon Steel renewed their records in February 1979, ranging from 431-452 kg per ton of pig iron.

- Increase of basic oxygen furnace (BOF) gas recovery.

  In early 1978, Nippon Steel recovered about 91 Nm^3 of BOF gas per ton of hot metal by optimizing the blowing, preventing combustion during recovery, and using the recovered gas more effectively. These efforts help to decrease dust emission, too.

- Increase of continuous-casting ratio.

  The continuous-casting process consumes about 50 percent less energy than that of the conventional ingot process. This process accounted for 50.8 percent of Nippon Steel's total semi-finished steel production in February 1979, more than double the world average.

- Improvement of reheating furnace fuel consumption.

Fuel consumption by reheating furnaces is lowered by intensifying combustion control, improving the furnace temperature distribution, lowering the discharge temperature, and controlling the rolling timing. Direct rolling eliminates reheating processes, and hot charging decreases fuel consumption effectively. At some steelworks in Nippon Steel, 50 percent of the product was produced by direct rolling and 40 percent by hot charging. These measures help to decrease air pollutant emission, too.

- Development of continuous annealing and processing line (CAPL).

In 1972, Nippon Steel pioneered a continuous annealing and processing line for cold-rolled strip. Conventionally, treatment of cold-rolled strip takes as many as 10 days. The new CAPL reduced this period to about 10 minutes and improved product quality. In addition, it efficiently recovers waste heat from the combusted gas and from the strip being cooled. It contributes to reducing air pollutants, too.

- Recovery of waste energy.

In two or three months, power generation utilizing the top pressure of blast furnace gas will be carried out on 22 blast furnaces nationwide. Dry quenching of coke, effected at some steelworks, permits recovering heat from red-hot coke and controlling dust emission.

- Improvement of rolling yield.

The Japanese steel industry's rolling yield is now 87.4 percent, about 15 percent higher than in the United States. It improved from 81.2 percent in 1970 to 87.4 percent in 1978. This improvement of yield saves the energy for producing about 8 million tons of crude steel per year.

With these efforts, Japan's steel industry is thought to have saved the energy equivalent of about 15 million tons of fuel oil in the five years since 1974.

FUTURE PROBLEMS

The aforementioned environmental improvements and energy conservation are not the results of improvements in equipment only. No doubt, maintenance and control of equipment are important, but no less important are the accumulation of careful controls and minor improvements concerning daily operations. They owe much to the voluntary activities carried out by the "small thinking groups" to which almost all of steel workers belong.

The Japanese steel industry has thus solved such difficulties as the increase in capital investment and running cost incurred by the severe environmental regulation and the need for energy conservation intensified by the oil crisis. Probably, we now have the world's cleanest and most energy-efficient steel industry.

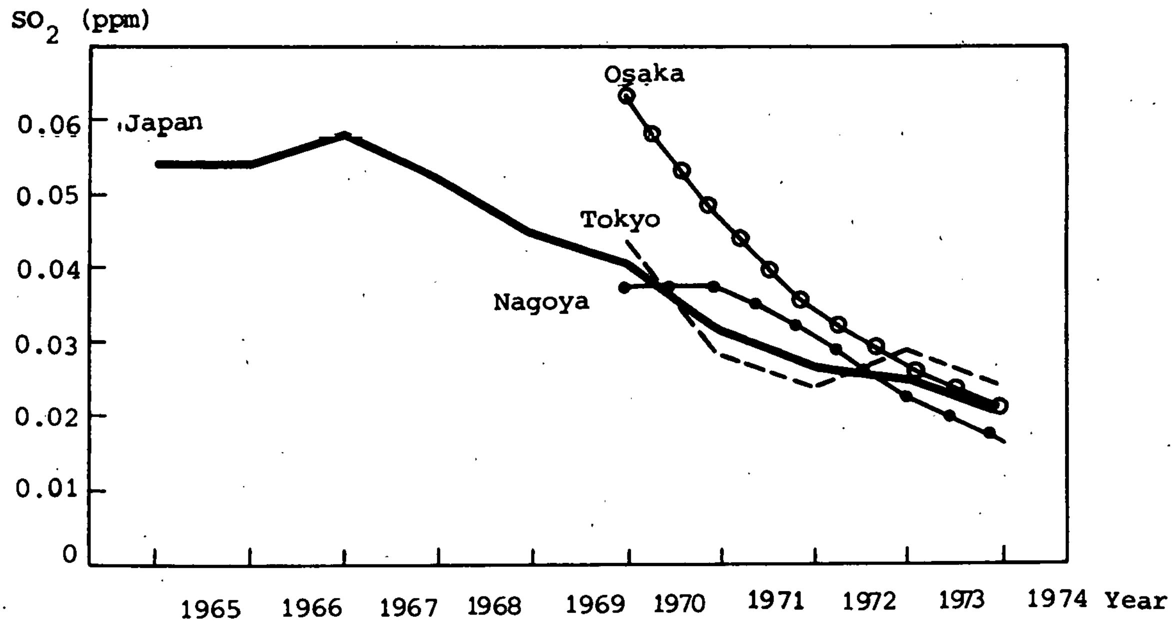
Our experience shows that the following two points must be considered as future problems:

First, it is our duty to develop clean production processes and pollution coltrol techniques causing as little loss of resources and energy as possible. Of course, it is more desirable that plants emit less pollutants and a "clean industry" be achieved. Realization of a clean steel industry, however, entails not only increased running cost but also great impact on energy consumption. At the same time, attempts at unreasonably higher cleanliness would involve waste of valuable resources and energy, and chances of running against the welfare of the people.

Second, international harmony is needed in the field of environmental policy. At present, the level of environmental quality standards and the stringency of environmental regulations differ materially from nation to nation. Of course, it is understood that environmental regulations differ somewhat with geographic considerations of each nation; but it is questionable that the distinct gap between environmental quality standards of nations should continue. Excessively severe standards may prevent rational distribution of resources and energy. Each country can choose an appropriate environmental policy, indeed. Needless to say, if any specific nation wastes environmental resources, sound development of the world economy must be hampered. But, on the other hand, if any specific nation imposes excessively heavy loads on industry, the same conditions may result.

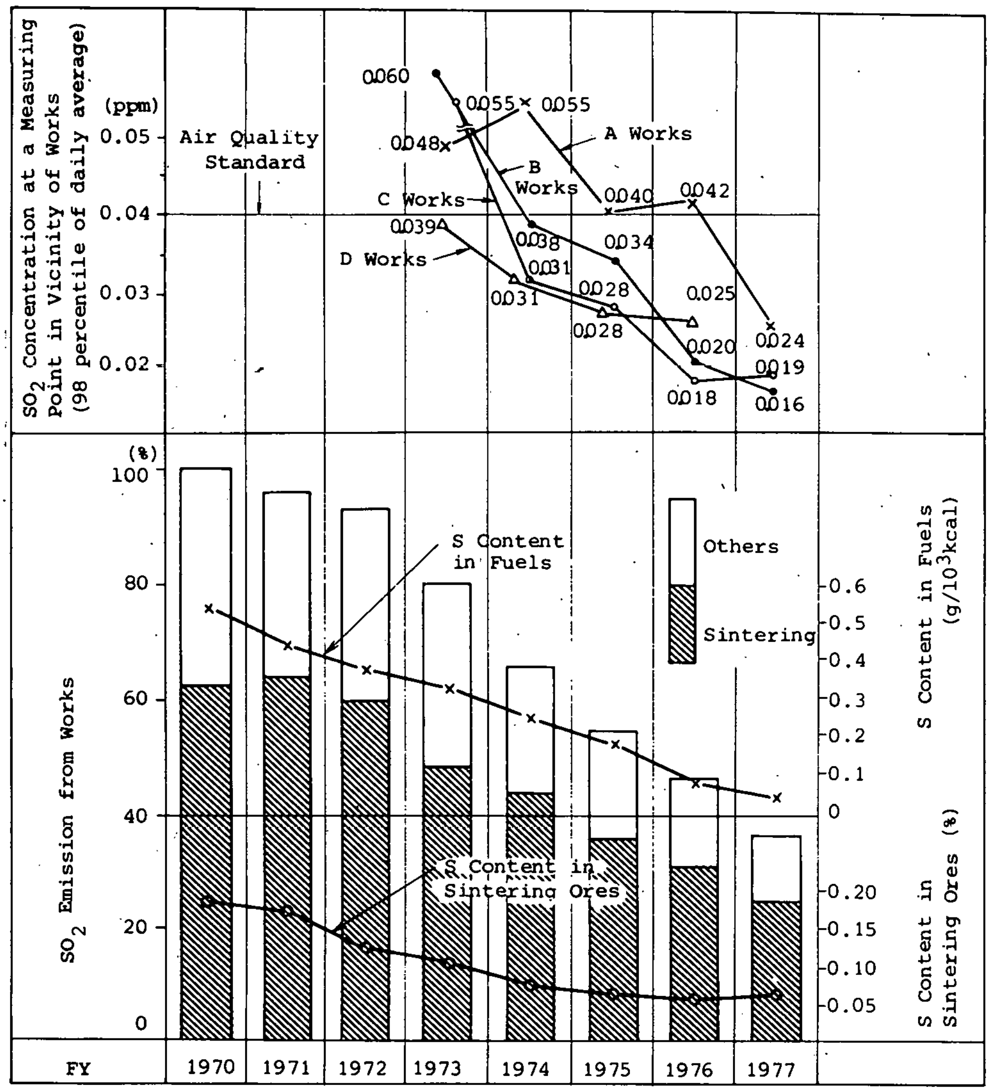
Consequently, it is desirable that environmental policies of nations harmonize with each other. Desirably there should be as little international gap as possible in the scientific knowledge and judgments on which the choice of policy is made.

Figure 1. SO_2 POLLUTION, JAPAN, 1955-1974 AND SELECTED JAPANESE CITIES, 1970-1974



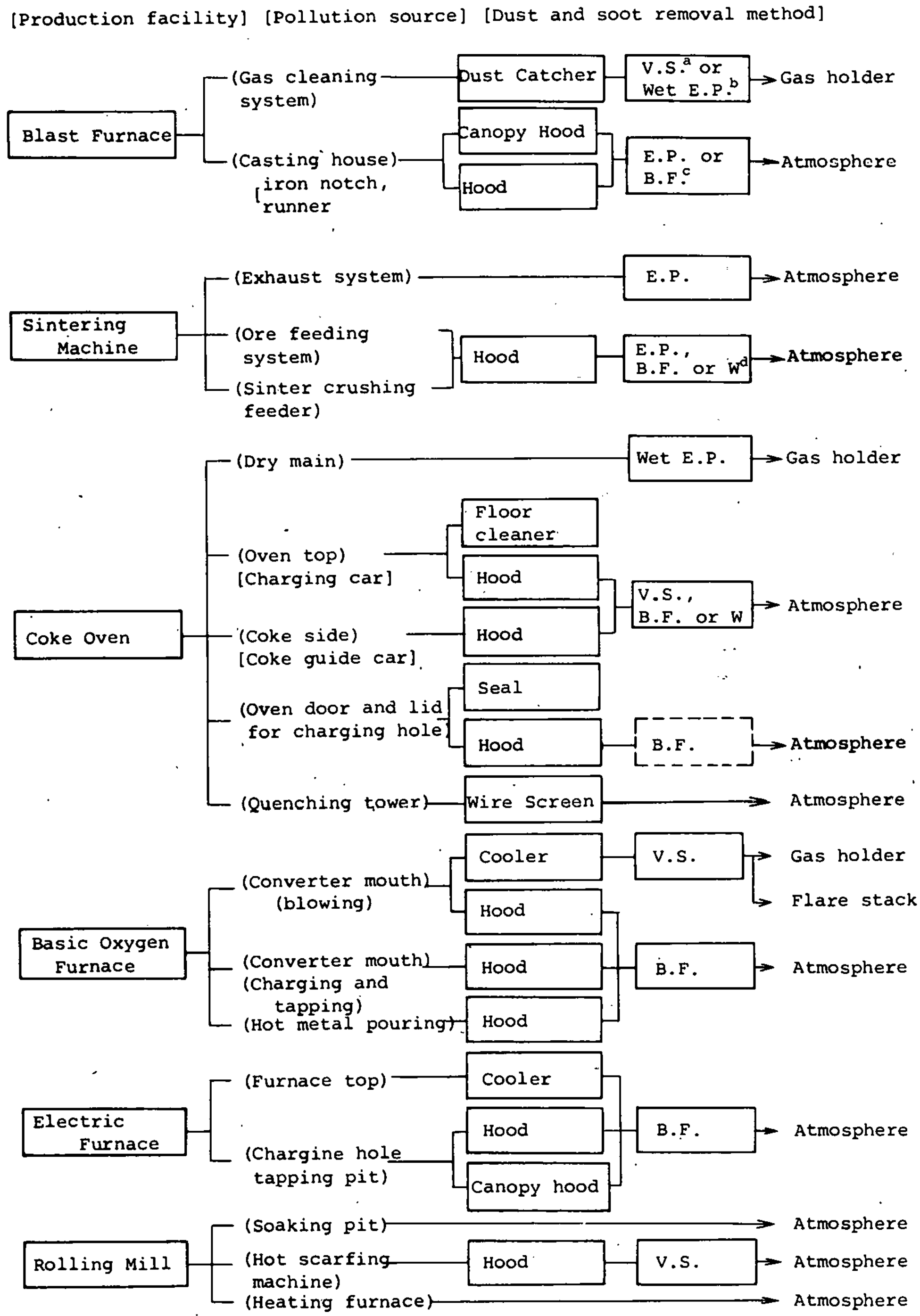
Source: Organization for Economic Cooperation and Development. Environmental Policies in Japan, 1977.

Figure 2. RESULTS OF SOx CONTROL IN N.S.C.



Source: Nippon Steel Corporation

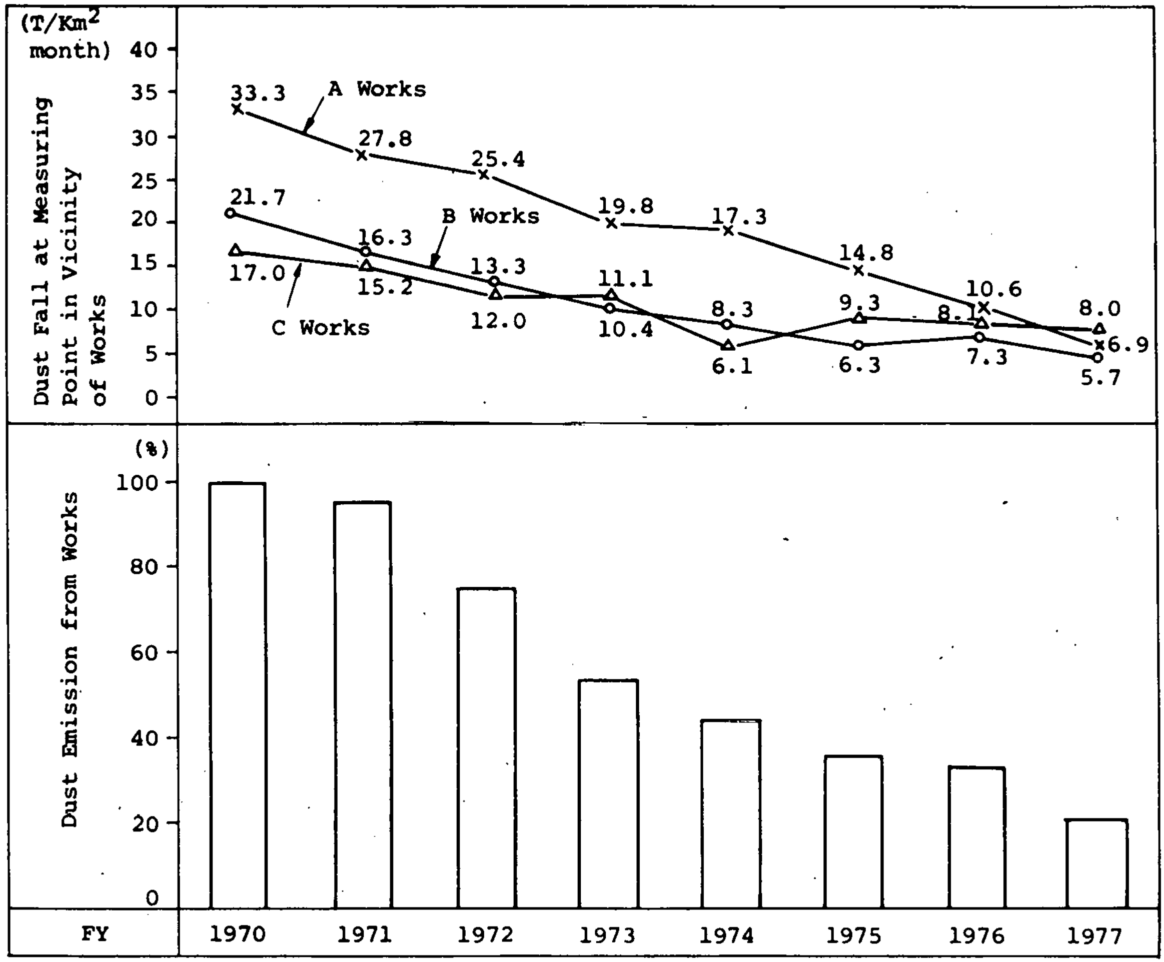
Figure 3. FLOWCHART OF DUST COLLECTING SYSTEM



Source: Nippon Steel Corporation

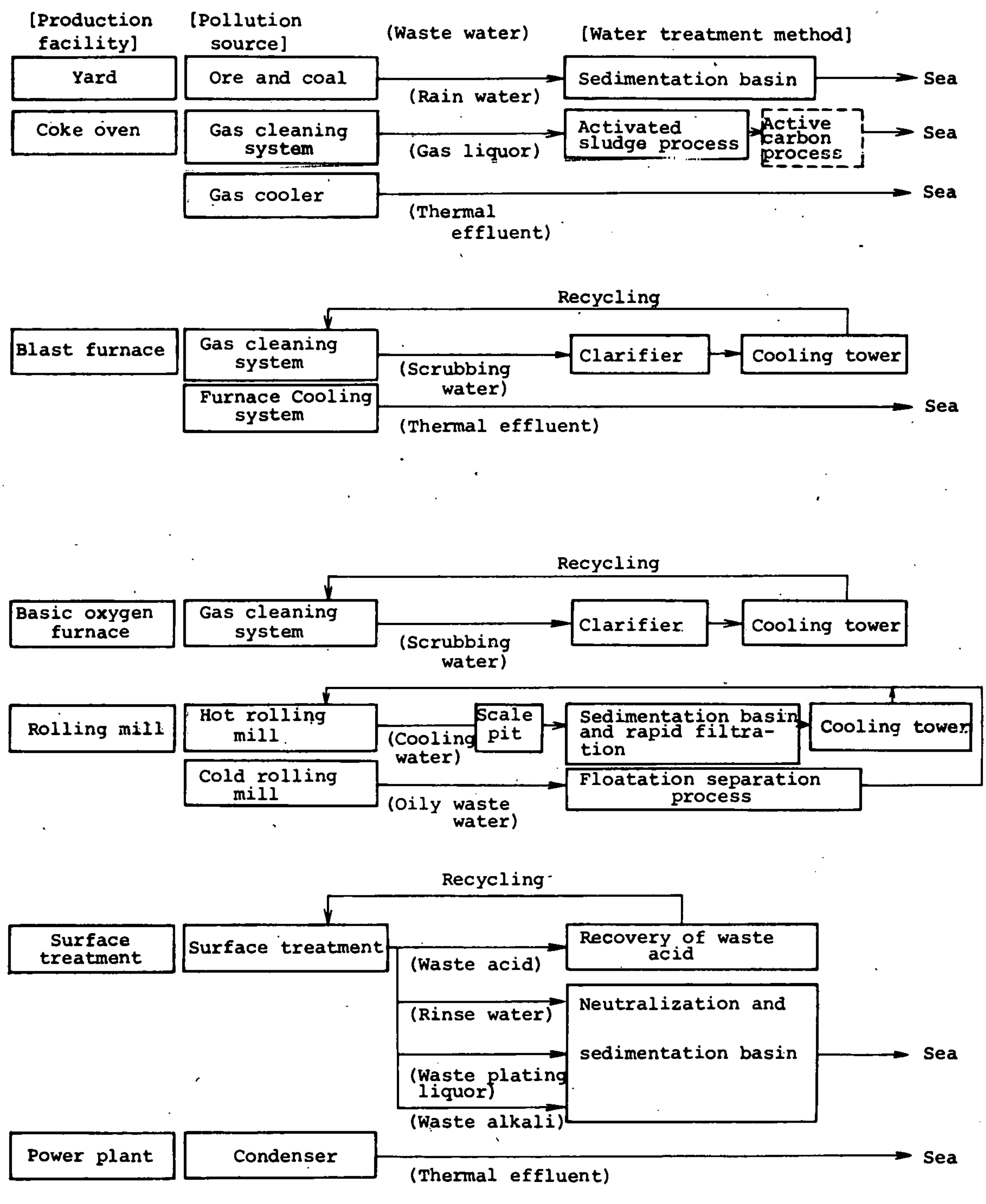
[a] Venturi scrubber
[b] Electric precipitator
[c] Bag filter
[d] Wet type dust collector

Figure 4. RESULTS OF DUST CONTROL IN N.S.C.



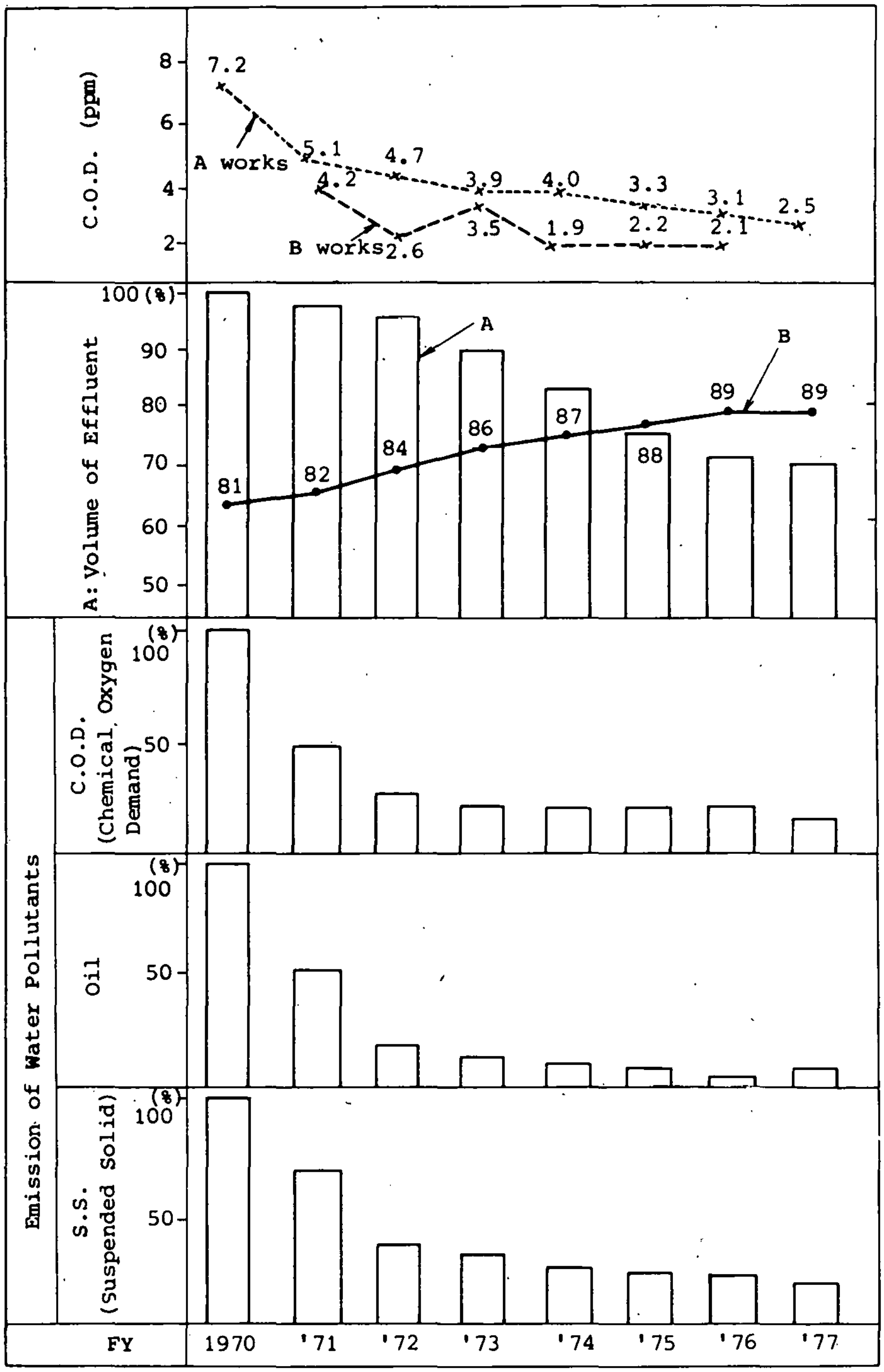
Source: Nippon Steel Corporation

Figure 5. GENERAL FLOWCHART OF WATER TREATMENT



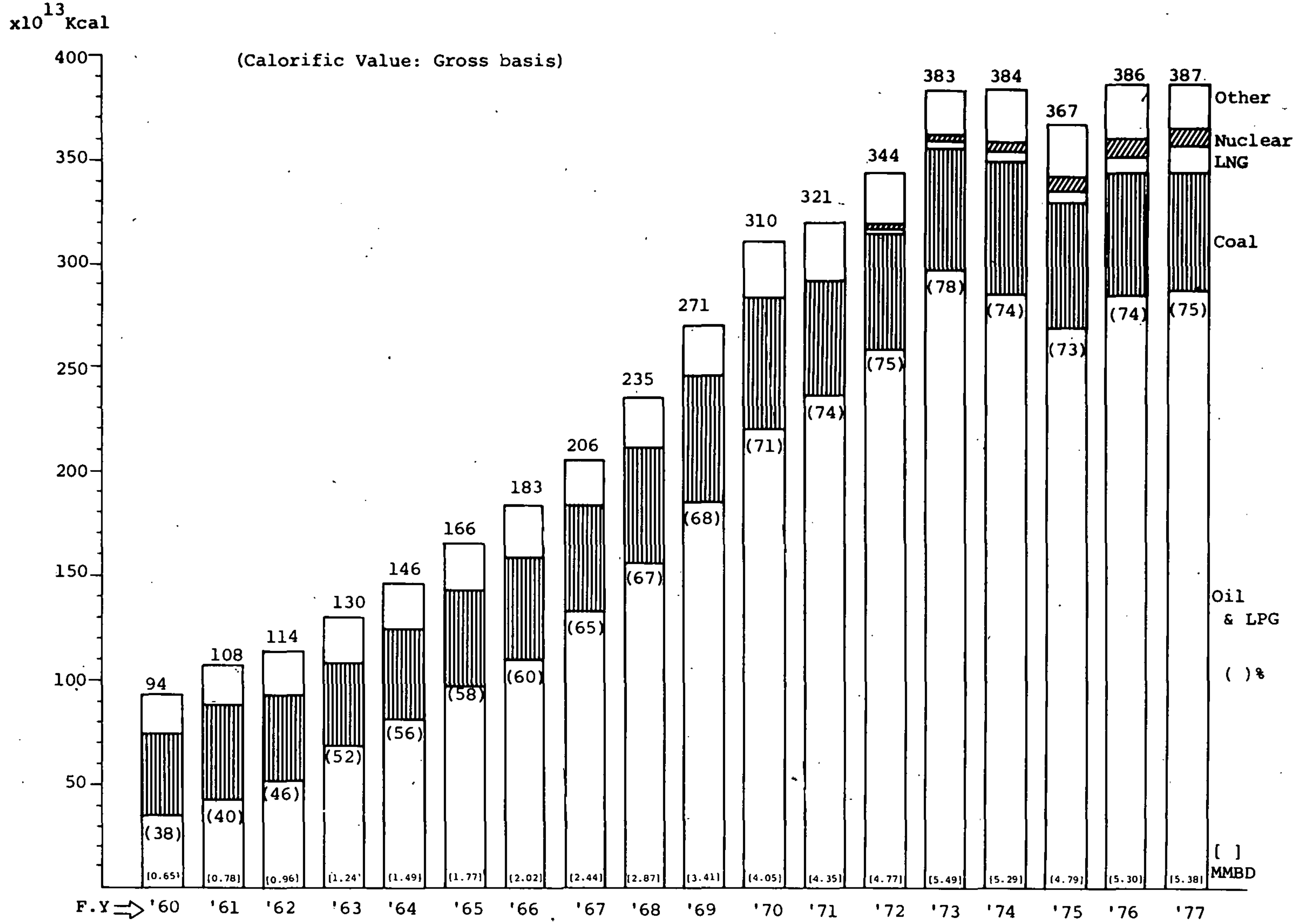
Source: Nippon Steel Corporation

Figure 6. RESULTS OF EFFLUENT CONTROL IN N.S.C.



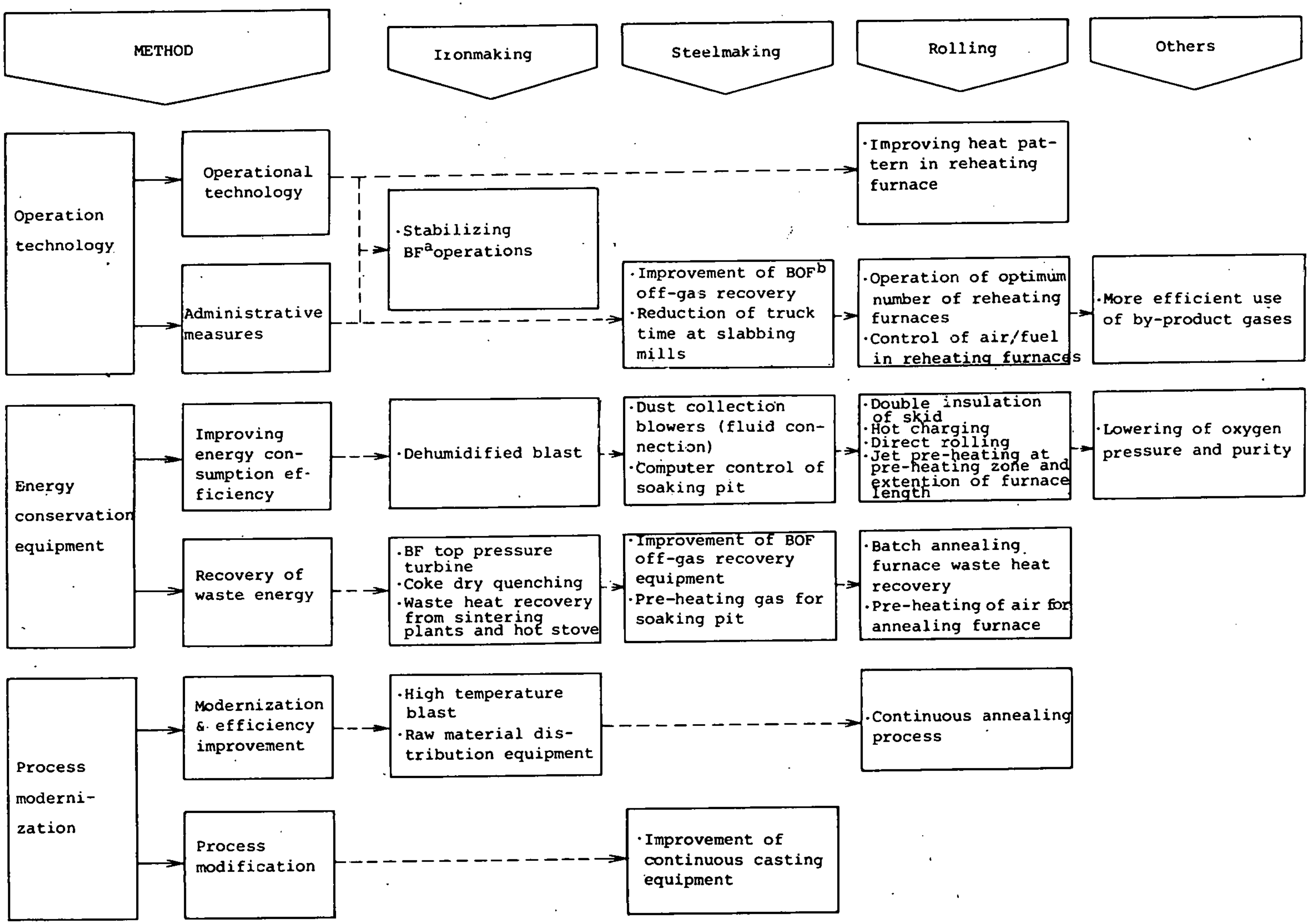
Source: Nippon Steel Corporation

Figure 7. TRANSITION OF PRIMARY ENERGY SUPPLY IN JAPAN



Source: Nippon Steel Corporation

Figure 8. MEASURES FOR REDUCING ENERGY CONSUMPTION AT INTEGRATED STEELWORKS

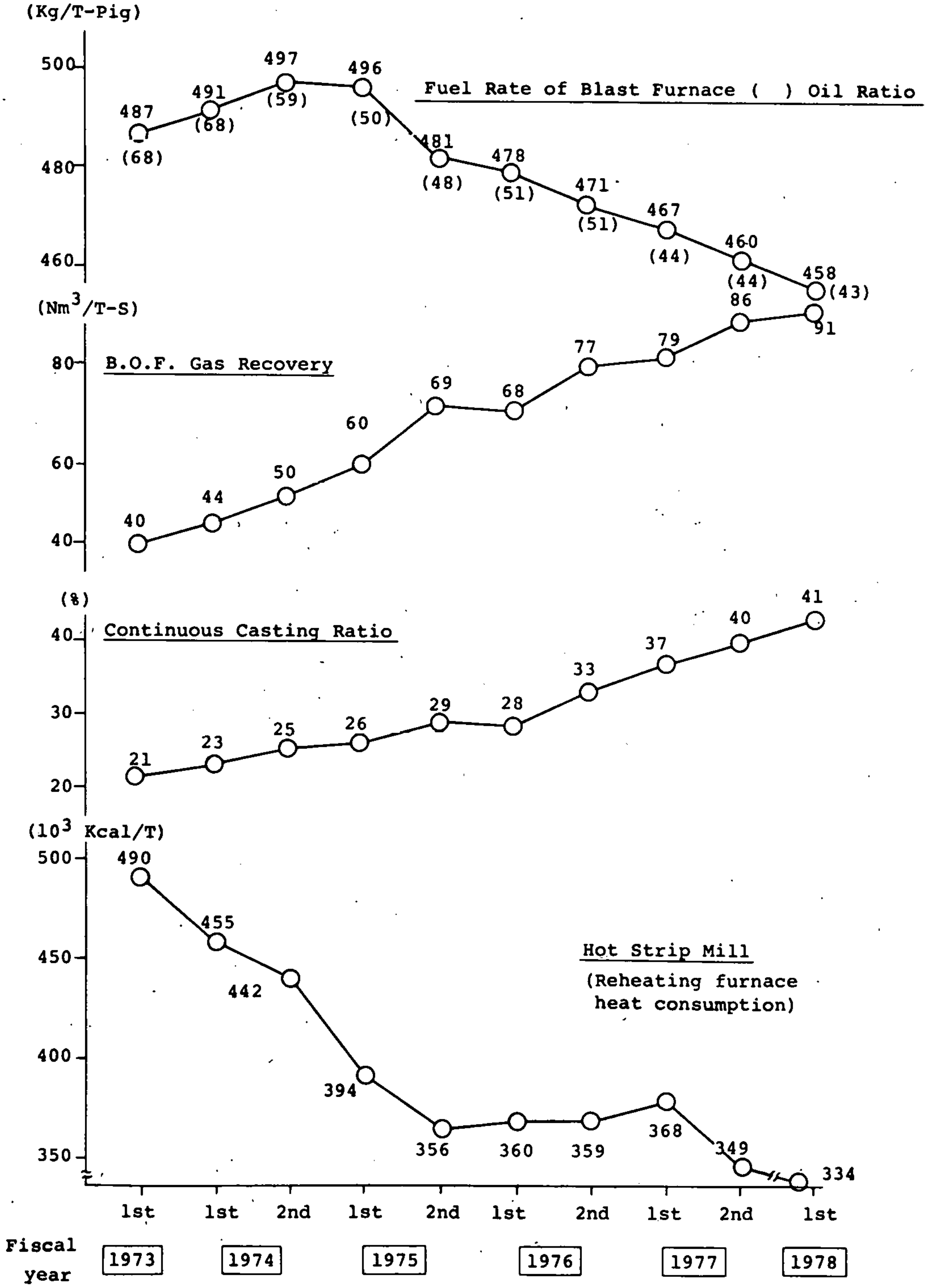


Source: Nippon Steel Corporation

[a]BF - bag filter

[b]BOF - basic oxygen furnace

Figure 9. TRANSITION OF ENERGY INDICES IN MAIN PROCESS



Source: Nippon Steel Corporation

MATERIALS, ENERGY, AND ECONOMIC GROWTH

S. Victor Radcliffe

THE ENERGY BACKGROUND TO SOME MATERIALS QUESTIONS

The existence of a serious and worldwide energy problem is now generally recognized by government and industry leaders. The public, especially in the United States, has frequently doubted the existence of such a problem, but is now rapidly accepting it as real. How is this problem, its associated policy issues, and the options for their resolution likely to be affected by the materials questions necessarily involved in energy production and use? This interplay is clearly important when considering whether the associated materials supply and the increasingly demanding requirements for the technical performance of materials can be met in the timeframes envisaged for exercising particular options for energy generation and conservation. Perhaps less obvious, but still important, is whether, or how much, changes in the energy conditions for materials might raise materials prices and increase import-dependence on processed materials for industrialized countries, including the United States. To varying degrees, all of these aspects appear to be behind the increasingly frequent contentions that strong and important interrelationships exist between energy and materials. This paper examines the validity of such contentions and the utility of any such relationships for addressing the materials implications of the energy situation.

What is the energy problem that now faces most of the world's countries, whether industrialized or developing? Fundamentally, it is the threat to stability and economic growth posed by the continually rising cost and uncertainty of the supply of energy. The present and medium-term version of the problem has a specific focus on oil, because that is the predominant source of energy used in modern economies and the control of its price and the amounts entering world markets has been exercised since 1973-1974 by the small number of oil-rich nations that comprise the Organization of Oil Exporting Countries (OPEC). However, the actions of OPEC can be viewed in one sense as simply having brought forward in time the type of price and supply consequences that were eventually bound to arise due to the geological limitations on world ability to continually expand oil production. The rapid growth of energy requirements that has accompanied increases in population and standards of living during this century was already hastening the onset of the inevitable peak in production expansion. Only the exact timing of the impact of that longer term physical constraint is as yet uncertain.

Given this central energy problem, the corresponding issues that confront the oil-consuming countries relate to the choice of steps to be taken to reach two closely related objectives: to minimize damage to their economies now and in the near term; and to facilitate, with the least possible economic and social costs, shifts away from oil toward a mix of energy sources and a pattern of energy use and efficiency that will lead over the longer term to improved adequacy and reliability of energy supply. The significant influences of energy supply, availability, and price on such national priorities and concerns as economic growth and employment, inflation, and security have made energy issues a central feature of national and international policies.

The criticality of the energy problem and the range of possible steps to deal with it vary widely from country to country. Likewise, a variety of derived problems and issues are perceived. Nevertheless, the basic concerns outlined above are common to all countries.

Also common to all countries is the fact that energy is only one of several physical resources that must be combined with labor, capital, and technology to comprise all the factors essential to the production of increased national wealth that constitutes economic growth and well-being. A significant degree of substitution among these factors is possible. The proportion of each factor used in particular industries varies considerably among countries, and over time in any one country. These variations depend on the differences in industry structure, in product mix, in technology, and in the relative availability of the various resources, as well as on the different relative prices among the inputs. Predominant among these other physical resources are materials, that is, the substances from which consumer and investment goods are made, maintained, and repaired. Such substances include steel and other metals; glass, cement, stone, and other ceramics; chemicals and synthetic polymers; and lumber, paper, cotton, and other natural polymers.

While materials and energy are only two among the key factors required by advanced countries for the provision of goods and services in their economies, contentions are frequently made, as indicated above, that special and close interrelationships exist between these two resources. But how valid are such contentions and how significant, in fact, is any such interdependence? In particular, in the present world of changing price and availability of specific forms of energy, are there relationships that really might provide useful insight into the corresponding changes in the demands likely to be made on materials? Do they offer insight into possible constraints that materials price and availability might place on a given country's options for dealing with the basic energy problem in relation to national priorities and concerns?

Clearly, materials are needed for traditional energy supply technologies--to expand and improve existing energy production processes, such as constructing new coal mines, or reducing losses in electric power generation and transmission. Likewise, advances in materials are needed to meet the unique performance requirements of new energy processes--for example, high-efficiency solar cells. They are also needed to improve energy efficiency in the use of consumer and investment goods, such as by permitting lighter-weight automobiles or better insulated buildings. Conversely, energy is required in the manufacturing processes of transforming materials into goods, and even more so, in the extraction and manufacturing of materials themselves.

Such specific forms of interdependence do offer practical means to define the changes in the performance, types, and amounts of materials needed to meet certain aspects of likely national patterns of future energy production and use. But the important question remains as to whether trying to extrapolate from such a case-by-case approach is a practical approach to obtain necessary information on patterns of materials requirements at the national level. Are there more general relationships for energy and materials in national economic activities that might provide a better guide to the consequences--i.e., to the critical questions and priorities for materials (and vice versa)--that could arise from the changes being sought in national energy supply and consumption?

In actuality, and in marked contrast to the case of energy consumption, there has been little quantitative analysis of the characteristics of the requirements for materials in a national economy, as opposed to their use in specific technical activities within limited sectors of the economy. Particularly new is the comparison of total materials requirements among several countries and as a function of economic growth (Radcliffe, 1978; Radcliffe et al., in press). One outcome of the latter approach is an inverse relation, noted for several countries, between the ratios of national materials consumption to national economic output and the ratios of energy consumption to output, which appears to imply a strong substitutability between materials and energy. Yet it remains uncertain whether or not this inverse relationship is fortuitous. If real, it could imply an important consequence for future materials requirements as the world patterns of energy supply and use change over the next several decades.

As a preliminary attempt to resolve uncertainties for this and other possible relationships, the present paper compares quantitatively the nature of requirements for materials and for energy in several advanced countries.

PRINCIPAL CHARACTERISTICS OF PAST CONSUMPTION

How have materials and energy consumption varied in different countries with time and changes in technology, with growth in GNP and in population, and with one another? To consider these questions, we examine consumption at several different levels of economic activity. First, the total requirements for the national economy, including both production and final demand. Secondly, the industry's requirements for the production of goods and services. Thirdly, we examine the interplay of energy and materials within the materials sector itself, i.e., within the extractive and manufacturing industries that produce materials in finished form for use by all other industries. Four major industrialized countries are considered: the United States from 1900; and Japan, the United Kingdom, and the Federal Republic of Germany, from the early 1960s. These countries exhibit a diversity of behavior in economic growth and industrial development, ranging from a slowly growing economy--the United Kingdom--to one of extremely high rate of economic growth--Japan. Among them they account for close to half the current world industrial production. The principal sources used for the relevant energy data are intercountry comparisons of energy consumption conducted at Resources for the Future (Darmstadter et al., 1977; Dunkerley, 1978, in press); national energy balance data from the Organization for Economic Cooperation and Development (OECD) (1976) and other international agencies; the Conference Board studies on energy use in manufacturing industries (Myers, 1974; Myers and Nakamura, 1978); and a number of process-oriented studies, especially those carried out for the Bureau of Mines (Battelle, 1976; Hayes, 1976). The materials data are drawn principally from the work at Resources for the Future on materials requirements in relation to economic growth, which involves six industrialized and two developing countries (Radcliffe, et al., 1979). The longer-term data for U.S. consumption of primary materials and primary energy from the beginning of the century is derived from Spencer (1972).

The consumption measures for energy and for materials are of two kinds: The principal unit for total energy is an equivalent physical measure based on a summation of the energy content of the amount of different primary fuels consumed; the actual unit used here is metric tons of crude oil equivalent, as adopted by the OECD. The second energy measure, also in terms of primary energy fuels, is the price-weighted index of physical volume used by Spencer to describe the long-term consumption behavior for the United States. This measure is the yearly summation of the products of the amounts consumed for each energy fuel in its customary unit of sale, and its price per unit in a single reference year (1967). For primary materials, a physical-volume measure analogous to the latter was also used (Spencer, 1972). In addition, a value measure for the consumption of materials in finished forms was derived from analyses of national input-output tables (Radcliffe, 1978).

National Consumption

For the United States over the major period of its economic growth from 1900 into the present decade, Figure 1 compares the changes in GNP (in constant dollars) and in population, with the consumption of both primary materials and primary energy. The consumption data are taken from Spencer's (1972) volume measures for 1900-1969 in constant (1967) dollars, together with linked data for the 1960s and 1970s converted from the input-output values (Radcliffe, 1978). Apart from the erratic behavior during the "economic gap"* of 1930-1945, use of both materials and energy grew consistently with increasing national economic activity and population. However, while the volume of materials required at the beginning of the century is larger than that of primary energy, the rate of increase over time is considerably less. By the late 1960s the amounts of energy required overtook the amounts of materials. The figure also shows that the general rate of growth of energy requirements is roughly similar to that of the GNP. In contrast, the trend for primary materials requirements appears to be much closer to that for population growth (Figure 2).

The changes over time in both materials and energy requirements relative to population are compared in Figure 2a. For materials, the requirements per capita, apart from a slight rise at the beginning of the century, remain approximately constant until the economic gap. After the gap, per capita consumption is again approximately constant, but at a somewhat higher level. Finally, after the beginning of the 1960s the requirements per capita begin to rise, and thereafter continue at a roughly constant growth rate until the present. In marked contrast, primary energy shows no period of essentially constant per capita consumption. Instead, per capita consumption increases throughout the century, although at differing rates of increase over successive periods of time. Even over the period of the 1960s, when per capita requirements for materials are also rising, the growth rate for energy consumption is considerably higher.

The behavior relative to overall economic activity is striking in its inversion from the per capita behavior. Thus, in Figure 2b the ratio of primary materials input to economic output (GNP) shows a steady downward trend over the entire century. In contrast, the corresponding ratio for energy varies much less over the century. After rising to a peak in the 1920s, it declines until the early 1950s and, thereafter, the trend is almost level. In the case of energy, it is well known that the consistently upward trend in per capita consumption over the century was accompanied by dramatic changes in the relative amounts of the different major energy fuels--firewood, coal, oil, and natural gas--that comprise that total consumption. Namely, the use of firewood and coal declined dramatically, while that of oil and natural gas both substituted for them and met a large part of the expansion of per capita consumption.

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*The "economic gap" refers to the periods of the Great Depression and World War II, during both of which economic activity deviated widely from the preceding and succeeding trends. Over that gap, the consumption behavior of materials and energy, as would be expected, deviates from the "normal" trends. The deep recession of the single year of 1921 is the only other period of like aberrant behavior.

In the case of materials, the total per capita consumption increased much less during the century, and exhibited two long periods of essentially constant consumption. Nevertheless, as in the case of energy, that behavior is the outcome of substantial changes in the nature of the per capita requirements for the major classes of industrial materials that make up total consumption. These classes are the metals, the nonmetallic mineral products, the chemical and synthetic products, and the natural products or organic polymers based on wood and agricultural fibers. Figure 3 illustrates the differences in the trends of per capita requirements for the primary materials corresponding to these principal classes of industrial materials. The per capita consumption of primary forest materials (timber) peaks shortly after the turn of the century, and thereafter declines to an approximately steady value that has persisted from the postwar period until the present. In contrast, the consumption of primary materials based on agricultural products rose steadily from the beginning of the century until the beginning of the economic gap. Only after World War II, did the consumption decline to the level that has been maintained since the middle of the 1960s.

For the primary mineral materials, consumption of all three major classes--metallic, nonmetallic, and chemical--exhibited increases over the century. In the case of the primary metallic materials, it is especially noteworthy that the World War I and World War II periods were both associated with jumps to higher levels of materials consumption per capita. This suggests that the technological changes associated with the wartime activities had strong effects in raising the general level of subsequent consumption of metallic materials. Overall, the very different behavior of each major class led to a substantial change in the mix of materials that comprises the total requirement. The principal feature has been a shift toward mineral materials and away from forest and nonfood agricultural materials. The share of the latter fell from some 75 percent of the total in 1900 to some 40 percent by the 1970s.

Although consumption data for Japan, Germany, and the United Kingdom is available for only the 1960s and the early 1970s, the comparison is instructive because this period covers levels of economic development spanning a large part of that experienced by the United States since the beginning of the century. The data for these three countries in Figures 4a and 4b, were derived for materials from national input-output tables and for energy from national energy balances converted to the primary resource units reported in the preceding figures. In Figure 4a, the per capita consumption of primary materials for the United States shows a steady upward trend with increasing economic growth expressed in terms of per capita GNP. The trend for the United Kingdom appears similar, but the actual level of consumption is somewhat lower. In sharp contrast, both Japan and Germany exhibit higher levels and much higher rates of increase in per capita consumption of primary materials with increasing economic growth than those for the United States or the United Kingdom. For primary energy consumption per capita, the general trends with economic growth are much more similar for all four countries (Figure 4b). Again, the United Kingdom has a slightly lower consumption level than the United States over a comparable range of income per capita. However, unlike materials consumption, Japan and Germany exhibit consistently lower levels of energy consumption per capita than the United States.

The ratios of consumption of primary materials and primary energy to GNP exhibit changes in relation to economic growth somewhat analogous to those for per capita consumption. For the materials/output ratios, Figure 5a shows that, over comparable periods of economic growth, data for the United Kingdom fall close to the data for the United States, whereas Japan and Germany have generally higher ratios. The energy/output ratios for the United States are the highest for all four countries, with the United Kingdom only slightly below. As with materials, both Japan and Germany exhibit energy ratios that are consistently and substantially different--in this case, lower.

These national consumption characteristics for materials and for energy in relation to time and to economic growth reveal strong differences in behavior among the countries. In particular, Japan and Germany exhibit considerably greater growth rates and higher consumption levels (both per capita and per unit of economic output) for materials, compared with both the United States and the United Kingdom. In the case of energy, the rates of growth in consumption are more similar among the countries. However, the levels of consumption for both Germany and Japan are substantially lower than for those of the United States and the United Kingdom over similar ranges of economic growth. Given these features, is there any evidence of relationships between material consumption in these countries that is sufficiently consistent to be potentially useful in judging likely future trends in consumption?

The analogous materials-energy relationships in terms of consumption per capita and consumption per unit of economic output exhibit similar differences among the countries (Figure 6). The questionable reliability of such relationships for estimating future behavior is indicated by the dichotomy of the Germany-Japan and U.S.A.-U.K. data. In addition, the data for the United States lie in the large "scatter boxes" (shaded in the diagrams), rather than in a smooth continuous function. The precipitous fall in the materials ratio data with respect to energy ratio (Figure 6b) is a reflection of the very different behavior of the two with respect to GNP that was shown in Figure 2b.

Industrial Consumption

The total national consumption of materials and of energy can be considered as falling into two major categories--consumption for the production of consumer and capital goods by the nation's industries, and consumption in the provision of services and for the use and operation of goods in final demand (such as the operation of automobiles and household appliances, and the heating and cooling of private homes). Much of the difference in energy consumption between the United States and other industrialized countries is accounted for by the differences in the final demand uses of energy. In contrast, the shares of total national materials consumption that are used directly in domestic final demand are relatively modest in all countries (Radcliffe, 1978). The greater share of direct materials use is for the industrial production of goods and services. Most of that is consumed by the manufacturing and construction industries alone.

Given these characteristics, it is reasonable to anticipate that the relationships between materials and energy consumption and industrial activity would be more consistent among countries than was the case for national consumption? Figure 7 shows that this is indeed the case, although there are still important differences among the countries. The level of industrial activity, or industry size, in this figure is measured by the value-added contribution from the manufacturing and construction sectors to the per capita gross domestic product. The results for materials shown in Figure 7a, confirm the greater similarity among the countries in their requirements for materials at a given level of industry size. Only in the case of Japan does the actual level of materials production differ from the other countries. In the case of energy (Figure 7b), where a complete series of annual data is available, the general trend of energy consumption is similar for three of the countries--the United States, the United Kingdom, and Japan. In the case of Germany, not only is the rate of increase in energy consumption somewhat lower than for the other countries (as was also true for materials), but the general level of consumption appears considerably lower.

Just as the trends in both materials consumption and energy consumption with respect to the growth of the industry sector agree more closely among countries, so the relationship between industrial consumption of materials and consumption of energy is much closer than was the case for national consumption. Figure 8 shows this relationship on a per capita basis. The agreement has been improved by excluding the consumption of energy by the energy sector itself, since the latter varies considerably in relative size among the countries, and is only a modest user of materials. In addition, the nonenergy uses of energy fuels, as in the manufacture of chemicals and other nonenergy substances, have also been excluded on the grounds that these substances have already been accounted for in materials consumption itself. However, even with these changes, it is apparent that, while the increase in materials consumption per capita with increasing energy consumption per capita is similar among the countries, there remain distinct differences in the levels of consumption. In particular, while the United States and the United Kingdom data appear to lie on the same trend line, the data for Japan and for Germany again lie distinctly higher.

The size of the industrial sectors in each country relative to their total economies differs considerably; the value-added contribution of industry to the gross domestic product varies from almost 51 percent in Germany to some 31 percent in the United States. Therefore, considering the industrial consumption of energy separately from the final demand consumption automatically corrects for some of the inter-country inconsistencies noted in the comparisons at the level of national consumption.

Materials Sector

It is well known that certain materials industries are among the most intensive users of energy in the production sectors of modern economies. The iron and steel industry is consistently the largest single industrial consumer of energy in the four countries under discussion. It accounts for 15-25 percent of all energy consumed in the industrial sector (including the energy industry itself), and 5-10 percent of total energy consumption. The chemical industry is likewise one of the largest single industrial consumers of energy, and accounts for some 6-8 percent of total energy consumption. Indeed, in some industralized countries, the chemical industries use an even larger proportion. For example, in both the Netherlands and in Italy, some 20 percent of total energy consumption is attributable to the chemical industries. The foregoing takes into account the fact that energy is consumed by the chemical industry both in the form of fuel and power, and also as industrial feedstock.

While there is some energy consumption data for such individual industries within the materials sector, data for the materials sector per se does not appear to have been compiled previously. Table 1 brings together summary data for the principal materials industries in the United States in 1972. The data are necessarily underestimates of the actual total for the materials sector since the data base is incomplete. This is especially so for the industries based on wood and nonfood agricultural products. Nevertheless, the available data probably approximate some 90 percent of the total energy consumption by the materials sector. The combined sector industries account for some two-thirds of total industrial consumption of energy, with chemical production alone requiring close to a quarter of that amount. In contrast, these industries represent less than one-third of the industrial contribution to GNP.

Among the materials industries, the relationship between energy requirements and industry size is somewhat analogous, as shown for the available U.S. data in Figure 9. The rate of growth of energy consumption decreases with increasing industry size (value-added). The data for the chemical industry span the full range, and show that this trend appears to be consistent within any one industry. The specific level of energy consumption at a similar level of economic size varies among the different materials industries, as would be expected from the differences in technologies involved. For a given industry, some of the change with increasing size is undoubtedly associated with differences in product mix, and in the scale of plants involved. However, although the energy required per unit of value added appears to decrease with increase in value added for all of these industries in the materials sector, the magnitude of this ratio consistently remains considerably higher than those for other industries. Consequently, for any given country, the size of its materials sector and the mix of materials industries are strong determinants of the magnitude of the industrial energy consumption and, correspondingly, of national energy consumption.

How consistent is the pattern of energy consumption to materials production in a specific materials industry, and how do the consumption characteristics differ among countries? At the present time, the steel industry is one of the few in the materials sector for which the requisite data are available. The output of the steel industry (expressed in tons of equivalent crude steel production) is shown in Figure 10 in relation to the corresponding energy consumption by the industry, 1960-1976. The general trend in the relationship is similar over the period for Japan, the United Kingdom, and Germany, with the two latter countries having a consistently higher consumption of energy per ton of steel produced compared with Japan. The data for the United States follows a somewhat similar trend until the mid-1960s, after which it deviates and moves erratically toward the values of energy consumption per unit of steel production that are much closer to the values for Japan. These changes in the intensity of energy required per physical unit of output are shown chronologically in Figure 11a. The fluctuations apparent in the ratio over time demonstrate the importance of using time-series analysis in any attempt to compare energy intensity characteristics among countries. In particular, the ratio is seen to fluctuate toward high values in any year in which there is a strong downturn in national economic activity, such as in 1975. This apparent decrease in efficiency of energy use is associated with the technological characteristics of the industry; many of the energy-consuming stages in large steel plants cannot be cut back in proportion to the reduction of steel production. Since economic downturns do not necessarily occur in each country in the same years, such annual fluctuations can lead to misinterpretations in year-to-year comparisons of the apparent energy efficiencies in the different countries. The longer-term data in Figure 11a demonstrate clearly that the energy efficiency in the Japanese steel industry has been consistently higher than in the other countries over the whole period, but has not changed a great deal in that time. In contrast, the efficiencies in Germany, the United Kingdom, and the United States at the beginning of the period are much lower than those of Japan, but drift up throughout the period. This is especially so for the United States. Indeed, the latter now appears to be closest to Japan in the overall efficiency of energy use in steel production.

The fact that improvements in the efficiency of energy use do not appear to be constrained to output size, or to the existence of extremely large production units, is shown by the data in Figure 11b. The results are particularly striking for the United Kingdom where energy consumption per unit of output fell by some 25 percent over a period when the annual output of crude steel remained relatively unchanged. Somewhat analogous effects are apparent for the United States after the mid 1960s. This figure also illustrates the marked decrease in energy efficiency that accompanies a downturn in the annual output of steel--as from 1974 to 1975 in Japan, for example.

PRINCIPAL FACTORS DETERMINING PAST BEHAVIOR

The following section identifies, and compares the principal factors that appear to determine the characteristics of energy consumption and of materials consumption at the national, industrial, and materials sector levels. In addition, consideration is given to the reasons why the coupling between materials and energy requirements was found in the analyses above to be relatively loose at all of these levels.

Total Consumption

In the case of energy, the total national consumption per capita depends principally on the size, nature, and use of the national stock of "capital goods." The size of this capital stock depends on the number and types of energy-using goods operated both by industry and by individual consumers. The energy-using characteristics that determine how much energy will be used in operating the goods are defined especially by differences in the technology and vintage of the goods. The rate of utilization of the stock, (for example, how many miles a day a car is driven, the level of home-heating or cooling, or the daily output rate of an industrial process) is likewise a strong factor influencing total energy consumption.

While these characteristics of the capital stock can be defined theoretically as the principal determinants of energy consumption, no adequate measurements of any of them are available, especially for cross-country comparisons. Correspondingly, any analysis based on this approach can be made only indirectly from data dealing with factors that influence the capital stock characteristics. These are considered to be principally income (economic output), the price of energy, and physical differences among countries. Such an analysis is outlined below (Dunkerley, in press).

Changes in national income or output appear to involve a direct link with energy consumption in that a rise in wages results in the purchase of more equipment and its more frequent use. In addition, it may also cause industry to use more energy as a result of investing in new capital equipment to try to offset the increased labor costs by substituting capital for labor. This direct effect of national income change can be further modified by both the specific rate of growth in income and the composition of the gross domestic product. Thus, the higher the growth rate, the more likely it is that older capital stock will be replaced, and the new stock is usually more energy-saving. The importance of this factor is shown by the fact that the high energy-intensiveness of basic industry led to investment in energy-saving equipment in those industries, despite falling real energy prices, in the period prior to the early 1970s. The composition of the gross domestic product is made up of a mix of different industry sectors with varying energy intensities. Thus, the actual energy use for any particular sector will be the product of its size and its energy intensity. Accordingly, a country with a large basic industrial sector tends to consume more energy than one with a small sector.

Comparison among the OECD countries shows that the greatest rate of growth of national economies is indeed associated with the greatest rate of growth in energy consumption per capita, and vice versa. However, the fact that the actual relationship of the rates of growth of energy consumption to those of national economies varies widely among countries suggests that income growth per se is not a unique cause of the rate of growth in energy consumption. The two other principal factors that appear important are energy prices and country "geography." Differences in energy prices can be quite large among countries. For example, the average prices in the West European countries have been some 80 percent higher than those in the United States over the past 20 years, a difference which still persists despite the oil crisis and price changes of the early 1970s. These price differences clearly influence both the size of the capital stock in a given country and the energy-use characteristics of that stock, i.e., its specific technology. In addition the price differences appear to affect the rate of use of the stock, at least in the short run. The geographic characteristics that influence energy consumption are principally climate, population density (both average and urban concentration), and individual tastes, such as the American preference for warm houses in the winter and cool houses in the summer.

It is concluded that the high energy use in the United States is due principally to higher income (approximately 70 percent), to lower energy prices (approximately 20-30 percent), and to sparse population patterns (approximately 10 percent). Dunkerley (in press) has used a mathematical model incorporating these factors to forecast energy consumption characteristics. The model gave a good retrospective prediction of consumption characteristics in the various OECD countries over the entire period 1960-1976. Simpler models would probably have given good results until the 1973-1974 crisis, but it is believed that this particular model is unique in its capability of taking into account the changes during and subsequent to that period.

In the case of the national consumption of materials per capita, it is possible to define the principal controlling factors in a manner analogous to that for energy. Thus, materials consumption would be expected to be dependent on the size of the annual addition to the stock of industrial capital goods and consumer goods (both durable and nondurable), on the materials intensity in manufacturing those goods (taking into account manufacturing scrap and the materials incorporated), and on the rate of use of materials in repair and maintenance (i.e., in the operation of the total stock). The last of these three points is undoubtedly much less important than is the share of national energy consumption used in the operation of the capital stock.

As with energy, information on the materials consumption characteristics of the growth and operation of the capital stock is inadequate. However, the indirect factors that are influential are the same as those that influence energy consumption, although the relative magnitude of the effects be quite different. Increases in national income will have the direct effect of producing more goods and correspondingly raising materials consumption. In addition, the growth of gross domestic product will result in the purchase of more capital goods which are materials-intensive, once again raising the consumption level of materials. Finally, the composition of the gross domestic product will exercise an influence in that the larger the industrial sector, the larger will be the quantities of materials required to meet the sector's greater production of goods and services. In addition, some individual industries are much more materials-intensive than others, so that the composition of industries within the manufacturing sector would also influence materials consumption.

Even more so than with energy, these various factors associated with changes in national income are likely to be the principal determinants of materials consumption within and among countries. The two remaining factors of materials prices and geography seem to have much smaller influence than was the case for energy. Thus, materials prices do not seem to have a direct effect on materials consumption, except insofar as an increase in average price of materials tends to increase materials conservation in the production processes of the materials-using industries. Furthermore, materials price effects do not appear to be a major factor in cross-country differences in materials consumption, since the materials prices differ only slightly, in contrast to the large differences for energy prices. Rather than materials prices per se, it appears that the price of goods (which, relative to income, will be a strong factor determining the rate of purchase of goods) in the different countries is a much more important determinant of varying materials consumption than are materials prices. Geographic differences among countries with respect to climate, population density, and taste, have some influence on the purchase of goods and correspondingly on the use of materials, but the effect would again be expected to be much smaller than is the case for energy.

Industrial Consumption of Materials and Energy

The rise in energy use in the industrial sector over the past two decades has been considerably slower than the increase in energy in the other major sectors. This lower rate of increase has occurred despite the fact that real prices of energy declined over the period and fell particularly sharply relative to wages. After 1973, industrial consumption of energy fell in all the OECD countries. However, it is difficult to separate clearly the effects of the price changes from those of the slowdown in industrial production which has also occurred in that period.

Energy use in manufacturing can be considered to depend on the following factors. First, when the demand for products increases, energy consumption increases in industry. Consequently, the ups and downs of the business cycle will have corresponding effects on energy consumption. Second, changes in the mix or composition of demand will influence energy consumption, depending on how the share of the more energy-intensive products is changed. Third, as energy prices increase, energy consumption in industry would be expected to decrease. However, in practice, it has not always been possible to distinguish this expected effect from other influences. Fourth, as capital investment in plant and equipment increases, energy consumption in industry may increase or decrease, depending on the nature of the investment. The reason for this is that investment is geared to overall cost minimization, not simply to energy cost minimization. Finally, technological changes and advances leading to new processes or products may increase or decrease energy requirements, since the purpose of the technological change is not necessarily to deal with the energy question per se. Given these various influences on energy use in manufacturing, it is clear that the level of energy consumption at any one time is the aggregate effect of all of these factors.

It is useful to note at this point that the actual use of energy in manufacturing is heavily biased toward providing heat and power. Thus, for the United States in 1974, 69 percent of the total manufacturing use of energy went into this category, with almost 17 percent going for feedstocks, and close to 14 percent for captive energy use. These numbers correspond as percentages of the U.S. total use of energy to 25, 6, and 5 percent respectively, totaling 36 percent as the manufacturing share of total U.S. consumption of energy.

All of the same factors delineated for energy, except price per se, apply in a similar way to determining materials consumption, as discussed above. Thus, the indirect effect of product prices on the demand for goods appears much more important than any direct effect from materials prices themselves.

In view of the several similarities among the various factors that influence both energy and materials consumption in industry, it is not surprising that a much closer correlation between materials and energy consumption was observed for industry than was the case at the national level.

Materials Sector Consumption of Energy

Energy is required in the production of materials for the following purposes:

- the physical and chemical processes involved in extraction and harvesting, purifying, and shaping and forming to the final materials product;
- the energy associated with the handling and transportation of materials and equipment; and
- lighting, heating, cooling, and other services.

Much of the largest portion of the energy consumed is taken up by the physical and chemical process steps, whereas the remaining two items, which are sometimes referred to as the energy overhead, are generally a relatively small share of the total in these industries. In view of this dominant use of energy in thermodynamically related processes, it is not surprising that the closest correlation between materials and energy is found within the materials sector itself. However, even there, as was noted in particular with the steel industry, the coupling remains loose. It can vary with time within a given country and among countries at any one time. A complicating factor is the absence of widely agreed-upon basis as to the units and process coverage to be used in measurements of energy consumption in the materials industries. This absence can lead to confusion and error in interpretations or deductions made from some of the reported data. This, in turn, contributes to the widely differing numbers quoted in the literature for energy consumption in materials production.

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

1. The relationships between national economic growth and materials consumption are influenced by quite different factors from those for energy consumption. Consequently, the relationships between total materials consumption and total energy consumption per se for a given country do not exhibit a degree of correlation that is useful for projections, and the relationships vary considerably from one country to another.

2. At the level of industrial production (manufacturing and construction), the factors that determine energy consumption are generally rather similar to those influencing materials consumption. This situation is especially the case for the materials production sector. Consequently, the relationships or correlation between materials and energy at these levels of economic activity are much closer than those observed at the national level. Used with caution, they could be of some assistance in judging future consumption trends.

3. Major factors that will determine future trends in materials and energy consumption levels are the growth of industry and its composition. The latter corresponds to the demand mix for industrial products, particularly for capital goods both for industry and for personal use. These characteristics of industry will be the main determinants of materials consumption requirements. In the case of energy, the fact that industry will always minimize cost among all the factors of production means that its energy use may go up or down as growth in overall industrial activity continues. For energy, moreover the national income level and distribution, and the price of energy will be especially important in determining future energy consumption. These factors influence the level and character of final demand purchases of energy-using goods and their rates of utilization, as for example, for houses, home equipment, and automobiles.

4. The degree to which materials are conserved (in the sense of attaining a similar performance of a good for a reduced material input, rather than in the sense of an ethical goal) in the materials-using industries depends on two factors in addition to associated energy costs and availability per se. First, there is the average cost of incorporating materials into a good versus the cost of the other inputs. The price of different materials, or rather the manufacturing cost to translate different materials into a desired product, will only determine substitution among materials. Secondly, there are the opportunities offered by new materials developments for new technologies, as has resulted over the past several decades from the new electronic materials and synthetic polymers. Both of these factors can be expected to exert strong influences on the resulting requirements for energy, and likewise on materials-energy relationships.

5. There is a clear need for a better range and quality of international data on materials use and associated energy effects. Such data (in particular with respect to long time-series, cross-country comparisons) could provide greater insight into the potential contributions to energy conservation of changes in materials technology compared with the effects of changes in the other factors that influence energy requirements. Likewise, such improved insight would facilitate the judging of appropriate priorities for specific materials research and development activities.

6. To this end, it is desirable that the professional materials societies and materials institutions encourage the various national and international organizations to improve the collection and analysis of the necessary materials-energy data, and offer help in designing improved methods. The quality of the present data collected by such international organizations as the OECD, the European Communities, and the United Nations, is mixed, as is that at the national level. Too much of it is confused, inconsistent, and incomplete. More generally, the data are too highly aggregated or too process-oriented to give the information

that is needed to better find and judge the value of technological opportunities for materials and materials industries in energy conservation and supply that are needed to assist the objectives of national energy policies.

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TABLE 1. THE MATERIALS SECTOR SHARE OF INDUSTRIAL ENERGY CONSUMPTION: U.S.A. - 1972

Major Materials Industries	% share of Total Industrial Consumption of Energy*	% Share of Total Industrial Contribution to GNP**
Primary Metals	20	8
Chemicals	24	10
Stone, clay and glass	8	3
Paper	10	4

*Total industrial energy consumption amounts to 46 percent of national energy consumption.

**Total industry value-added amounts to 31 percent of Gross National Product.

Figure 1. TOTAL REQUIREMENTS FOR PRIMARY MATERIALS AND PRIMARY ENERGY (BILLIONS 1967$), COMPARED WITH THE GROWTH IN REAL GNP (BILLIONS 1967$) AND IN POPULATION (MILLIONS) IN THE UNITED STATES. Shaded area is the "economic gap" (see text).

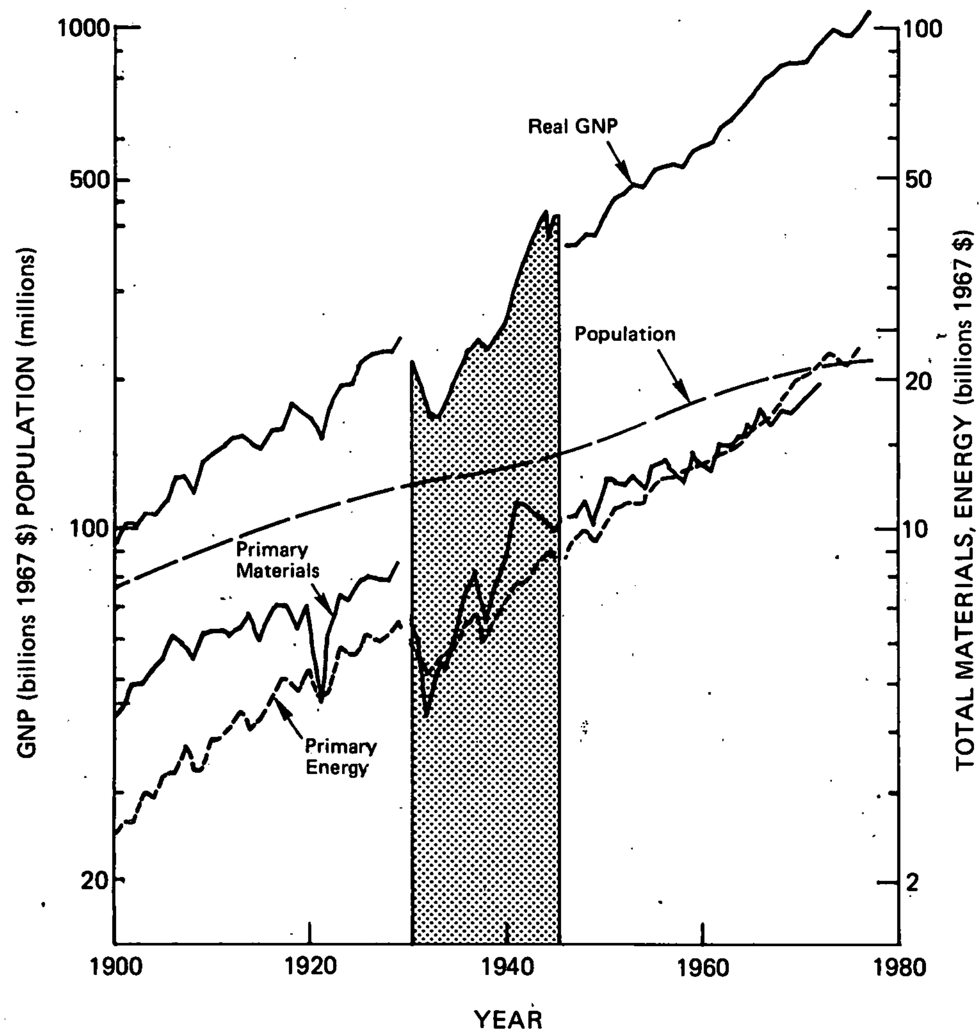

Figure 2. TOTAL REQUIREMENTS FOR PRIMARY MATERIALS AND PRIMARY ENERGY (a) PER CAPITA AND (b) PER UNIT OF NATIONAL ECONOMIC OUTPUT (GNP) IN THE UNITED STATES.

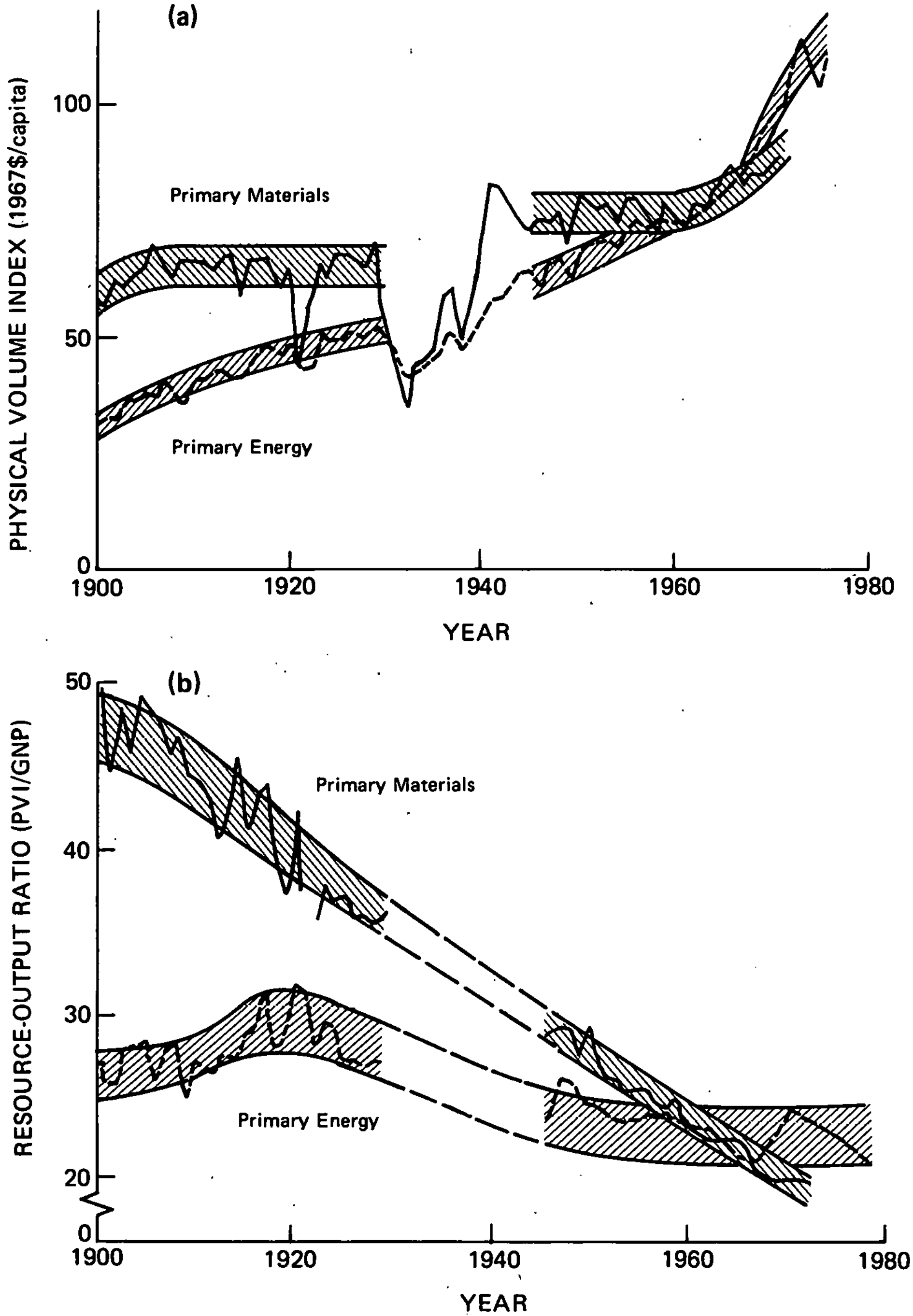

Figure 3. TIME DEPENDENCE OF THE PER CAPITA REQUIREMENTS FOR THE PRINCIPAL CATEGORIES OF PRIMARY MATERIALS IN THE UNITED STATES.

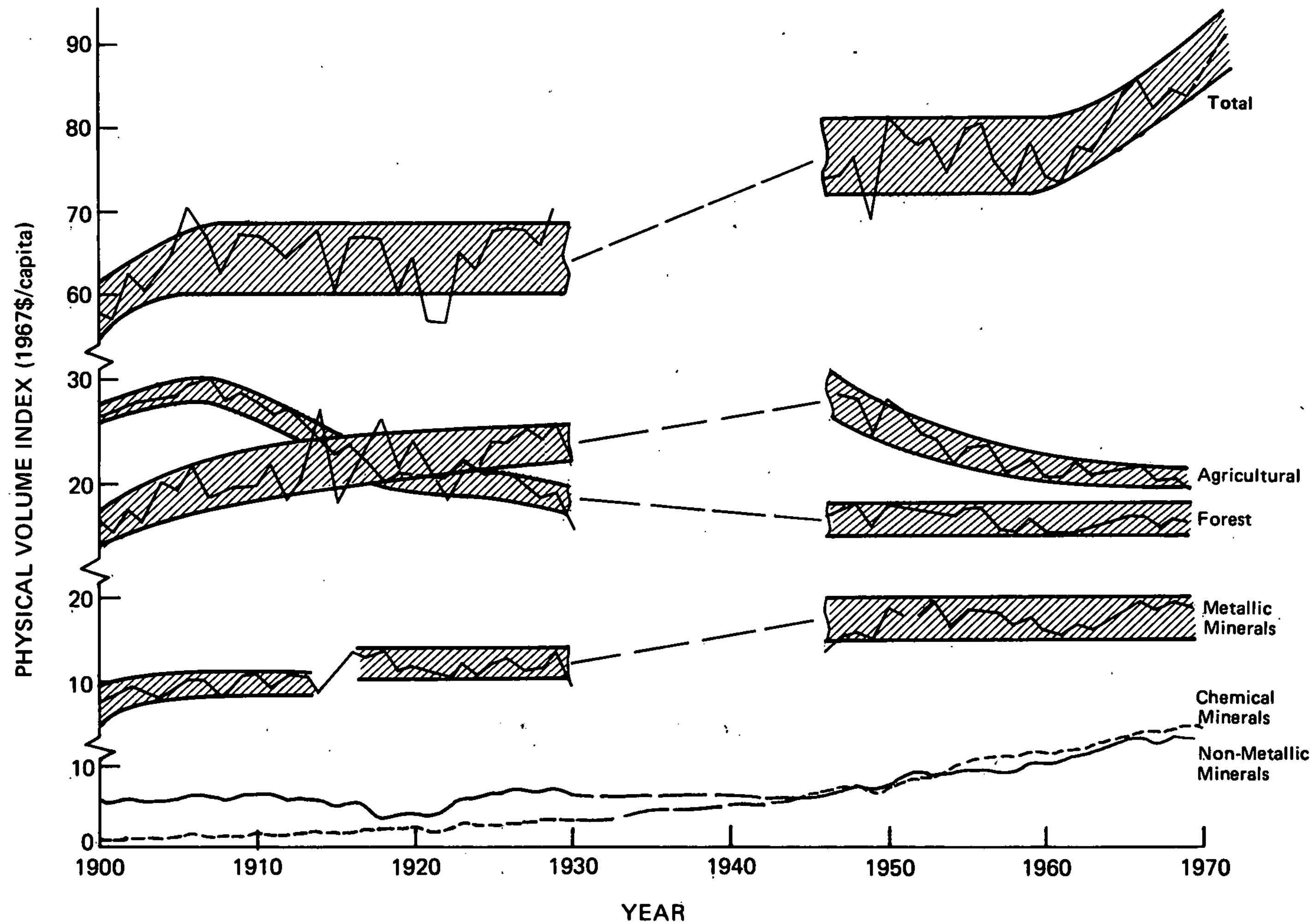

Figure 4. COMPARISONS OF PER CAPITA REQUIREMENTS FOR (a) PRIMARY MATERIALS AND (b) PRIMARY ENERGY, IN RELATION TO ECONOMIC GROWTH (GNP PER CAPITA).

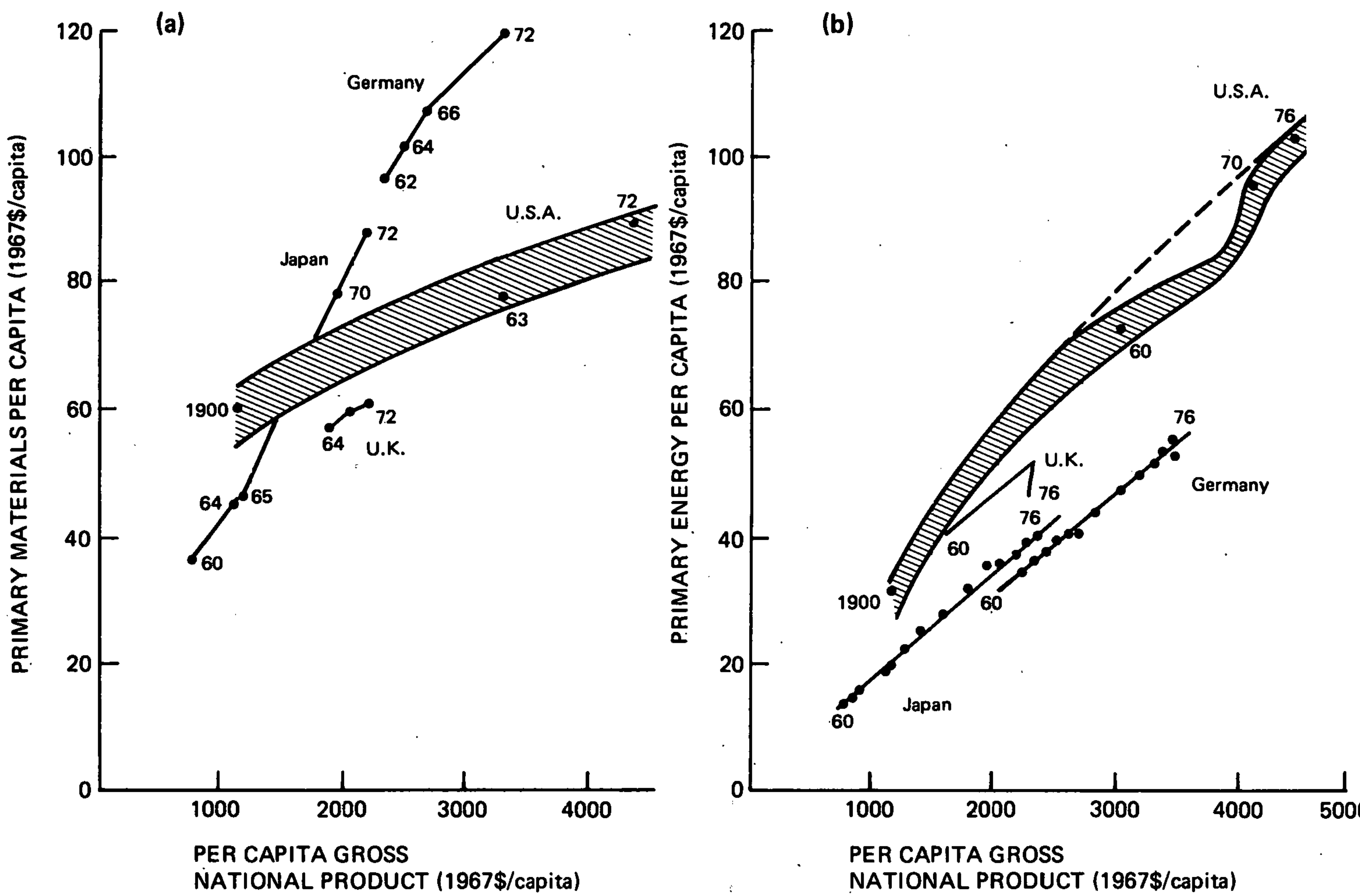

Figure 5. COMPARISONS OF REQUIREMENTS PER UNIT OF NATIONAL OUTPUT FOR (a) PRIMARY MATERIALS AND (b) PRIMARY ENERGY, IN RELATION TO ECONOMIC GROWTH.

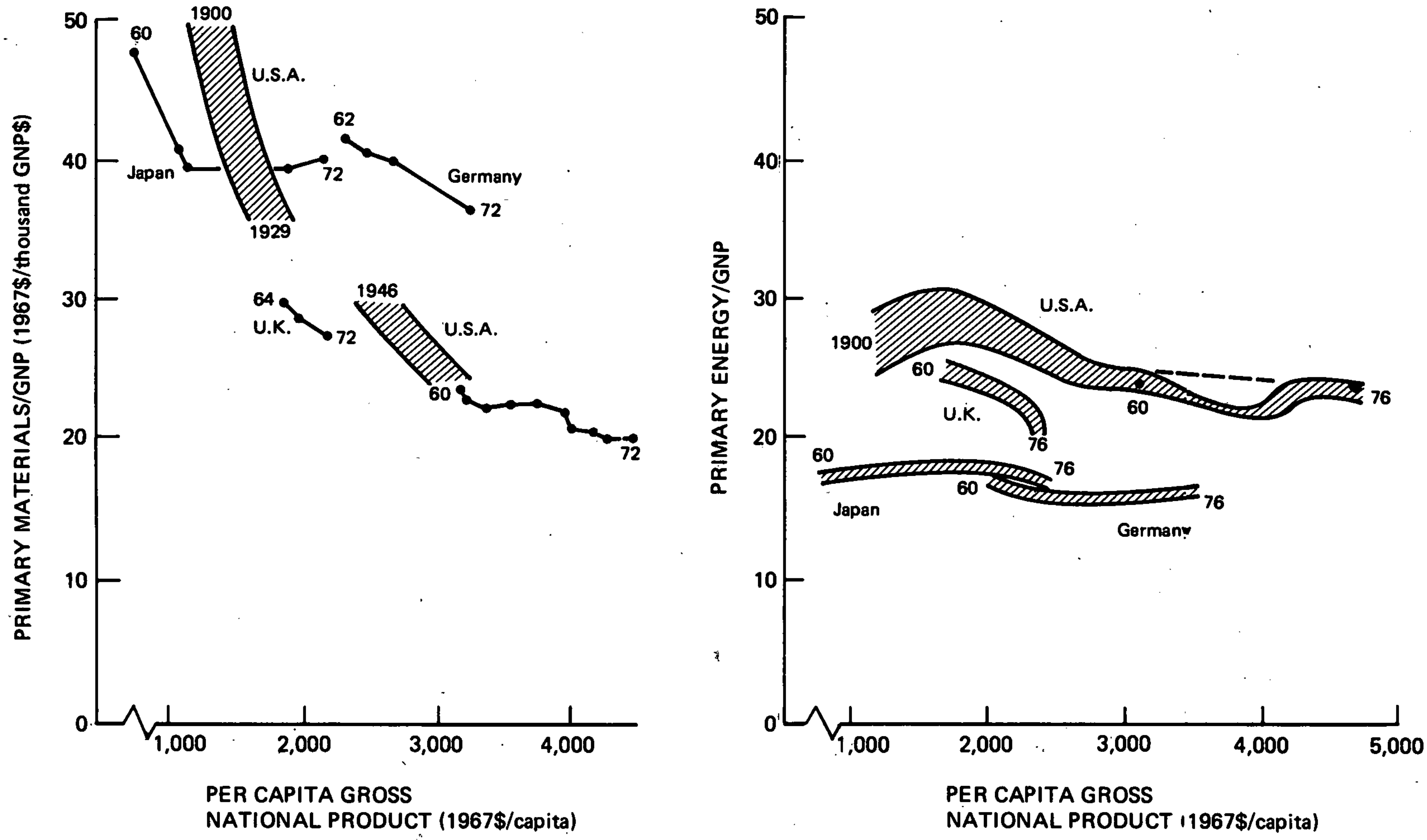

Figure 6. COMPARISON OF RELATION OF MATERIAL REQUIREMENTS FOR PRIMARY MATERIALS TO THOSE FOR PRIMARY ENERGY (a) PER CAPITA AND (b) PER UNIT OF NATIONAL ECONOMIC OUTPUT.

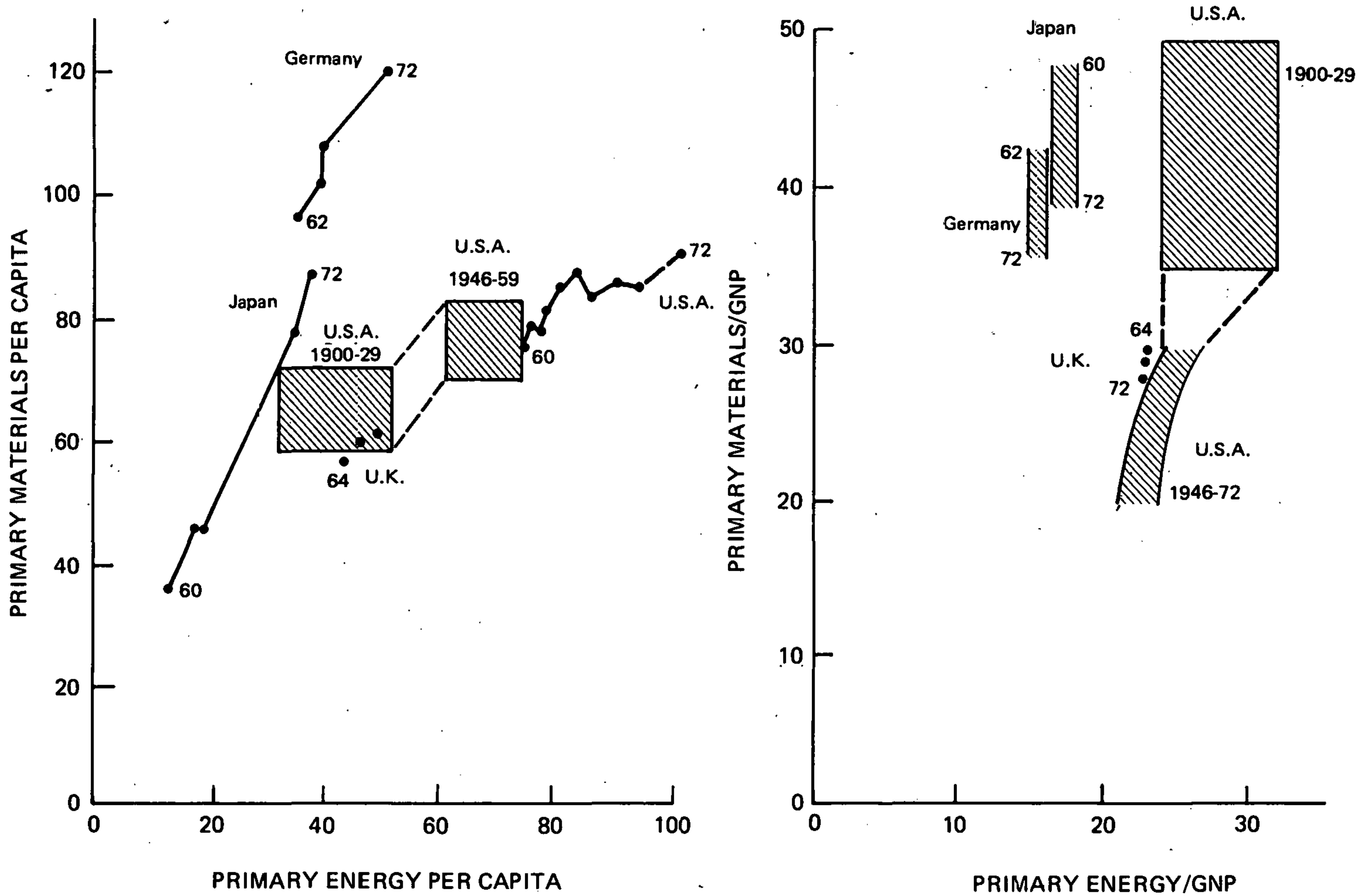

Figure 7. PER CAPITA INDUSTRIAL REQUIREMENTS OF (a) FINISHED MATERIALS AND (b) ENERGY, IN RELATION TO THE SIZE OF THE MANUFACTURING AND CONSTRUCTION SECTORS, 1960-1972.

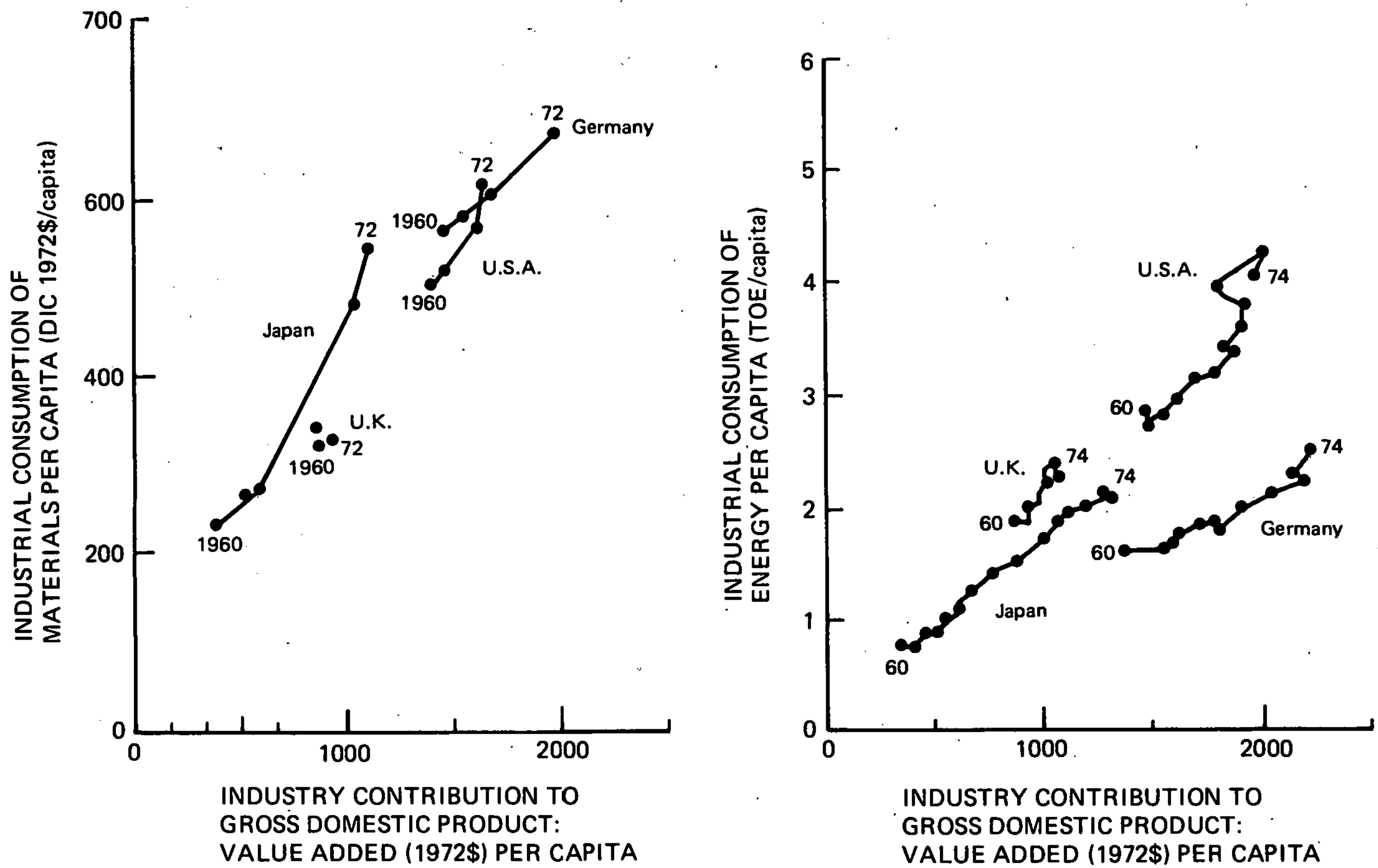

Figure 8. COMPARISON OF THE RELATION OF INDUSTRIAL REQUIREMENTS FOR FINISHED MATERIALS TO THOSE FOR ENERGY, 1960-1972.

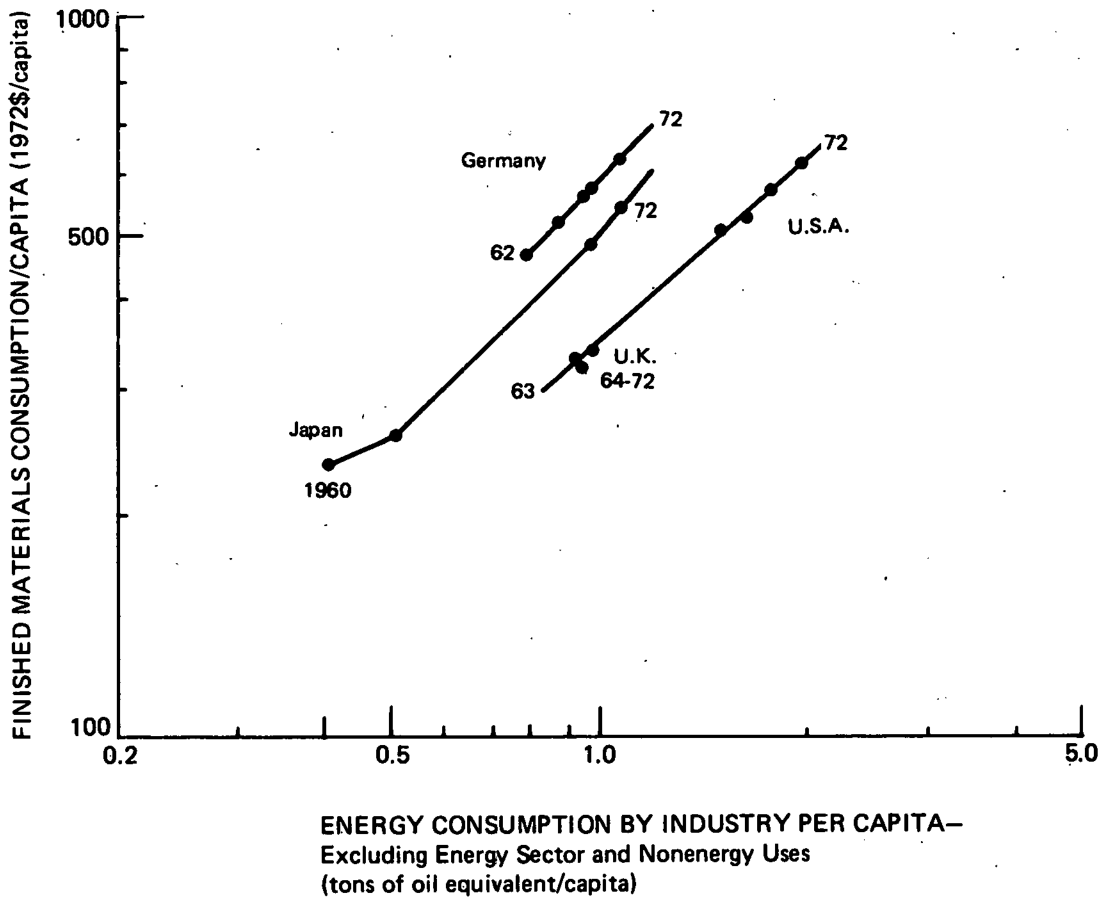

Figure 9. DEPENDENCE OF ENERGY CONSUMPTION IN SELECTED MAJOR MATERIALS INDUSTRIES ON THE SIZE OF THE INDUSTRY IN THE UNITED STATES.

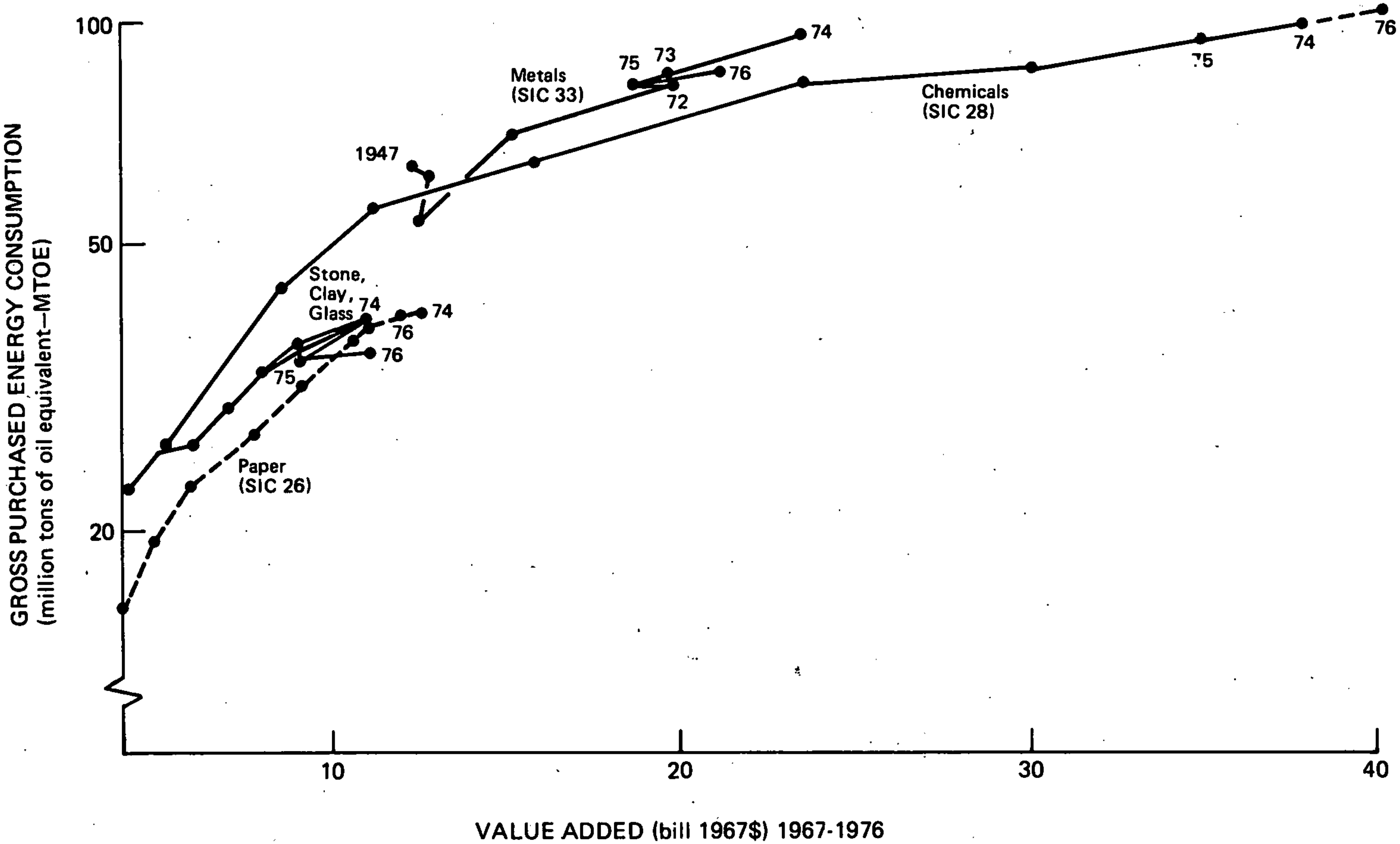

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Figure 10. TOTAL ENERGY REQUIREMENTS IN THE STEEL INDUSTRY IN RELATION TO CRUDE STEEL PRODUCTION, 1960-1976.

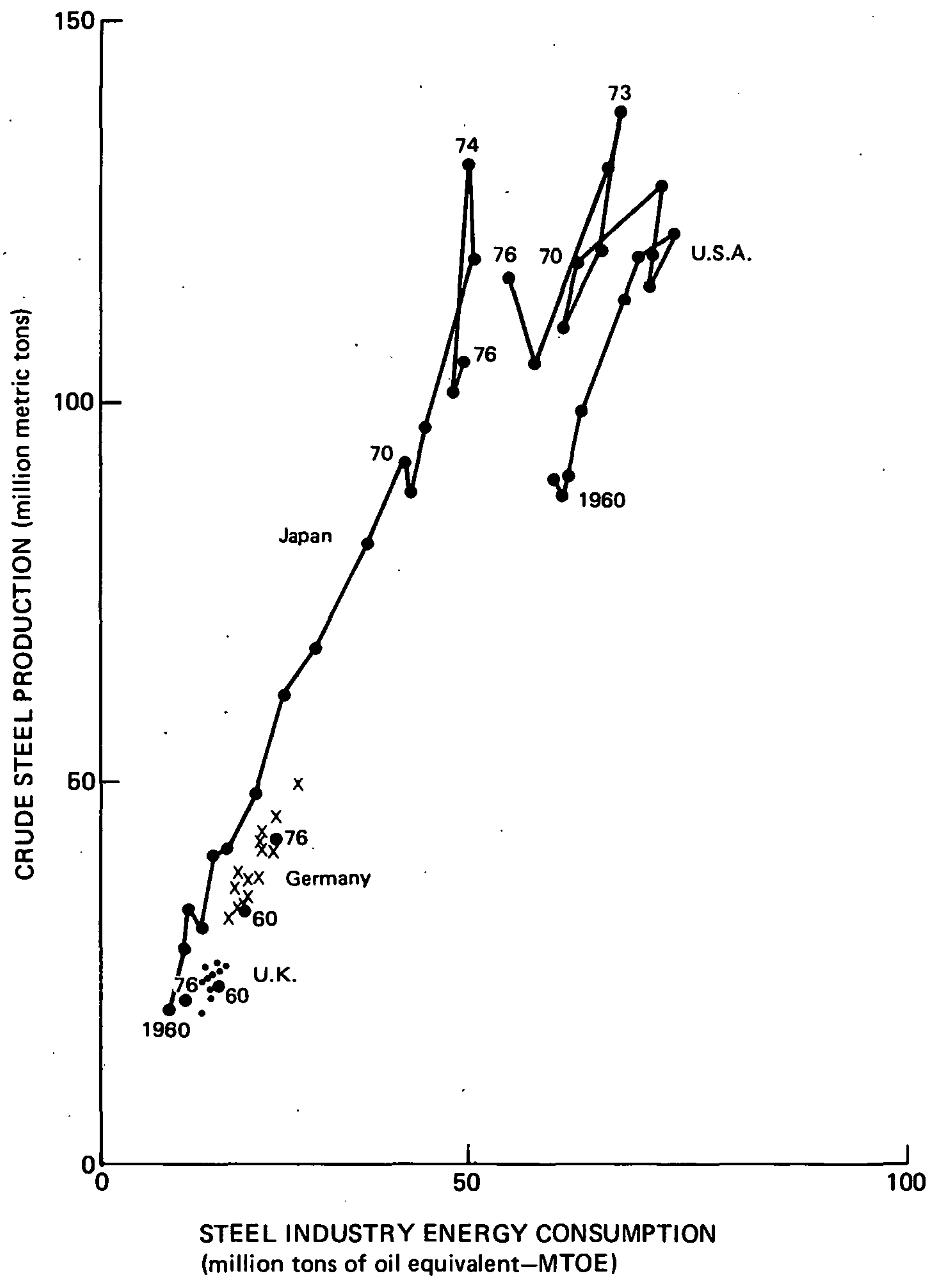
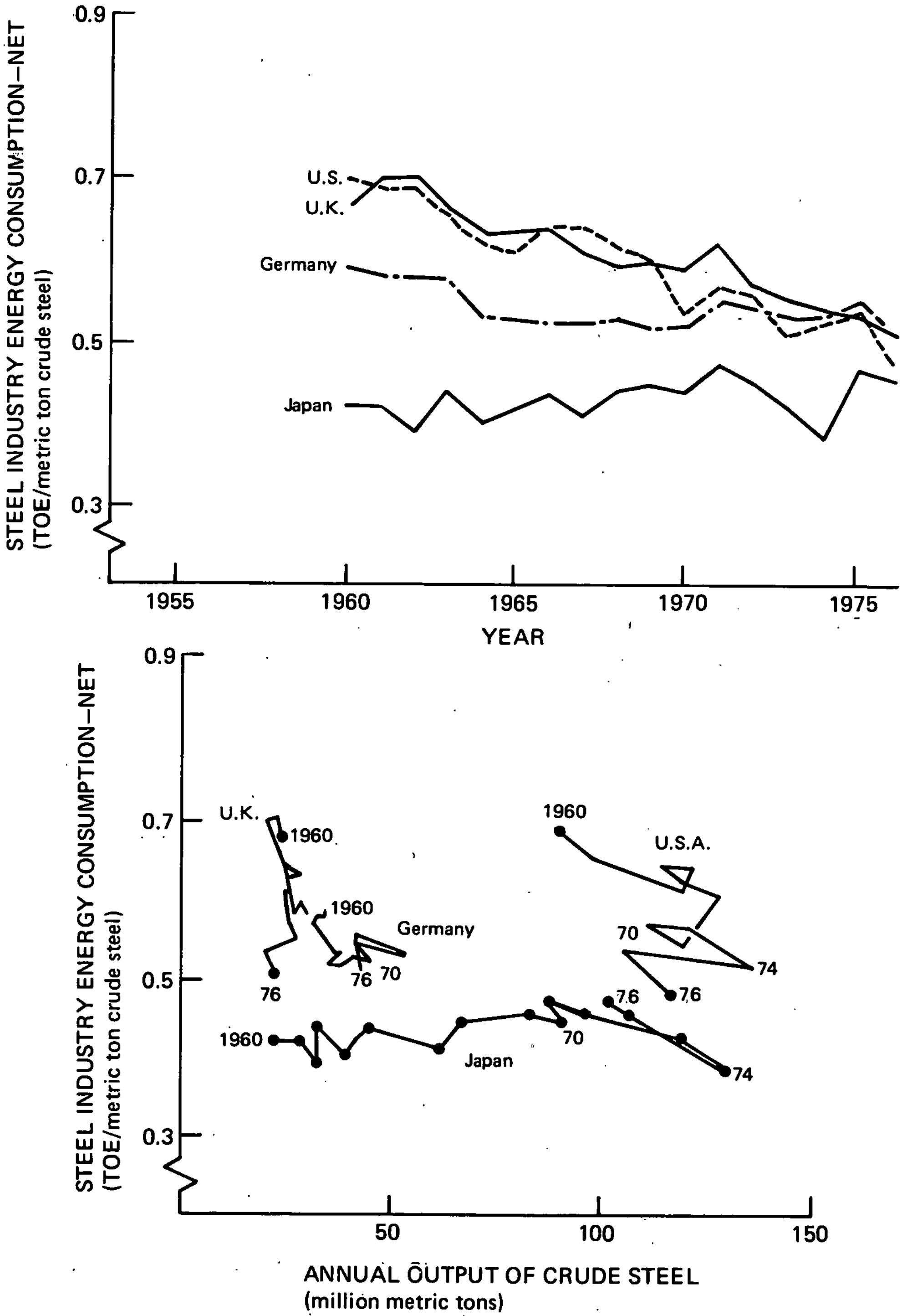


Figure 11. COMPARISON OF THE INTENSITY OF ENERGY CONSUMPTION IN STEEL PRODUCTION (a) 1960-1976, AND (b) IN RELATION TO LEVEL OF CRUDE STEEL OUTPUT.



ENERGY SOURCES AVAILABLE IN THIS CENTURY

S. William Gouse

INTRODUCTION

My assignment for this conference was to present some material that might serve to place the workshop participants on a common basis with respect to understanding what energy resources will be available during the next two decades and then, if possible, to explore the implication of a world materials policy relying on short-range future sources of energy. In order to come to grips with the general issue, one does not have to undertake an original resource assessment. One can find more than enough information in the literature.

For the next 20 years or so, there is sufficient certainty on the downside, even though much more uncertain on the upside, about the data base to draw general conclusions. Information available on proved reserves is quite reliable, although, I believe, conservative, since the fraction of our resources that might be recoverable under various conditions cannot be defined with certainty. Generally resource-reserve estimates have always been conservative. This, of course, must be balanced against the fact that no matter what particular resource we consider the amount of it available is, in fact, finite even though we have not yet found it.

SUMMARY OF FINDINGS

For a period of several decades, there is no physical shortage of resources that may have energy of sufficient thermodynamic availability to make them economically interesting. They are primarily fossil energy resources--oil, gas, coal, shale, tar sands, peat, etc. The distribution of the known reserves and resources is not uniform and leads to difficulties in national security, balance of payments, and development aspirations. In simple terms, the world is sufficiently well endowed with resources to permit a reasonable transition from present patterns of energy use to some pattern as yet undetermined, presumably relying more heavily on renewable resources, or nuclear resources, i.e., fission and fusion. The world could face a much more serious problem with respect to fossil energy utilization than the fossil energy resource foresee that higher prices of energy and more processing of lower quality materials would lead to greater demands for higher temperature, more wear-resistant materials. However, this does not appear to require a major breakthrough in materials science and engineering. If one were to examine a longer time period than the next several decades, one could come to different conclusions. While not known definitively today, the potential material requirements of breeder reactors and various fusion concepts are likely to be more severe than we are able to meet economically at the present time.

One could conclude that the world is relatively rich in terms of sources of energy. While the distribution of various forms is not uniform, there is in principle no insurmountable barrier to reasonable access. However, the potential for mismanagement by governments is large, and the probability of the occurrence of that mismanagement is sufficiently high that it would be wise for all to have developed early, extensive contingency plans, i.e., a number of options. The behavior of the United States in the last five years in trying to come to grips with the energy problem facing this country does not leave one with a warm feeling about us in the world as a whole.

RESOURCE ASSESSMENT

For our purposes it is useful to look beyond the category of "proven reserves," to more general, less certain, definitions of resources. As real prices rise, resources become reserves and one can, in fact, make estimates of what the supply/price curve for various sources of fossil energy might look like. One must, however, keep in mind that a supply/price curve is not a production/price curve. There is a large time constant and a great deal of effort involved in turning potential supplies into production rates. It is fortunate for us, that the Institute of Gas Technology has been publishing regular reviews along these lines and has examined a variety of reserve-resource estimates (in particular, those in the World Energy Conference), trying to put them on a consistent basis. Data from one such study are shown in Tables 1 and 2. There are, of course, earlier studies.

The "Estimated Total Remaining Recoverable" column in Table 1 is somewhat speculative but relatively conservative. From the Table one can get a feeling of the distribution of various resources around the world; that gas has not been used as much as oil; and that there are enormous amounts of coal and shale. One could also conclude that certain parts of the world have essentially no resources, principally South America, Africa, and parts of Asia. However, one must keep in mind that only a small percentage (the order of 10 percent) of the exploratory wells have been drilled in these apparently resource- and reserve-poor areas. The judgment reflected in the distribution of exploratory drilling may reflect fossil energy-poor regions, or it may reflect lack of exploration. From the information in Table 1, one can construct Table 2, which depicts the potential life of world fossil fuel resources at base, and that is the unknown but to some extent likely to be adverse effects of carbon dioxide build-up in the atmosphere.

Fairly conservative definitions of the reserve base indicate that on a global basis there is no absolute supply crisis for the next several decades. However, the difference between what is potentially available because it is in the ground and what is available at end use in finished fuel form is considerable. Examination of the United States as an example, shows how difficult this problem can be. We have enormous resources of coal, oil, shale, and probably unconventional gases. Our inability to achieve expeditious resolution of conflicts between various national goals has led us into a situation where we are unable to use what is physically in place. In addition to conflicts among various goals, in particular social goals--e.g., environment, health, safety, and economic well-being--we have not as a nation, been willing to face the fact that new domestic supplies of energy will cost us more than we have been accustomed to paying, more than imported oil. Over the long term this is true for the world as a whole. These higher costs involve significant questions of equity and the distribution of the resulting cost and benefits among various members of our society. Finally, the time constants for implementation of most concepts to exploit domestic resources are long compared with several decades.

Under normal circumstances the order of exploitation of energy resources having attractive thermodynamic availability, would be to proceed from conventional oil and gas to more unconventional sources of oil and gas, exploitation of heavy oils and tar sands, conversion of shale to liquids, and finally the gasification and liquefaction of coal. Since the supply/price curves for finished fuels from the various sources overlap, it is reasonable to believe that depending on the richness of deposit, location with respect to end use, detailed characteristics of the particular resource, etc., one would find a number of these more expensive supplies exploited in parallel. In fact, some of these more unconventional resources are currently being exploited in various parts of the world as well as in the United States.[1] The implications of such a path of exploitation on world materials policy, at least from the point of view of the United States, would not be extraordinary. One can

[1]South Africa is producing gasoline and other hydrocarbons from coal, and recently announced its third plant. There are some 20-30 commercial coal gasification plants in the world producing fuel gas and/or feedstock for various processes. There is some production of unconventional gas and some implementation of enhanced oil recovery techniques. Shale oil is produced on a commercial scale in China and tar sands are being exploited in Canada.

various constant-demand growth rates based on 1976 year-end estimates. If one takes the highest growth rate and the most conservative estimate, i.e., proven reserves, then the reserve consumption ratio drops to 10 years in the year 2005; and for the lowest growth rate of 1 percent in 2029. For the most optimistic assessment and the highest growth rate, the year is 2067. These numbers in themselves are not important. However, getting a feeling for where one might be in Table 2 for the world as a whole, is important; that is, how reasonable are the numbers in Column C? The generally accepted growth rates for the future, at the present time, are on the order of 3 percent. In order to make this assessment, it is useful to consider what is not included in Table 1, and therefore in the construction of Table 2. First, the numbers in parentheses in Table 1, were not included since those are more speculative numbers than one can normally include under a category called "estimated total remaining recoverable." Also, Table 1 does not include peat and does not really allow for enhanced oil recovery. It makes uses of fairly old estimates for the tar sands and heavy oils in South America. It is based on old information with respect to Mexico and mainland China. Table 2 does not allow for the limited exploration of much of the world, and includes no unconventional gases. In the nuclear area, it does not allow for thorium-based fuel cycles.

MORE UNCONVENTIONAL SOURCES OF ENERGY

The scope of this paper does not permit an extensive analysis of the materials not included in Table 1, but some information is necessary to establish the reasonableness of a potentially large resource base that could be reserves, at no more than 2-3 times the present real price of oil. It can provide some basis for planning for the future. Table 3 estimates the reserves of peat and its potential energy content in the United States with specific information for 15 states with the largest reserves. Note that potential available energy in quads[2] is on the order of 1400. Figure 1 is a map showing the distribution of these peat deposits along with coal of several ranks. It is interesting to note that the peat is generally found in those parts of the country that have no coal. (Alaska is not shown.) The data base for peat is not very extensive, but it is estimated that the U.S. number (the order of 1400 quads) is about one-eight of the world's total. Peat is currently commercially exploited for combustion for either process heat or electricity generation in Ireland, Finland, and the Soviet Union. We do not know how thick the various peat deposits are, what their energy content is, what the environmental effects of exploiting them might be, or even what the best technical approaches might be. My purpose in presenting this information is not to advocate exploitation of peat, but to point out that there is a great deal of it that could be exploited if we had to, and that we ought to learn more about it.

[2] 1 quad = 10^{15} Btu

The heavy oil (not included in Table 1) is not a tar sand, but an oil that cannot be pumped because it is in a matrix that does not permit flow of the material even if its viscosity is reduced. This is different from heavy oils that are commercially produced in California and elsewhere through the application of thermal enhancement techniques, either steam-flooding or fire-flooding. In some of the heavy-oil reservoirs the mobility of the oil can be increased by viscosity reduction, so pumping is feasible. In other heavy-oil deposits, viscosity reduction must be accompanied by some sort of fracturing. The Bureau of Mines has estimated (Figure 2) that there are on the order of 100 billion barrels of this material in the United States.

Table 4 indicates the order of magnitude of total stored energy in organic-rich shales of the United States and principal land areas of the world. The world totals for oil shale containing 10-65 percent organic matter and the energy content in units of 10^{18} Btu, or 1000 quads, are on the order of one million billion barrels of oil equivalent. If the energy equivalent of the leaner shales, 5-10 percent organic matter, is added the numbers are really staggering. Much of this will never be exploited for a variety of reasons. The point is, there are really large amounts of this material in various parts of the world. Our knowledge of this resource in terms of characteristics, depth, quality, etc., is not good enough for serious governmental planning. Our knowledge base is adequate to indicate there are enormous amounts of it. It is an option for the future and we ought to know more about it.

Table 5 provides an estimate of the target for enhanced oil recovery. The difference between the third column and the second column is what is left behind after employment of techniques currently used, i.e., primary production and the use of water flooding and perhaps carbon dioxide. It is unreasonable to believe that all of this difference will be recovered, but some fraction of the 300 billion barrels of the oil left behind will be amenable to economic extraction in the future. We already know where it is.

Table 6 is an estimate of unconventional sources of natural gas from four sources: Eastern shales, tight sands, the methane in coal seams, and the methane in geopressured aquifers. Figure 1, showing the coal fields in the United States, can also be used to indicate where the unconventional gases might be found. The Appalachian region is where the Eastern shales or Devonian shales are located. The Western coal fields are also where much of the tight sand is located, but it is found elsewhere as well. The Gulf Coast of Texas and Louisiana is where the geopressured aquifers are found. Figure 3 is one estimate of the supply/price curve for unconventional gas.

There have been, of course, other attempts to develop supply/price curves that might be useful for energy policy planning. Prior to the 1973 oil embargo, the National Petroleum Council had conducted a number of studies looking into the future. Unfortunately, the cost basis has changed so dramatically since 1973 that it is very difficult to interpret these older documents. The most recent set of supply/price curves for a variety of fossil energy resources were prepared in a market-oriented program planning study (MOPPS) (U.S. Department of Energy, 1977) undertaken by the Energy Research and Development Administration. This work has never been formally released but the documents are available from the Department of Energy. Figure 4 is reproduced from that study and shows what the MOPPS group thought in 1977 about the high-Btu gas supply/price curves for the future. There is considerable uncertainty in Figure 4, in particular the shape of the curves for Devonian shale, methane from coal, and tight sands are suspect. However, it was a useful study in that for a variety of resources it put future supply-price estimates on a common basis. Again, one should keep in mind that supply-price curves are not production-price curves.

Most of these estimates about the future of high-Btu gas, both conventional and unconventional, do not consider deep resources, that is much below 20,000 feet. Nor do they consider that there may be a source of methane other than decayed fossil material. Recent work by MacDonald (1979) postulates that there is considerable evidence that methane continuously comes up from fairly deep within the earth. This may be in addition to that being generated from biological material, or it may be how all of the more deeply situated gas became trapped. In any case, his work is important in that it changes the perspective in terms of exploration for gas and may open considerably the range of geologic regions which might be fruitfully exploited.

Figure 5 shows world patterns of energy use until 1975. It shows the rise and fall of wood and coal as a percentage of total contribution, indicating that oil, gas, and nuclear are still rising. Hydroelectric and geothermal are not shown. To be serious about gas, one probably should separate the gas found along with oil and place that with the oil curve. This would further separate the oil and gas curves in Figure 5, indicating that we are very early on the gas utilization curve. The curves for resources like shale, heavy oil, and tar sands have not even started. In any case, the options available to us in the future for fossil energy sources are considerable, assuming the environmental aspects of carbon dioxide do not overwhelm us.

At this point I would like to raise a caution concerning the material presented here. One should not interpret anything here beyond the next two decades. In particular, one should not infer that nothing should be done in the next two decades to get ready for what comes beyond. Examination of a longer time period would indicate that considerable research, development, exploration, etc., must be undertaken in a rather vigorous manner in order that we understand the constraints that may be developing around us and that we have ample technological information to take advantage of the options that are physically and economically possible in a timely manner.

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TABLE 1. Nonrenewable World Energy Resources by Region (December 31, 1976)

	Proved and Currently Recoverable	Estimated Total Remaining Recoverable
	[Billion (10^9) Units]	
United States		
Natural Gas, 1000 CF	216	790-1160
Natural Gas Liquids, bbl	6.4	21-31
Crude Oil, bbl	30.9	148-374
Shale Oil, bbl	74	1026 (2000)‡
Bitumens, bbl	2.5	15
Coal, short tons	215	1036-1788
Uranium Oxide*		
short tons at < $15/lb	410	1675
short tons at < $30/lb	680	3370
Western Hemisphere (incl. U.S.A.)		
Natural Gas, 1000 CF	352-382	2546-2946
Natural Gas Liquids, bbl	9.3-10.1	67-78
Crude Oil, bbl	66-71	320-420
Shale Oil, bbl	130	1500 (5000)
Bitumens, bbl	80	500
Coal, short tons	224	1114-1866
Uranium Oxide*		
short tons at < $15/lb	628	2345
short tons at < $30/lb	955	4331
Europe (excl. U.S.S.R.)		
Natural Gas, 1000 CF	152-173	484
Natural Gas Liquids, bbl	4.0-4.6	13
Crude Oil, bbl	19-26	39-79
Shale Oil, bbl	15	150 (1400)
Bitumens, bbl	N.A.†	N.A.
Coal, short tons	141	356
Uranium Oxide*		
short tons at < $15/lb	76	129
short tons at < $30/lb	621	914
Asia–Pacific (incl. European U.S.S.R.)		
Natural Gas, 1000 CF	1415-1672	5064
Natural Gas Liquids, bbl	37.5-44.3	134
Crude Oil, bbl	402-445	1005-1175
Shale Oil, bbl	35	115 (6500)
Bitumens, bbl	N.A.	N.A.
Coal, short tons	280	3865
Uranium Oxide*		
short tons at < $15/lb	322	427
short tons at < $30/lb	367	501
Africa		
Natural Gas, 1000 CF	199-223	996
Natural Gas Liquids, bbl	5.3-5.9	26
Crude Oil, bbl	50-63	136-166
Shale Oil, bbl	10	100 (4100)
Bitumens, bbl	N.A.	N.A.
Coal, short tons	17	32
Uranium Oxide*		
short tons at < $15/lb	370	423
short tons at < $30/lb	500	677

*Thousands of units.
†Not available.
‡Values in parenthesis include estimates of undiscovered or unappraised resources in the 25-100 gal/ton yield range according to Duncan and Swanson, 1965.
SOURCE: Parent et al., 1979.

TABLE 3. Estimated Reserves of Peat and Potential Energy in the United States and for the 15 States with the Largest Reserves

Geographic Area	Acres (millions)	Quantity (billion tons)	Potential Energy Available Quads (10^{15} Btu)
Alaska	27.0	61.7	741
Minnesota	7.2	16.5	198
Michigan	4.5	10.3	123
Florida	3.0	6.9	82
Wisconsin	2.8	6.4	77
Louisiana	1.8	4.1	49
North Carolina	1.2	2.7	33
Maine	0.77	1.8	21
New York	0.65	1.5	18
Hawaii	0.48	1.1	13
Georgia	0.43	1.0	12
Indiana	0.38	0.9	10
Massachusetts	0.35	0.8	9.5
Virginia	0.31	0.7	8.6
Washington	0.20	0.5	5.5
All Other States	1.5	3.4	41
Total	52.58	120.3	1443

Data from U.S. Department of Agriculture Soil Conservation Service. Conservation Needs Inventory.

Basis of potential energy; peat contains 35% moisture, bulk density equals 15 lbs/cu ft. caloric value equals 6000 Btu/lb and one acre of peat 7 ft. deep equals 2287 tons or 27.44 × 10^9 Btu of energy, per Dr. R. S. Farnham, Professor of Soils Science, University of Minnesota.

SOURCE: Punwami and Rader, 1977.

TABLE 2. Life of World Fossil Fuel Resources at Various Fixed Demand Growth Rates (Based on 1976 Year-End Estimates)

Annual Growth Rate, %	Year When Remaining Reserve/Consumption Ratio Drops to 10 Years		
	A	B	C
4	2005	2050	2067
3	2010	2067	2090
2	2017	2097	2130
1	2029	2164	2226

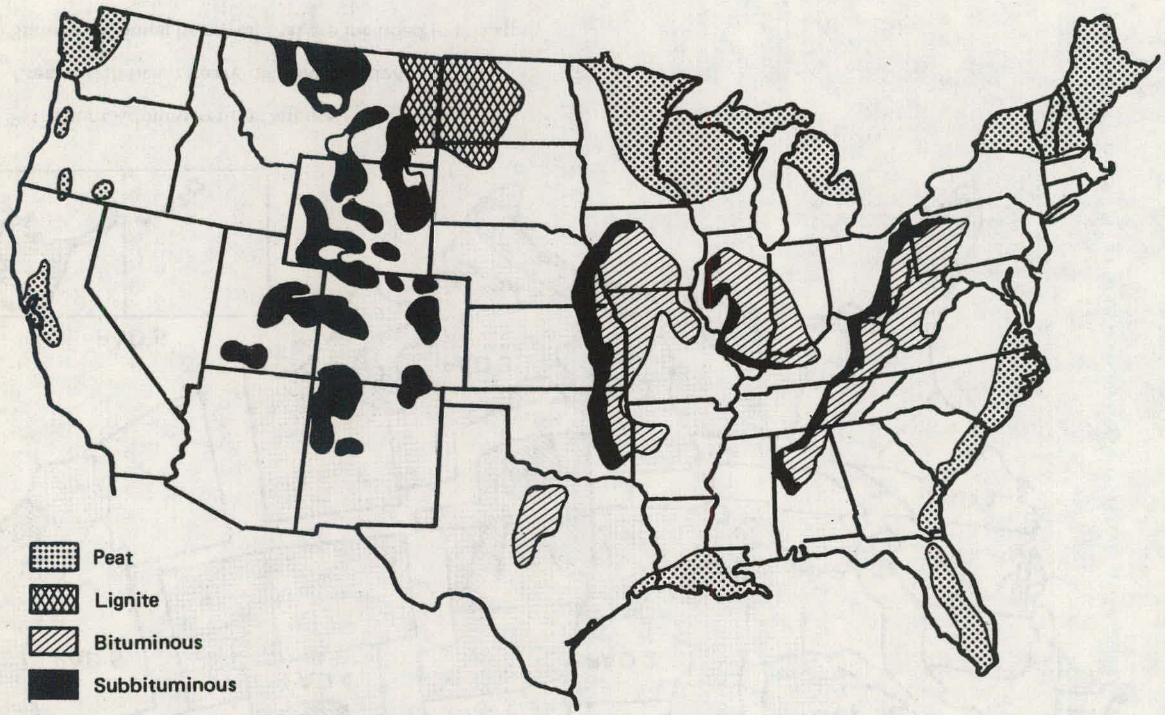
A–Proved reserves: 0.748 to 0.776 × 10^{12} tce; mean = 0.762 × 10^{12} tce.

B–Total remaining recoverable resources: 5.054 to 5.683 × 10^{12} tce; mean = 5.369 × 10^{12} tce.

C–Doubling of estimated B resources.

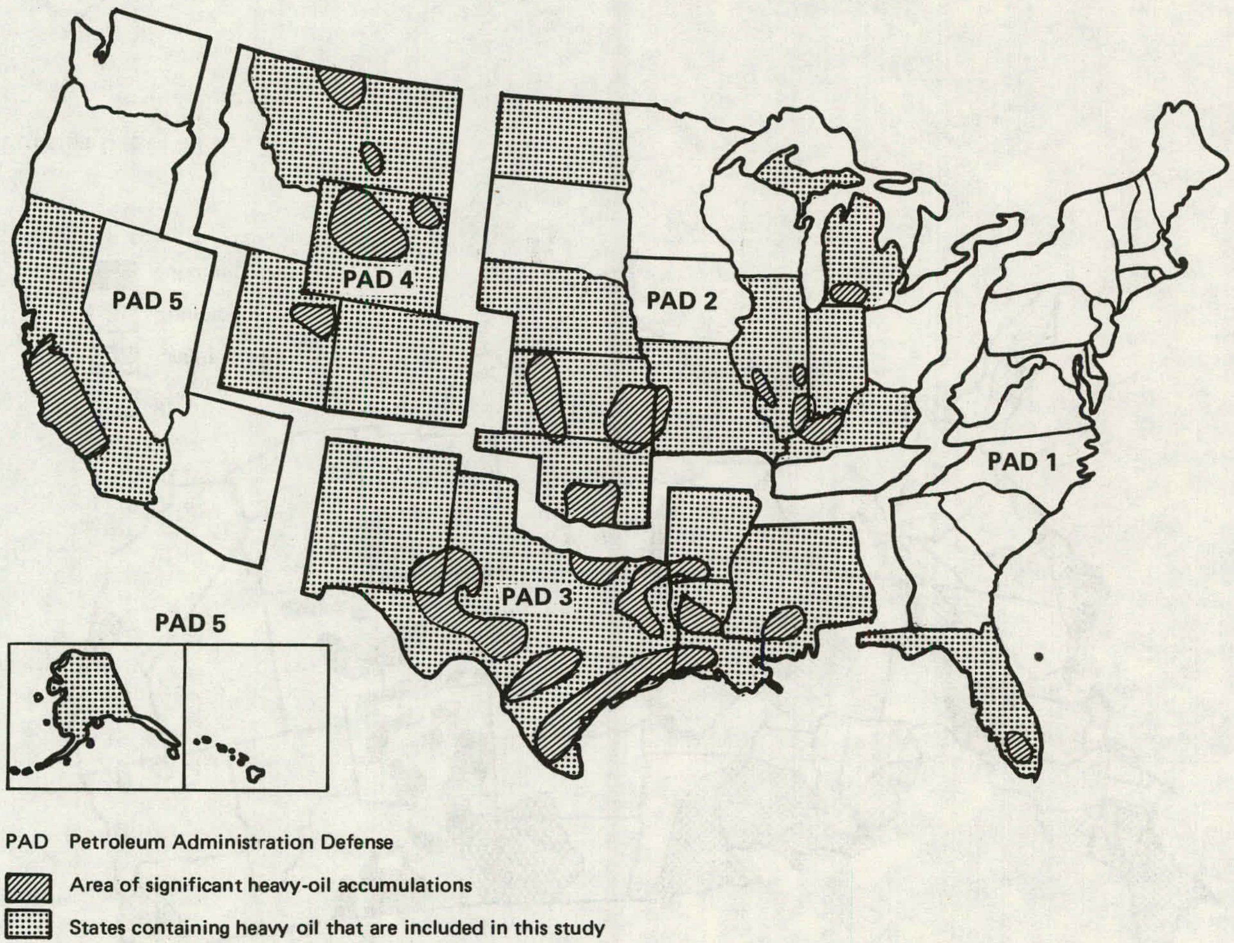
SOURCE: Parent et al., 1979.

Figure 1. U.S. COAL, LIGNITE, AND PEAT DEPOSITS



Source: Punwami et al., 1977.

Figure 2. STATES CONTAINING HEAVY CRUDE OIL INCLUDED IN THIS STUDY



Source: U.S. Bureau of Mines, 1967.

TABLE 4. Order of Magnitude of Total Stored Energy in Organic-Rich Shale of the United States and Principal Land Areas of the World (Estimates and Totals Rounded)

		Shale Containing 10-65 Percent Organic Matter			Shale Containing 5-10 Percent Organic Matter		
Continent or Country	Approximate Area Underlain by Sedimentary Rocks (millions of square miles)	Shale in Deposits (trillions of short tons)	Minimum Organic Content (trillions of short tons)	Combustion Energy Content Q (10^{18} Btu)	Shale in Deposits (trillions of short tons)	Minimum Organic Content (trillions of short tons)	Combustion Energy Content Q (10^{18} Btu)
United States	1.6	120	12	310	1,200	60	1,600
Africa	5.0	370	37	960	3,700	190	4,900
Asia	7.0	500	50	1,300	5,000	250	6,500
Australia	1.2	90	9	230	900	45	1,200
Europe	1.6	120	12	310	1,200	60	1,600
North America (including United States)	3.0	220	22	570	2,200	110	2,900
South America	2.4	180	18	470	1,800	90	2,300
World total	20	1,500	150	4,000±	15,000	750	20,000±

SOURCE: Duncan and Swanson, 1965.

TABLE 5. Historical Record of Production, Proved Reserves, Ultimate Recovery, and Original Oil in Place, Cumulatively by Year, Total United States (Billions of Barrels of 42 U.S. Gallons)

Year	Cumulative Production	1975 Estimate of Cumulative Ultimate Recovery*	1975 Estimate of Cumulative Original Oil in Place*
1959	62.3	122.3	384.7
1960	64.7	123.3	387.8
1961	67.2	123.7	389.8
1962	69.8	124.7	392.5
1963	72.4	125.3	394.7
1964	75.1	126.2	397.8
1965	77.8	127.6	402.4
1966	80.6	128.0	404.4
1967	83.7	128.7	407.0
1968	86.8	139.2	432.5
1969	90.0	139.8	434.8
1970	93.3	140.4	437.1
1971	96.6	140.9	438.7
1972	99.9	141.1	439.6
1973	103.1	141.4	440.9
1974	106.1	141.6	441.4
1975	109.0	141.7	441.9

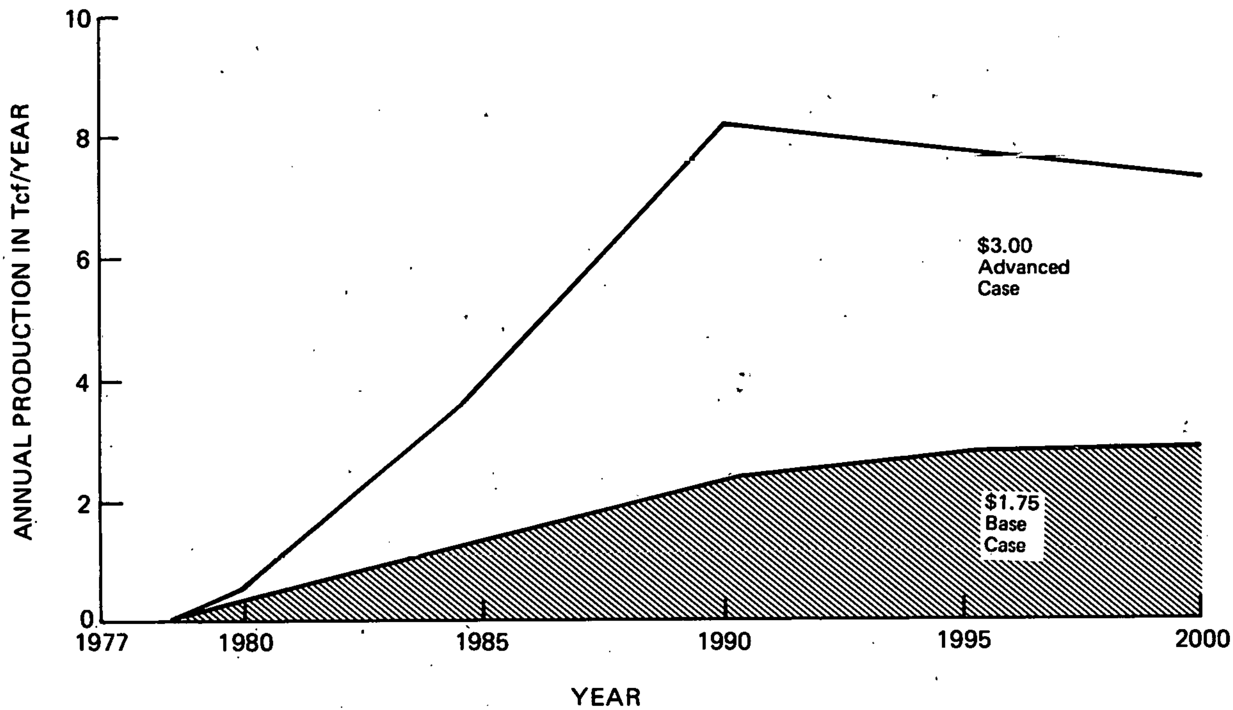
*For all fields discovered prior to the indicated year in Column 1.
SOURCE: American Gas Association, American Petroleum Institute, and Canadian Petroleum Association, 1976.

TABLE 6. Unconventional Sources of Natural Gas

Source	Estimated Resource Base, TCF	Estimated Recoverable at Marginal Cost Up to $4/1000 CF, TCF
Eastern Shales	600	30
Western Tight Sands	600	170
Coal Seams	2,500	350
Geopressure Aquifers	3,000-100,000	160

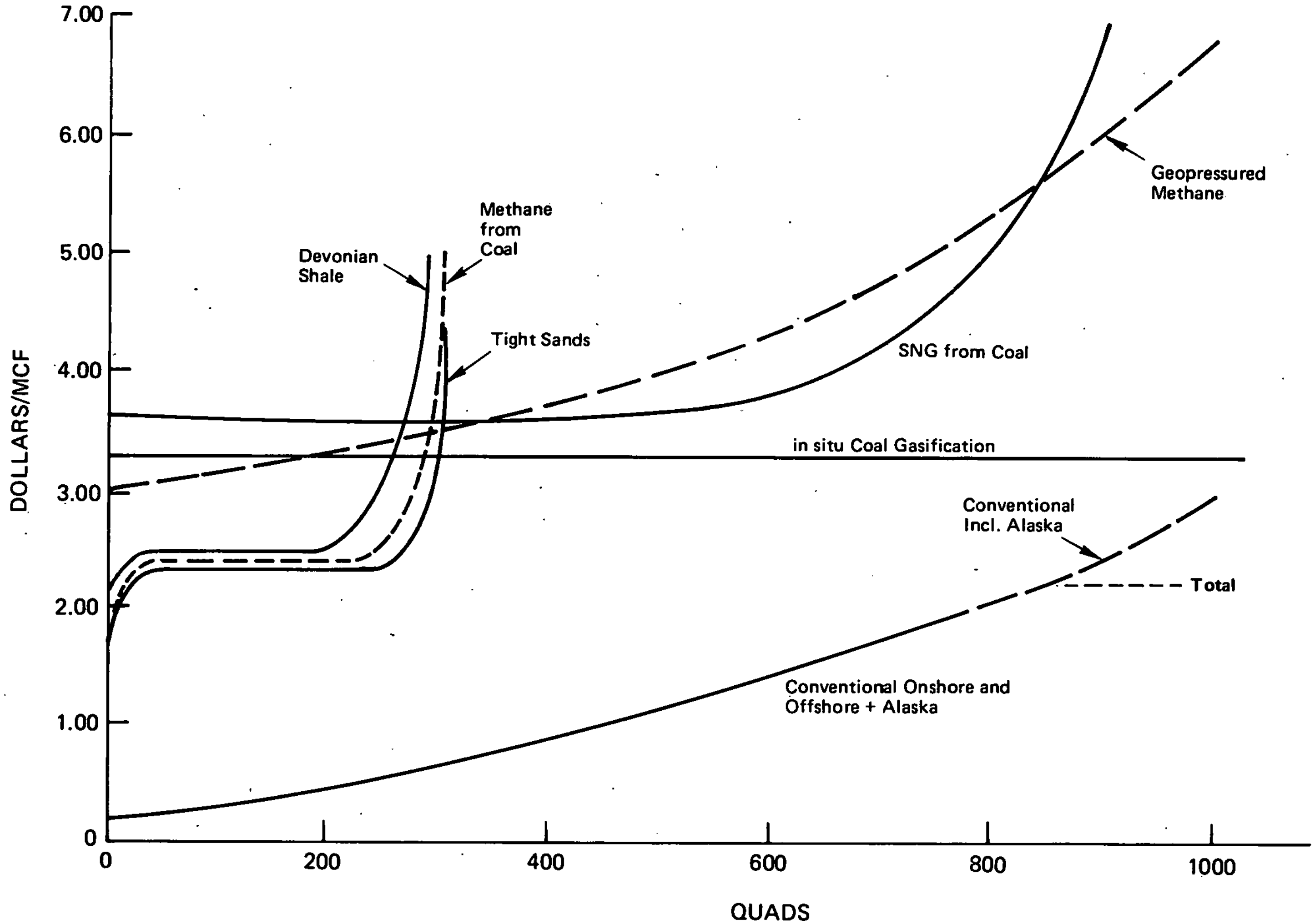
SOURCE: Linden et al., 1979.

Figure 3. ANNUAL PRODUCTION FROM UNCONVENTIONAL SOURCES TO THE YEAR 2000 AT $1.75 AND $3.00/MCF



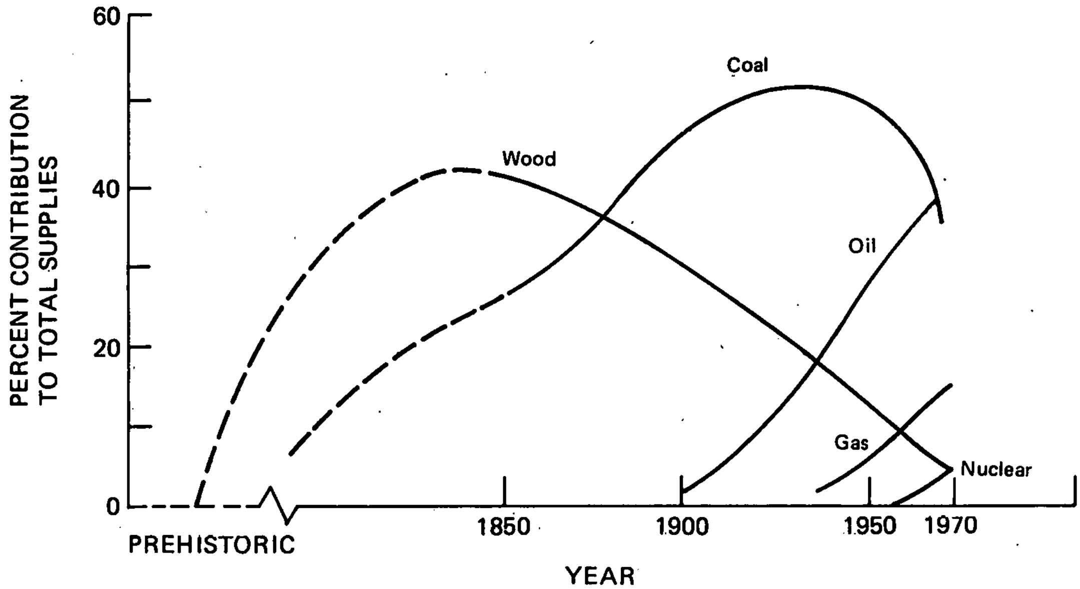
Source: Kuuskraa et al., 1978.

Figure 4. ESTIMATE 1 HIGH-BTU GAS SUPPLIES



Source: U.S. Department of Energy, 1977.

Figure 5. ENERGY PATTERNS TO THE YEAR 1975



Source: Clarke, 1974.

WORKSHOP REPORTS

These reports summarize the discussions, conclusions, and recommendations of the workshop participants.

Issue summaries submitted in advance for use in the workshops are in Appendix A. Except for a very few late submittals, they were provided to the Congress participants as preprints.

A few selected papers designated by the workshop organizers as of interest beyond a specific workshop area are reproduced in Appendix B.

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WORKSHOP 1

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE-ENERGY-EFFICIENT MINING, PROCESSING, AND RECYCLING

Dieter Altenpohl, Chairman
Carl Rampacek, Organizer
Ralph C. Kirby, Rapporteur

The 40 participants in this workshop dealt with five topics: mining hard rock; beneficiation; unconventional resources; metal production processes; and recycling material wastes.

Perhaps the most difficult problem encountered throughout the entire day was keeping the participants' thoughts focused on energy efficiency and conservation so they did not stray to unrelated technical matters concerned with the topics under consideration. Nevertheless, there was an excellent exchange of ideas, opinions and views in each of the sessions, which contributed to a better mutual understanding of some of the energy-related problems associated with each subject. However, a number of the participants attached less importance to developing energy-efficient systems than they did to the economic aspects of the processes under consideration.

MINING HARD ROCK

Are there significant energy savings possible in hard rock mining? What are the trade-offs involved (among energy, capital, metal recovery, labor, and environment) in any of the new developments in mining?

An abundance of cheap energy in the past has resulted in energy inefficiencies in mining. The use of increasingly larger and more sophisticated mining machines, for example, to achieve higher productivity under stringent safety rules, has resulted in more energy-intensive operations. There are two basic avenues for improving the process: to reduce the amount of energy required, and to use more abundant forms of energy.

The 19th century miner broke as little waste as possible, and the waste he broke was moved a minimum distance. Where he had to break waste to provide working room he blasted and moved away some of the hanging wall before blasting the vein. He sorted and he disposed of his waste as close as possible to the face.

This same minimum-energy approach to mining not only can reduce energy consumption today and tomorrow, but it also offers promise for improving the economics of production and reducing certain environmental concerns. If the amount of waste that must be broken and moved to extract a given amount of metal from the ground can be reduced substantially, then the amount of energy required for grinding and processing also will be reduced, and production costs should be lower because the difficulty and cost of waste disposal is directly related to the amount of waste produced by the mill.

Approaches to achieving greater efficiencies in energy use were suggested, and their impact on underground hard rock mining discussed. Selective mining is a more energy efficient step than bulk mining, but at present bulk ore mining is the preferred method because of its lower cost. Selective mining, will require complete knowledge of the geological structure and physical characteristics of the deposit and an evaluation as to whether the deposit is amenable to selective mining.

Selective mining also will require new technology such as development and application of new remote sensing techniques and systems encompassing in-situ analysis of the ore bodies to better differentiate between the ore-bearing strata and the barren rock. R&D has been under way for some time to perfect such systems but much more effort is needed.

Other energy-efficient approaches are: the need to develop more efficient mechanical miners; the trade-offs involved in the use of blasting energy to minimize the energy consumption in the subsequent mechanical mining operations; the use of in-mine preconcentration to eliminate excessive energy costs in transportation and hoisting in deep mines; and the need to give increased attention to back filling of worked-out areas with mining and processing wastes to minimize surface subsidence.

Mining is only part of a somewhat complex system that involves transportation, hoisting, and beneficiation in most cases. Certain apparent incremental energy savings or efficiencies in the mining phase of any ore must be analyzed carefully and evaluated with respect to their impact on the total energy requirements when transportation, hoisting, and processing of the mined material also are considered.

The importance of economics as the guiding principle in determining mining methods and approaches used in ore extraction was a recurrent topic. The economics of mining are a primary concern, and energy requirements and effecting cost savings go hand-in-hand.

BENEFICIATION

Can rock comminution (crushing and grinding) be made more energy efficient, or can we minimize the amount of comminution required in ore beneficiation?

Grinding ores for beneficiation and subsequent additional processing is a major energy consumer, generally amounting to somewhat more than one-half of the total energy used. The energy is required to grind ores to finer sizes to achieve liberation of the ore minerals; and to overcome mechanical inefficiencies of the grinding equipment and system and inefficiencies in the techniques employed. Nothing can be done about the former, but greater energy efficiencies can be effected in the latter.

Reducing energy requirements in comminution has been largely unsolved. Extensive theoretical comminution research on various approaches and schemes to reduce energy input for grinding has identified only incremental energy savings which have been ignored by industry or have not been applicable to practical grinding systems. Current grinding operations, for example, employ energy-inefficient autogenous grinding mills or conventional, mechanically inefficient or vastly oversized, rod or ball mills. This results in grinding overkill with an attendant excessive energy consumption.

Energy requirements in comminution might be reduced by more intensive inventigations on the use of chemical modifiers such as surfactants to reduce surface energies of the ore minerals, thereby reducing their resistance to particle size reduction in the grinding operation. Comminution is only a part of an ore reduction system; there is a need to improve the classification of ore pulps concurrent with grinding to remove the liberated ore minerals more efficiently and promptly from the grinding circuits if less energy-intensive grinding is to be achieved.

Innovation in grinding has been virtually nonexistent; principal efforts have been focused on improving existing techniques and equipment. There is a need to consider new and preferably innovative comminution approaches encompassing new ideas which take into consideration mineral properties as well as the external forces acting on the ore minerals during grinding.

Dry grinding and pneumatic classification are potential energy savers and should be looked at more critically not only in grinding such materials as cement clinker but also in preparing properly sized and dust-free feeds for further dry beneficiation or concentration. Use of high-intensity and high-gradient magnetic separators having permanent magnets instead of electromagnets to recover weakly magnetic minerals from certain ores in lieu of flotation offers an opportunity for maximum energy savings. Other approaches for more energy-efficient beneficiation processes may be to develop more efficient methods for filtering and drying beneficiated products, and the wider application of systems analysis to optimize all the steps involved in any beneficiation process.

Will mining and processing of sea nodules provide us with copper and other metals at less overall energy consumption than from conventional ore sources? And second, are there other unconventional resources and what energy requirements will be entailed in their processing?

The Bureau of Mines has four R&D projects under way utilizing unconventional resources:

- Although technologically feasible, energy requirements for the hydrochloric acid are about 40 percent higher than for alumina products by the Bayer/bauxite process. A lengthy discussion of the alumina from clay research now under way by the Bureau resulted in the conclusion that energy requirements are not the primary motivating factor in considering unconventional resources such as clay for alumina production. Rather, strategic considerations are the primary concern.

- Research is also under way on the recovery of tungsten from Searles Lake brines, and the possibility of recovering a variety of other metallic elements such as lithium, zinc, and lead from geothermal brines in conjunction with using the brines as an energy resource also was discussed. No assessment of the economics of the processes was made.

- Work has been done on recovering nickel, cobalt, and chromium from domestic low-grade laterites.

- Accessory minerals have been recovered from mineral processing streams. In the described research, strategic considerations such as improving the mineral supply posture of the United States, reducing reliance on imports of certain mineral materials, or environmental considerations are of more concern than the energy requirements for achieving these objectives.

The recovery of metals such as zinc, lead, silver, and copper from the Red Sea sludges on a commercial basis by a consortium comprised of a German company, Saudi Arabia, and the Sudan was brought to the attention of the group. Although technically successful, no reliable data are available on the energy required to process the sludges. Saudi Arabia would provide flare-off gas for process heat to concentrate the sludge to the point where it can be shipped to Germany for the final processing by smelting and electrolysis.

Mining and processing seabed nodules to recover the manganese, copper, nickel, and cobalt must be considered in light of the complicated mining systems required to recover the nodules from the sea floor, and to transport and process them. They would be quite energy intensive and certainly would require much more energy than mining and processing conventional low-grade land resources. It might well turn out that the total energy required to mine and process the nodules might be prohibitive, and that a systematic and meaningful study should be made of the types and quantities of energy required as part of a full assessment of mining of sea bed nodules.

A general consensus of the participants was that recovery of metals and minerals from unconventional resources, as a rule, generally will be more energy intensive than producing the same materials from conventional sources.

METAL PRODUCTION PROCESSES

How can process change lead to reduced energy consumption for metal production from conventional or lower-grade ores?

Aluminum is the most energy-intensive of the common metals, but steady, incremental improvements are being made in current technology worldwide. These are geared to the availability of existing resources of minerals and energy.

Proven reserves of high-grade bauxite will last for at least 300 years and the hugh quantities of low-grade should last 1000 years. Therefore, it will not be necessary from a resource standpoint to use clay-type materials except to achieve a better balance of payments or for national security reasons.

The French-Canadian research in France of the double acid (hydrochloric and sulfuric) process for recovering alumina from clay has been terminated temporarily, probably because costs and energy requirements are higher than those for alumina extracted from bauxite imported from Latin America, Africa, and Australia. However, development of processes such as this one and others like the Bureau of Mines work for recovering alumina from nonbauxitic resources was viewed by a number of the participants as highly desirable to reduce dependence on imports despite the abundance of bauxite world wide.

In the Soviet Union, alunite and nepheline have been used as alumina feed stock. Portland cement is a by-product amounting to about 10 tons for each ton of alumina produced. The alunite process has been abandoned and Russia is importing more and more bauxite for treatment by the conventional Bayer process in two larger Bayer plants. The nepheline plants also have been phased out because of high energy requirements and the lack of convenient outlets near the plant areas for the excessive quantities of by-product cement produced. Despite the problems experienced by the Russians a number of the participants expressed a strong opinion that such processes might have definite merit in certain circumstances and should not be down-graded.

In countries such as France, Mexico, Argentina, and Iran which have smelters but no bauxite and are short of hard currency, the use of clay-type materials and nepheline as feed stock for alumina production remain under consideration. Mexico is now in an early stage of developing a process for producing aluminum metal from nonbauxitic materials. This process is a variation of the subhalide process in which clay is smelted at 1600°C with coke and some recycled aliminum, and is reported to require 30 percent less energy than aluminum produced by the conventional Bayer/bauxite process. The main reaction product is aluminum chloride.

Another development in Mexico, with an indirect impact on energy requirements in metal production, is the replacement of aluminum-silicon-magnesium alloys in buildings and construction using aluminum alloys with a 40-90 percent zinc content. Mexico is short of aluminum, and imports most of the metal, but the country has an abundance of zinc. Use of these alloys, some of which are superplastic, will substantially reduce the requirements for costly imported aluminum.

The major criteria for siting new alumina plants and smelters in developing countries are the existence of bauxite reserves in close proximity to low cost and abundant electricity. A well-prepared background paper was submitted giving a survey of available energy sources, principally hydropower, and available sites for new smelters in developing countries.

Energy improvements may also be achieved in the iron blast furnace and by using direct reduction processes. Direct reduction is limited to locations where surplus gas or liquid fuels are available inasmuch as direct reduction is not an energy saving process when compared with the conventional blast furnace.

RECYCLING MATERIAL WASTES

What energy is required for conventional recycle of secondary metals relative to production of primary metals from ore? How much more energy will be required to recycle metals, paper, and glass from municipal solid waste? What are the prospects for efficient recycling of such industrial wastes as steelmaking fume? This was such a broad issue that in the interest of time we could only concentrate on a few matters such as automobile recycling and solid municipal waste.

There were a number of views expressed on the problems involved in waste recycling and the approaches that might encourage more effective recycling. There were differences of opinion as to whether legislation is desirable to require fabrication standards that might facilitate more effective recycling, whether incentives would be appropriate, or whether more effective recycling can be achieved just in the free market.

External factors such as changing the composition of automobiles to reduce weight and improve the mileage/energy ratio were identified as influencing the type of scrap that will be recycled in the future. Plastics and aluminum are two materials that will be used more widely. The industry may in time favor certain uni-alloy products which will facilitate recycling; for instance, only one group of aluminum alloys should be used for sheets and perhaps two or three alloys for castings. Separation of these materials would be achieved by dismantling junk autos rather than by shredding.

There is a need for more municipal solid waste recycling in order to minimize land pollution and conserve material resources, and incidentally save energy. The different types of waste available, their location, and how they might be recycled most effectively and efficiently must also be identified. A national materials policy might have some impact on providing the incentive to recycle the wastes. Solid municipal waste is an example of current recycling efforts, the driving force of which is not so much economics as it is protection of the environment. A principal goal is to minimize the quantities of waste disposed of in landfill sites throughout the United States.

The consensus of the workshop on recycling was that substantial energy can be saved, particularly in recycling energy-intensive materials; that higher energy costs will probably encourage more recycling; and that every encouragement should be given to increasing recycling where feasible, not only for energy conservation but also as an environmental and materials conservation measure.

DISCUSSION

- Technology transfer may be a very important method of conserving energy in developing materials. Two examples are: In the space program they found it necessary to sort the materials that they used for recovery in an effort to bring down their costs. And they came up with a technique for sorting nonferrous alloys from shredded automobile waste, a technique that is based on the use of ferrofluids and gravimetric phenomena, and it turns out to be very effective.

  The other example relates to the extraordinary cost of millions principally because we do not know when to stop. In the course of some work that was done in making catalysts for the petroleum industry, where over-milling results in an ineffective catalyst, a technique was evolved for determining when to stop milling when the desired size had been reached. This is based on an indicator placed in the mill to determine the flow of electrons to ground through a milliammeter, the so-called x-o electron emission technique. This is something in another field that we have not yet brought it into ours.

- It has been discussed that under particular circumstances it may be highly desirable and convenient to develop nonbauxite resources. Pechiney is conducting the major European project in this area; there is no evidence that this project is stopped permanently. At the present time the results of the planned experiments are

are under evaluation, and, from all of the infromation available now, a new pilot plant of a higher capacity will be decided upon soon. In other countries such as Argentina and Mexico it also might be convenient and desirable to work on nonbauxite processes.

There is no basis for the conclusion that alumina from nepheline or other minerals is impractical. Evaluations have been made and they have proved that under certain conditions, alumina from these sources could be competitive with the alumina from imported bauxite.

Under special and very well-defined conditions--an availability of cheap energy in the vicinity of nepheline processing plants, and a market for the by-products (concrete, etc.)--this process might be quite successful.

- There is a disappointingly high degree of uncertainty about the data concerning energy requirements for various aspects of materials, of different metals processing. It is very important that this conference recognize this deficiency in order to lay a much better foundation for comparisons for the future as to what advances may or may not be made. Professor Alexander's paper (Appendix B) points out that publication of energy utilization data in metallurgical materials processing operations has been widespread in recent years.

  However, such data is in rather an early stage of compilation. In some cases there are discrepancies of two to three times between values in different countries. Recent work in the United Kingdom aluminum industry is also revealing that energy auditing in routine metallurgical establishments covering extended periods is showing double the hitherto assumed values. It is incumbent on professionals to try to determine why these remarkable differences in the reported data exist, and what in fact seem to be the data on which we should rest future advances.

- In regard to capturing alloy additions used in steel, the steel maker has the option when he designs a grade, to choose several different materials. For example, in high-strength alloy steels he may choose vanadium, niobium, molybdenum, nickel, copper, and other types of additions to obtain certain properties. When this material goes into an automobile it fulfills that function. It gives high strength. When this is recycled what happens to these alloy additions? Certain alloy additions such as vanadium and niobium will be oxidized out and cannot be recovered. They go off as an oxide in a slag. But other alloy additions such as nickel, molybdenum; and copper would be recovered in the scrap steel. We can devise a way to use these residual elements in this steel; they are in fact the base for another series of alloy-type steels. By segregation of this kind of scrap we can make use of these valuable metal units.

WORKSHOP 2

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE-ENERGY-EFFICIENT BUILDINGS

Larry W. Masters, Chairman
Elio Passaglia, Organizer and Rapporteur

INTRODUCTION

Background

Considering that materials have been used in buildings for thousands of years, one must question why materials problems are observed within buildings and why materials science and technology is a topic for discussion at this Congress.

In the past, materials have been used for reasons of strength, durability, availability, utility, design, and cost. But there has been little consideration for flow of energy through materials. Now with the need to conserve energy, the building industry must use new materials and it must use traditional materials in new ways. This frequently results in materials problems. The building industry is conservative and resistant to change. To some extent this is due to the fragmentation of the industry and to the position frequently taken by unions. The resistance to change makes it difficult to optimize and balance the three important factors which we must consider in selecting materials: cost, durability, and performance.

Two key considerations were addressed by the workshop regarding the use of energy in buildings: energy consumed by the building after construction and energy consumed in the manufacture of materials.

In the United States, roughly 33 percent of our total energy consumption is associated with residential and commercial buildings; in the United Kingdom, the value is approximately 20 percent. Table 1 illustrates where the energy in buildings is consumed (National Bureau of Standards, 1973). The top two categories, space heating and water heating, account for nearly two-thirds of the energy consumption.

These figures show wide variation because of building type and geographical location. Lighting, for example, is far more important in commercial buildings than in housing. However, these averages show the importance of energy consumed in buildings.

TABLE 1. Consumption of Energy in Buildings in the United States

Of the 33% for Buildings

Energy Consumption	Percentag Percentage
Space heating	53
Water heating	12
Air conditioning	8
Refrigeration	7
Lighting	5
Other electrical	5
Cooking	4
Cloths drying	1
Miscellaneous	5
	100

It has been estimated that a sizeable portion of this energy could be saved by effectively utilizing our existing technology. For example, in the United States, 40 percent of the energy that would be used in new buildings and 25-30 percent of that in existing buildings could be saved using existing technology.

Steps to conserve energy with existing technology include increasing the level of thermal insulation, reducing air leakage, and better use of shading, windows, and passive solar concepts. To illustrate this point, the Association of Heating, Refrigerating, and Air Conditioning Engineers, has recently developed a standard--ASHRAE 90-75, Energy Consumption in New Buildings--which results in more than a 50 percent savings in the energy consumption of new buildings with existing technology.

The second major consideration addressed by the Workshop, the use of energy in the manufacture of materials, is illustrated by an approach being taken by Brazil. That country utilizes an "energy index" to determine the energy content of materials.

Using this approach, improved selection of materials can be made based on the energy content. However, such an approach seems to be much more relevant to Brazil than the United States. In the United States, the energy consumed in manufacturing materials is less than 10 percent of the total energy that is consumed by the building during its lifetime. Because Brazil does not have a heavy space-heating load, the energy of manufacture is much more significant there. Hence, in relative terms, this approach appears to be much more relevant for countries with low space-heating requirements than for countries with high space-heating requirements, although it clearly is relevant everywhere.

Scope of Workshop

With this background, the workshop participants addressed the following objectives:

- To identify the materials problems that pose barriers to more energy efficient buildings; and
- To identify research directions needed to overcome the barriers.

Presentations by principal discussants, were followed by periods of discussion. The four topic areas were Building Envelopes; Mechanical, Electrical, and Heating Systems; Integrated Utility; and Solar Heating and Cooling.

Representatives from seven countries participated in the discussion; these were Great Britain, Australia, Sweden, Holland, Brazil, Egypt, and the United States.

IDENTIFICATION OF BARRIERS TO MORE ENERGY EFFICIENT BUILDINGS

If the ability of materials to meet the requirements that are placed on them is to be assessed, the requirements must be clearly identified. In particular, the functional attributes of the materials must be identified. Table 2 lists five functional attributes that were identified and considered in the workshop.

TABLE 2. FUNCTIONAL CONSIDERATIONS

Barrier to energy flow
(i.e., building envelope)

Conversion/extraction
(solar absorber, heat pump)

Transport

Storage

Utilization
(motors, electric lights, etc.)

Table 3 lists the identified barriers to energy-efficient buildings. The list is divided into technical and nontechnical barriers and the table indicates in which of the four discussion areas the barriers were identified.

TABLE 3. BARRIERS IDENTIFIED

Technical	Envelope	Systems	Integrated Utility	Solar
Measurement technology				
• service life	X	X	X	X
• systems	X			
Life costs/payback	X	X	X	X
Technology transfer/design	X	X	X	X
Knowledge of use conditions	X			X
Materials substitution	X	X	X	X
Knowledge of required performance: standards	X	X		
Raw materials availability	X			
Fixes leading to problems	X			
Lack of experience			X	X
Nontechnical				
Regulations/consistency of policy	X			X
Building codes	X	X	X	X
User attitudes	X			X

Two important considerations were identified regarding the first technical barrier, measurement technology. The first is called "service life" and addresses the long-term performance aspects. For traditional materials, particularly those that are used in familiar applications, service life data are available from experience. But for new materials or new applications of traditional materials, experience is not available and the service life is not known. It is essential, for these materials, to measure or predict the long-term performance based on short-term testing. Existing procedures are seldom fully adequate for this.

The second barrier in measurement technology is called "systems." This barrier addresses the fact that improved procedures are needed to measure the properties of systems as opposed to specific materials. For example, the thermal conductivity of an insulation material is frequently measured. The more important consideration, however, is the thermal conductivity of the composite wall or roof which includes the insulation and other materials.

The second technical barrier, life costs/payback, addresses the need for data to permit improved selection of materials based on life costs as opposed to first cost. This barrier is strongly linked to service life prediction because if the service life is not known, it is impossible to assess life cost.

The third barrier is technology transfer/design. The basic thought here is that it is essential to better disseminate research data to designers, builders, and the general public. Improved dissemination of data is expected to lead to improved energy efficiency of buildings through better design of buildings and more effective use of materials.

The lack of knowledge of use conditions was identified as a barrier in two of the discussion areas. In the discussion of building envelopes, for example, data are needed on the moisture content in the exterior envelope to aid in assessing the ability of materials to perform. Likewise, in solar heating and cooling systems, data are needed on the temperature and other environmental factors to which materials will be exposed.

The materials substitution barrier addressed, for example, the substitution of foam for glass fiber insulation, the substitution of blended cement for Portland cement and the substitution of plastic for metals. A key factor in selecting a substitutional material is to identify materials that will perform as well as or better than traditional materials. There is a continuing search in the building industry for substitutional materials and research data are needed to aid the effective selection of these materials.

The lack of knowledge of required performance can be illustrated by the fact that data are needed to define the levels of thermal conductivity required for walls or roofs in various geographic locations. The point to be made is that, frequently, little is known about the level of required performance.

The next barrier addressed was problems encountered in obtaining raw materials. As shortages occur in raw materials supplies, the manufacture of materials can be stifled.

The next barrier, fixes leading to problems, is problems such as increased moisture content in the exterior envelope resulting from increased thermal insulation.

Lack of experience with new materials or traditional materials used in new environments was identified as a barrier in integrated utility systems and solar heating and cooling systems. The problem created from the lack of experience is that the performance and durability of materials are now known and this hinders effective materials selection and development.

The first of the nontechnical barriers addressed is regulations and consistency of policy. An example of this barrier is when petroleum shortage occured, a reduced amount of petroleum was available for feedstock and this inhibited the manufacture of foam plastics which would be used in insulation. Another example is that the addition of a solar system can increase the value of the building, which increases the property taxes. In one case, the taxes were known to increase more than the fuel cost savings from the solar system. This is a good example of inconsistency between the local and the federal policy.

Building codes are a nontechnical barrier. In the United States, in particular, there are many different codes and it is difficult for the industry to deal with all of them.

User attitudes are a barrier in that acceptance of new designs and concepts is frequently hampered by consumer or user attitudes.

MATERIALS RESEARCH NEEDS

Based upon the barriers listed in Table 3, nine areas, described below, were identified for materials research.

Research is needed to improve measurement technology. To meet the demands of energy conservation, new materials are being used and traditional materials are being used in new ways, resulting in the need for improved technology of service life prediction. Research is needed in several areas to improve the existing technology. First, the degradation factors or environmental factors that can change attributes or properties of materials must be more fully characterized and quantified. Second, the degradation mechanisms must be more fully characterized to ensure that short-term tests induce the same mechanisms as those observed in service. Third, improved tests are needed to assess changes in properties, and fourth, improved procedures and models must be developed to analyze the data from short-term tests. Recently, the American Society for Testing and Materials (ASTM) (1978) has accepted a standard, E632, which provides a framework for improving accelerated tests to aid service life prediction. Research is also needed to assess better the performance of systems as opposed to individual materials comprising a system.

Research is needed to develop the technology for effective substitution of materials. Research, in particular, must provide a means of ensuring that substitutional materials will be as good as or better than traditional materials.

Research is needed to improve the technology of corrosion protection and prevention. Specific examples cited in the workshop discussion were corrosion in water-cooled heat pumps, underground corrosion of piping, and reflectors and heat transfer loops for solar energy systems.

Research is needed to improve the efficiency of electric motors. Electric motors consume the largest segment of electric power in all of industry. For example, of the 10 percent of building energy consumed by fans and auxiliary equipment, most is attributable to motors.

Research is needed to develop improved refrigerants. Freon is deficient as a lubricant and lubricating additives must be included with it. These additives present problems in heat exchangers.

Research is needed to develop improved heat exchanger materials. Steel exhibits corrosion problems while copper and stainless are costly. Improved heat exchanger materials that are durable, have good heat recovery, and are light weight are needed. In a related area, higher heat capacity fluids are needed.

Research is needed to develop more durable polymers. There are many applications for more durable polymers in buildings. A specific example is the need for piping to transport waste heat from power plants to dwelling units in conjunction with Swedish integrated utility systems.

Research is needed to develop improved energy storage materials and facilities. Storage of energy is a major weak link in energy utilization, particularly in regard to integrated utility and solar energy systems. Swedish integrated utility systems currently utilize pit or lake magazines for storing energy from summer to winter. Higher heat capacity materials and improved phase change storage materials are needed.

Research is needed to develop materials for use in solar energy collectors and systems. This research need addresses materials for use as absorbers, enclosures, seals, insulation, piping, etc. In particular, optical materials are important. Current activities include research in Australia and Israel, at the U.S. Solar Energy Research Institute, and at the U.S. National Bureau of Standards.

RECOMMENDATIONS

The following recommendations are made:

- Perform materials research outlined in the nine areas of the previous chapter to achieve more energy-efficient buildings. Of particular importance are: research to develop improved short-term service life tests; research on materials for solar energy collectors and systems; research on materials for energy storage; and research on corrosion of metals and heat exchangers.

- Establish consistent building codes.

- Establish an international data collection system. Each nation has a data bank of materials performance, including data on in-use exposure conditions and recommendations on the use of materials in specific climates. The participants in the workshop feel that compilation of these data would be valuable. We recommend: defining data that are needed and the form in which it is needed; identifying sources of data; and identifying compilation and dissemination mechanisms.

- Establish mechanisms for better educating designers, builders, and the general public on the findings of research and on the implication of the findings to achieving more energy-efficient buildings.

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WORKSHOP 3

MATERIALS SCIENCE AND TECHNOLOGY FOR NEW ENERGY RESOURCES AND MORE-EFFICIENT ENERGY CONVERSION—FOSSIL FUELS, GEOTHERMAL, AND SOLAR

R. I. Jaffee, Chairman and Organizer

The topic of reliability was added to the scope of Workshop 3 as being perhaps more important than efficiency, although we recognize both objectives are very important. Also, in addition to new energy sources, the workshop spent most of its time on an old energy source, namely coal. Discussion of new energy sources was limited to geothermal and solar. Since many aspects of solar power were being covered by other workshops, we confined our attention to solar energy in conjunction with energy conversion.

In discussing issues relating to coal, we covered three: current steam power plants, coversion of coal to clean fuels, and the use of coal-derived fuels in combined cycle plants.

In general, the workshop considered fairly narrow issues in order to focus on real-time problems. The issues were mostly based on questions at which current R&D is aimed. Most of the research is still ongoing. We hoped that exposition of issues would be useful to those of us who are engaged in such research.

PLANT PERFORMANCE AND RELIABILITY

L. Hagn, Discussion Leader
R. C. Bates, Rapporteur

The first issue on current steam power plants was aimed at finding out the extent to which improved materials and processes might help the thermal efficiency and relaibility of current steam power plants. In terms of loss of profit--approximately $500,000 per day for a 1200-MW nuclear plant at $50,000 per day for a fossil-fired, 340-MW plant--the costs of breakdowns of power plants further illustrate the need for increased reliability and availability. Failure statistics of European power plants were presented, and the failures divided into three parts: faults relating to the product itself, faults relating to the operation of the equipment, and external circumstances which might affect performance. About two-thirds of the faults lie in the product itself. Usually these faults result from improper design. The faults relating to materials themselves tend to be rather small, but the improvement that might be made in the product through better materials certainly is an important aspect for research and development.

The chief contributors to forced outage in power plants are, in order of magnitude: the steam generator, the turbine, the condensor, and the electrical generator.

The statistics show that large plants, although more economical in terms of capital costs, are less reliable. Selection of the size of a plant must balance these two factors.

Data were presented which broke down the cause of turbine outage into the components. The components which failed were, in order of magnitude, turbine blades (28 percent), bearings (14 percent), rotors with discs (14 percent), shaft seals and balance pistons (13 percent), and casings with base plates and screws (12 percent). The chief cause (about 35 percent) of blade outage is corrosion fatigue in the transition row, where the initial moisture condenses from the dry steam as it expandes through the turbine and where it contains the highest concentration of impurities. The first condensed droplets are practically saturated salt water, even though the impurity content of the steam may be very low, on the order of 10-20 ppb. The second chief cause of blade outage is overstress from resonance at a natural frequency (about 20 percent of blade failures). The corrective action for overload or resonance failures lies with improved design, while the corrective action for corrosion-related failures lies with improved design, improved feed water conditioning and steam quality control, and selection of materials resistant to corrosion effects. For instance, one approach is to clean up the steam. This is done to the greatest extent possible, such that the specifications generally demand that the water purity be better than 10 ppb impurities. For example, the first moisture to form at the Wilson line in LP turbines may have concentrations of NaCl of several percent if the inlet steam to the LP turbine contains more than a few ppb of NaCl. This high concentration rapidly dilutes with additional condensation only a short distance downstream. Design or operational changes can shift the point at first condensation from critical to noncritical locations (e.g., from a rotating blade row to a stationary blade row). A materials approach is to look for more corrosion-resistant materials. In Germany they are looking at pit-resistant stainless steels, such as ferritic steels with high chromium and molybdenum contents (pitting is the cause of the corrosion fatigue crack initiation). In the United States, we are looking at titanium alloys for this application. Both approaches seem to be bearing fruit. One candidate for blade material for improved performance in corrosive environments is Ti-6Al-4V. Corrosion fatigue data for Type-403 stainless steel (a common LP turbine blade material) shows that 20 percent NaCl reduces the fatigue strength by 50-70 percent, depending on the pH. Ti-6Al-4V suffers less than 15 percent loss of its fatigue strength under similar conditions.

Examples of other materials that can be improved are turbine rotors and discs in which compositions can be optimized to resist temper embrittlement and stress corrosion; and high pressure steam piping in which microstructural changes and corresponding changes in properties caused by service stress and temperature must be better understood, particularly in weld regions.

Efficiency may be improved by increasing the inlet temperatures and pressures without sacrificing reliability. The experience of the Eddystone Plant of Philadelphia Electric is an example. Originally designed for 1200°F/5000 psi inlet steam conditions, the plant had problems with poor response to load changes, so inlet steam conditions were reduced to 1125°F/4800 psi (compared with 1000°F/2400 psi for most plants being built today). The realiability (availability) record of Eddystone has been excellent.

And, finally, through better steel making, one can eliminate practically all the sulfur. Most cracks at the center of a rotor forging originate at sulfide inclusions, which concentrate in the inverted V segregation bands near the center of the forging.

ARE COAL CONVERSION MATERIALS A BARRIER TO THE BUILDING OF LARGE COAL GASIFICATION OR COAL LIQUEFACTION PLANTS?
W. T. Bakker, Discussion Leader
Jerry Sorell, Rapporteur

The consensus was that materials will not be a barrier and that plants can be built that will operate satisfactorily. Consequently, the question is, "How can modern technology help to make coal-derived clean fuels competitive with other fuels in the foreseeable future?"

The greatest contribution by the materials sciences and engineering community would be the reduction of operating costs and achievement of high plant service factors. Translated into action terms, there must be rigorous application of modern materials technology during all phases of plant design, operation, and maintenance. In particular, gasifiers involve a very difficult, corrosive environment, in which most metallic materials will not survive for the typical 10-20 year lifetimes expected for power equipment. When corrosion-resistant metals are employed in gasifiers, they will have to be inspected and replaced during repair periods. However, most of the internal construction of gasifiers, particularly of the slagging type, will be made of refractory materials. Slagging gasifiers are smaller and less capital intensive, and receive most of the efforts in development.

Sulfidation is the chief contributor to metal corrosion. If low-sulfur coal were gasified, the corrosion environment might be handled by metallic materials. However, it is the high-sulfur coal that is of most interest in gasification. Thus, the use of metallic internal components must be minimized in favor of ceramic components.

The problem of liquefaction, so far as materials are concerned, seems to be much less difficult than gasification because:

- Front running hydroliquefaction processes (EDS, H-Coal, SRC) are quite similar to modern petroleum refining processes. Consequently, materials technology is transferable.

- Except for erosion, hostile environments in oil refining and coal liquefaction are nearly identical to one another as regards temperature, pressure, and aggressive substances (e.g., H_2S, H_2).

- Hydroliquefaction temperature conditions ($500^{o}C$ maximum) are much lower than gasification environments ($1000 \leq 1800^{o}C$) in advanced thermal gasification processes.

However, there is critical concern about erosion in let-down valves, where pressures of several thousand psi are relieved by releasing the slurry through a plug-type valve. This problem is being attacked by a combination of erosion-resistant materials such as cemented carbides, and designs utilizing pressure let-down in several steps, to make it easier on the valve trim. Another erosion problem is found in slurry pumps, which pump solvent containing large amounts of suspended ash. The pump erosion problem is not as serious as in let-down valves, and the best solution appears to be through materials selection. Erosion-resistant stellite facings, white cast iron, or other erosion-resistant materials improve pump life. Also, there is a need for high-capacity centrifugal pumps. This will increase the erosion problem of pump materials compared with that in slower moving reciprocating pumps.

A strong in situ materials evaluation/corrosion monitoring program is essential to developing material performance data for commercial plant design. Importantly, it must incorporate testing of full-size components, and methodical failure analysis. Such programs must be integrated into the design and operation of pilot plants, not added as an afterthought.

MATERIALS FOR COMBINED CYCLE POWER PLANTS

B. Ilschner, Discussion Leader
Chester T. Sims, Rapporteur

Economically it is cheaper to burn coal in a steam plant with a scrubber on the back end than to burn coal-derived clean fuels in a simple cycle gas turbine. To compete with direct combustion scrubbers, it is necessary to use the coal conversion products in a combined cycle, where the coal-derived fuel is first burned in a gas turbine, whose exhaust gases are used in a waste-heat boiler to provide steam for a steam turbine. Thermal efficiences over 40 percent can be achieved in combined cycle plants, compared with mid-30 efficiencies for coal-fired boilers with scrubbers. The combined cycle turbine operates at higher temperatures than industrial turbines in the past. Although the coal-derived fuels are clean, they are not so clean as distilled petrochemical products. The alkali and particulate impurities offer a real threat to the reliable operation of the gas turbine.

A typical combined cycle power plant (CCPP) is one major power generation tool for future use. The three basic types of gas turbines are: the aircraft (10 MW), present "small" industrial (100 MW), and future large (500-1000 MW). Since the combined cycle gas turbine requires a high temperature, generally 2200°F or above, the critical design property is creep which must be kept low. Also, the accumulation of creep damage must be controlled. One approach is to use a higher temperature material than superalloys. We have run out of temperature-strength capability for superalloys, and we must turn to high-temperature ceramics, such as Si_3N_4 or SiC, in uncooled turbines. The other approach is to cool the superalloys to a temperature at which they are adequately strong. Water cooling is of greatest current interest, because it can be used with higher temperature combustion gases than air cooling.

Corrosion resistance of these hot parts is a critical factor, with CO, residual hydrocarbons, low oxygen partial pressure, and sulfur important elements in the process. Particulate matter causes erosion or failure, unless controlled.

On the question of cooling versus ceramics, the tendency in Europe seems to be to count on solving the ceramics problems. In the United States, most of the emphasis seems to have shifted to either advanced air cooling or water cooling. A side benefit of water cooling is that the size of the gas turbine is about one-third the size of turbines using air cooling, thus reducing the capital cost of the combined cycle plant.

The maximum turbine inlet temperature with air cooling is about 2200°F; with water cooling perhaps 2600°F might be achieved. In terms of anticipated lifetime, most gas turbines for aircraft use are aimed at 10,000-20,000 hours. That would not be long enough for an industrial base-loaded combined cycle gas turbine. We must look toward turbines that will last longer, perhaps 100,000 hours. It appeared improbable to many in the workshop that a gas turbine would last that long. Therefore, the thought was presented that gas turbines should be used in tandem. While one was being overhauled, the other one could be used in conjunction with the steam turbine.

Design of gas turbines using ceramic components is still an active research topic. The problem is that the critical flaw dimensions generally are too small to be inspected. Therefore, statistical design methods, such as Weibull analysis, must be used. Weibull reliability requires that the components be small in size. The probability of avoiding critical-size flaws in large components for turbines built out of ceramics was considered to be small.

In gas turbines for combined cycle use, corrosion and erosion will be critical using coal-derived fuels. The amount of sodium and potassium present in a gasified or liquefied coal will be somewhat higher than in the petroleum derived distillates that we use now. Furthermore, the presence of potassium, which is unique to coal, will be worse than sodium alone which is present in petroleum. Recent work shows that 25 mole % K (with Na) triples the corrosion rate compared with Na alone on some superalloys. Further, if significant quantities of ash come through the process, turbine fouling occurs.

The effects of combined creep and fatigue, a metals degeneration effect which has not yet been successfully analyzed is an important factor. Gas turbine design lives of 100,000 hours are unrealistic. Further, while laboratory specimen tests are helpful, evaluation of the durability of materials in actual service or in pilot plants is an essential part of a materials development process.

Economics plays a key role in usage of coal-derived fuels in turbines. In producing coal products, the desulfurization process balances quality and purity against cost, which, of course, is balanced against gas turbine capability. Interestingly, still bottoms (contamined and ash-laden tarry materials) probably will be gasified to further generate energy from the back end of these systems.

The Shell-Kopper gasification process generates only about 1 ppm solids; thermal efficiencies of about 44 percent in combined cycle operation are expected. Corrosion behavior also can be treated by Weibull analysis.

FLUIDIZED BED TECHNOLOGY
John Stringer, Discussion Leader
S. J. Dapkunas, Rapporteur

Fluidized bed boilers substituting for ordinary pulverized coal boilers generally are smaller and less capital intensive. Pressurized fluidized bed boilers have the added bonus of high thermal efficiency. characteristic of combined cycles. Combustion takes place at lower temperatures, so that sulfur and nitrogen oxide evolution is kept low. Two serious materials problems have emerged in conjunction with fluidized beds. The first is a hot corrosion-erosion problem of in-bed heat exchanger tubes. The second, similar to the combined cycle gas turbine, is erosion from bed particles that pass through hot gas clean-up, and carry-over of sodium plus potassium, which can hot corrode the gas turbine. Hot corrosion of the in-bed tubes results from a coating of $CaSO_4$, CaO, and ash deposited on the tubes. The oxygen potential in the condensed part of the bed is low enough (about 10^{-12} atm) and the corresponding sulfur potential high enough (about 10^{-6} atm) that there is danger of sulfidation of the heat exchanger, particularly if it is made of high-nickel and high-cobalt alloys. In fact, one measurement using a zirconia probe showed a PO_2 of 10^{-14} atm. At this low level, formation of metal sulfides, and thus accelerated corrosion, is possible.

The probability of erosion occurring in a fluidized bed is illustrated both by the experimental experience at Exxon and Battelle-Columbus Laboratories, as well as by simple analysis showing particle loadings in the bed of about 5 x 10^5g/standard cubic foot, with a small fraction of these having relatively high velocities.

There are two major areas of difficulty in the pressurized fluidized bed (PFB) application--namely in-bed corrosion and erosion, and alkali-induced corrosion and particulate erosion in power recovery turbines operating on the PFB off-gas.

Calculated levels (confirmed by laboratory measurements) of 1 ppm or more of alkali metal vapor species in the PFB off-gas are expected to induce severe hot corrosion; Curtiss-Wright experienced severe corrosion of PFB heat exchangers in the vicinity of a coal feed port.

Erosion of turbine components will be expected because of the inability of commercial scale, economic, inertial separators ($<5\mu m$) to remove small particles from the gas stream. Data show the severe effect of erosion of turbine materials by $2\mu m$ (median) Al_2O_3 at 600 feet per second after 28 hours of exposure. Even extremely efficient particle removal can still cause component erosion due to flow stratification within the turbine itself. In commercial experience extreme erosion of in-bed components of calciners and roasters has been found. Materials tested by exposure for varying lengths of time have shown that: INCONEL-600 corrodes severely after 50 hours' exposure; 316 stainless steel shows isolated sulfidation attack after 3000 hours, for reasons as yet undetermined; and INCONEL-601 showed sulfidation after three hours' exposure at high temperatures.

Research needs include: 20,000 hour test data; well characterized compatibility test; micro- and macro-environmental characterization of the bed; determination of the applicability of small-scale bed results; knowledge of bed chemistries; translation from one technology to another (e.g., gasification of FB); and extrapolation to long times.

In many applications sulfur partial pressure has an overriding influence on hot corrosion.

It appears that 900-1000°F steam for steam turbines can be raised in fluidized bed boilers, but it is doubtful that 1600°F air for a Brayton cycle gas turbine can be produced without excessive corrosion. In the pressurized fluidized bed application, where combusted high pressure gas is expanded through a turbine, the approach will be to clean up the gas as much as possible and periodically clean the gas turbine, whose hot parts are protected from corrosion by suitable coatings.

GEOTHERMAL FLUID HANDLING
D. W. Shannon, Discussion Leader
Philip Lamori, Rapporteur

The dry steam geothermal resource is relatively small, with a current generating capacity of about 700 megawatts, and a potential in the U.S. of about 2000 megawatts. There are extensive hydrothermal resources, particularly when lower temperature resources suitable for district heating are included. The hydrothermal resource generated only 15 megawatts in 1975, but is expected to be 80 MW in 1978, 350 MW in 1982, and, by year 2000, will generate at most 60,000 MW, of which 20,000 MW would be electric. The lower temperature geothermal resource is used for district heating, where there are no materials problems. The higher temperature geothermal resource would be flashed and used in a binary turbine cycle. Most of the hydrothermal is low salinity, with about the amount of salt in sea water and a pH of 6 or greater, which would not cause serious corrosion problems. Carbon steel heat exchangers and piping and conventional steam turbine materials would be suitable. Most of the hydrothermal resources deposit a silica-rich scale on the piping and heat exchangers. This requires periodic maintenance, but is not a serious problem. Perhaps the most important problem is how long the hydrothermal resource lasts. To justify a power plant based on a geothermal resource, a resource should last at least 20 years to pay for the investment.

MATERIALS FOR SOLAR ENERGY CONVERSION

Solar energy conversion devices are of two types: photovoltaic and central receiver. The solar energy is free, but it is of low quality and intermittent occurrence. The capital costs in building solar energy equipment are very high. Due to lack of experience the costs of operation and maintenance on solar energy conversion equipment are unknown.

The chief materials requirement for the primary collector is low cost. A target of \$2.50 per M^2, which is about the cost of plate glass, is a goal. The collector should be light weight, rigid, stable, and cleanable. Absorption in the solar range should be high, and the reflection in the thermal range high.

The leading converter materials are: silicon, GaAs, and CdSi. Silicon is the primary candidate, with the primary goal to deposit it in inexpensive form.

Solar-thermal energy conversion utilizes a heat exchanger inside of a central receiver which receives reflected solar energy from a heliostat field. Metallic heat exchangers operate satisfactorily up to about 1600°F. Ceramic heat exchangers are required if the working fluid is to be heated to 1800°F or higher. The performance of metallic heat exchangers has been relatively satisfactory. No information is available on ceramic heat exchangers, but reliability problems are anticipated. Another materials problem is the stability of the insulation used in lining the central receiver.

DISCUSSION

For countries which do not have concentrated sources of energy such as oil and coal, dispersed energy sources, especially solar, are very important. Reduction in cost of materials needed to utilize such sources is essential.

For solar energy, silicon is an important material. Silicon is concentrated by rice in rice hulls and that is one of the important sources of silicon carbide for reinforcements in composites. Exxon makes silicon carbide by a pyrolytic process which was developed in a university laboratory. But whether silicon is more cheaply obtained from rice hulls, from products of plant silicon, or from unit solidification, etc., is under examination.

In some parts of the world, energy distribution systems are not readily available and in some they are non-existent. In those places, local economics are different from countries in which energy distribution systems already exist and all one must do is plug into it. Dispersed energy sources are therefore more important.

In addition to lowering the cost of solar collectors and converters, there is the problem of maintaining the performance of those materials over their lifetimes. Continued research is needed along all three lines.

In some parts of the world, transportation systems for energy are not readily available, and they are non-existent in many areas. In those places local economics are different from countries where energy distribution systems already exist and one merely plugs into them. Dispersed energy systems are especially important to countries with little or no existing energy transportation systems.

WORKSHOP 4

THE ECONOMICS OF MATERIALS USE UNDER CONDITIONS OF RISING ENERGY COSTS

Dieter G. Kamphausen, Chairman
Anne P. Carter, Organizer and Rapporteur

Delegates from four countries--the United States, India, Israel, and the United Kingdom--opened the discussion with remarks on five topics: the changing importance of materials and materials costs in the world economy; materials economics and technological adaptation; investment requirements and the changing role of materials in the international economy; the political economy of materials policy; and materials markets, international institutions, and materials policy.

Discussion of these topics raised many questions: How have rising energy costs affected the cost of producing and using different materials? What are the critical price levels for energy that might induce major shifts in the relative advantages of specific materials? Have rising energy costs led to increased relative importance of materials costs as compared with costs of labor and capital? Are costs prospects sufficiently clear to warrant commitments to new materials technology? What is the future of recycling in the context of changing ore grades, conversion techniques, and energy costs? To what extent do the relative costs of producing or using different materials vary among regions with different labor, capital, pollution control, and other local cost factors? How might these cost differentials affect choices among materials technology options in different parts of the world? What are the direct and indirect costs and the lead times involved in shifting to new materials technology? How long will it take to effect transitions to new materials on a wide scale?

There was general agreement that the world will not run out of resources in any literal sense in our lifetimes. However, instability and crises in materials markets may bring recurrent difficulties in the years ahead. Professor Robert Pryor emphasized this point:

> If we live in a real world and not a fantasy one, then it is the market availability and not physical availability that matters....Dislocations in free markets in mineral materials will arise...precisely because some resources are not evenly distributed and...purchasing power is not evenly distributed. These dislocations in certain materials may be severe and...

will distort the focus of usage of materials and they will be aggravated by the long lead times in exploration. Therefore, the materials world...should not take for granted the ability of the mining world to overcome the political and environmental and other constraints that are being placed upon it. Perhaps it is because of this that I feel that there is a role for international institutions in material resources that can synthesize the information and formulate an unbiased set of options for the national and international policy makers.

Various interest groups--countries, sectors, regions, owners, workers--will tend to have conflicting objectives. It is not realistic to expect a single unified world policy in this field. Different countries face different constraints. Their resources and other endowments, their foreign exchange positions, etc. differ and, therefore, their policy choices will differ. Even homogeneous groups must consider a wide range of objectives, e.g., income levels, distributional considerations, environment, stability, and trade-offs between the present and the future.

A number of measures were proposed that would serve the interests of many, if not of all, interest groups: Increased R&D should expand technical options. Wider and earlier exploration could provide more orderly markets. Comprehensive information systems and projections might clarify the options and improve the effectiveness of market mechanisms. Independent initiatives of scientific communities in various countries might be effective in the pursuit of these objectives.

The session also considered how R&D should be focused and which foci are most promising. Comprehensive information systems that combine engineering process information with more aggregate economic information in an integrated framework may be useful in exploring alternative paths. Projections must embody explicit assumptions about social and technical changes. Changing these assumptions may show whether there are alternative strategies to reach a given target.

No comprehensive list of technical problems involved in evaluating and projecting materials and energy supply and demand was attempted. However, it was agreed that, despite the theme of the conference, energy should not be assumed to be the only important input affecting choices among processes; labor, capital, and other specific resources must be considered simultaneously. The relative influence of different inputs varies from place to place and from time to time.

Measures of energy intensiveness should take account of total primary energy requirements, both direct and indirect. In some areas the energy potential of materials, such as wood, are important. In calculating direct and indirect energy use it is necessary to consider the energy content of capital goods and also the durability of the product. How much service does a given product deliver per unit of energy embodied in it? Some products have greater recycling potential than others. Several participants emphasized the quality as well as the quantity of energy required. Does a process require electricity or other particular forms of energy?

Some special concerns of developing countries were emphasized. In particular, the inadequacy of available techniques of project evaluation was pointed out. Developing countries find that changing resource prices on world markets leads to problems of internal as well as external inequities. Innovations can have serious implications for the development prospects of poor countries and these should be studied before the new techniques are implemented. Some time was devoted to the question of whether agricultural research institutes should be the prototype for expanding research institutions in specific materials problems.

It was the consensus that the world materials information system could be upgraded through contributions by individual countries, private institutions, universities, and international agencies. More realistic focus in this field of energy and materials requires more data. However, data will be meaningful only if they are developed in the context of a rational framework. This workshop could only point the way toward deeper study along these lines.

WORKSHOP 5

MATERIALS EDUCATION FOR THE INTERRELATED ENERGY AND MATERIALS WORLD

Anthony Kelly, Chairman
Daniel Drucker, Organizer
Charles A. Wert, Rapporteur

SUMMARY OF DISCUSSION

To provide the motivation and problem-solving capability, necessary for a materials scientist/engineer to be immediately useful, the content of the course is more important than the teaching method.

Developing Countries

Slowly and with difficulty the universities have been developing materials programs. Laboratory courses are considered important in promoting manipulative skills, scientific objectivity, and communicative skills. However, the student body is small, and it is sometimes difficult to match the graduate to the industry of the country.

Countries such as Nigeria, India, and the Philippines have found that materials education as currently followed in the industrial nations may not always be the most appropriate. Courses need to be designed so they are appropriate to existing conditions. They must relate an older indigenous technology to a more modern one (e.g., iron smelting) or be related to the plentiful supply of unskilled labor (e.g., a laundry). An example is Egypt where plants tend to be over-manned, by Western standards, in order to correspond to the labor-intensive economy. India provides good examples of the demand for courses that develop an awareness of the need for a diffuse energy supply. In these tropical countries the materials-energy relationship is considered important.

Argentina has followed a different route, and has been committed to nuclear power. Materials education developed to support this has been successful in providing advanced materials scientists in Argentina and other countries in Latin America through the Organization of American States. Despite the fact that nuclear power only provides a small percentage of Argentina's total energy requirement, it is considered a worthwhile commitment.

Courses need to be evaluated to ensure that they promote relevant technology. Developing countries can be assisted by: exchange of faculty, sister institution relationships, and specific joint materials research projects such as those in India.

It was also suggested that tourism could be used to assist technology transfer.

Developed Countries

The principal experience drawn upon was that of the United States, the United Kingdom, Germany, and Japan. These countries have a mature education structure with active courses in materials science and engineering (MSE).

The materials-energy relationship is not producing any great change though some graduate courses are developing, e.g., energy engineering. Nuclear metallurgy has been established as a course in many universities since the 1950s. One university in the United States (Vanderbilt), has developed a materials science course on the total resource cycle.

In research, investigation of novel methods of energy production has been developed, and in some cases these have been used to teach materials science concepts, integrating both undergraduate and postgraduate studies (e.g., at MIT). New ideas are likely to emerge in connection with studies of the biological growth of some microstructures and concentration on the properties of materials of low specific energy of production. However, great changes in undergraduate courses, in order to consider energy costs of materials, are not generally possible.

CONCLUSIONS

The education of materials scientists and engineers around the world does not divide itself neatly into two categories--developed countries and developing countries. On the one hand, the exchange of students and professionals through many decades and the extensive use of similar textbooks (mainly published in English now) have fostered homogeneity of thought, especially in metallurgy where the exchanges have been extensive. However, the education itself is embedded in such a variety of industrial requirements and social structures in the various countries that a great variety of educational needs exist. Thus a continuous spectrum exists among countries in the history of materials education, age and size of institutions, availability of faculty, number of potential students, and industrial needs of their societies. Therefore, the specific curriculum development in various countries has countervailing forces: one is a need to fit specific demands of the society it serves--this tends to produce diversity; the other, a long history of extensive interchange of students and practicing professionals--this tends to produce similarity of style.

Rising energy costs and energy shortages are important factors in utilization of materials and in construction and operation of energy conversion systems. Even so, our inability to predict what the detailed problems will be in a few years makes specific response to these factors by the educational system uncertain, given the long time constant of the impact of education on specific industrial needs. Furthermore, education in MSE is based on principles of mathematics, physics, and chemistry as they relate to such matters as applications of thermodynamics, kinetics, phase relations, elastic and plastic behavior, macro- and microchemical composition, etc. These basic features permit acknowledgement of energy-related factors in materials education, but do not warrant a massive shift to energy- and materials-related problems.

RECOMMENDATIONS AND DISCUSSION

- A pluralistic style of education in materials should develop in our countries to correspond to the respective demands of industry and society. The tendency toward similarity fostered by decades of association and exchange of professionals, together with a common acceptance of the basic subject areas underlying our field, tends towards commonality. Yet the enormous range of subjects in the entire materials cycle together with the great variety of perceived need in the various countries forces any educational institution to select only a part of the entire range of applications for emphasis. Thus, similarity of basic principles together with diversity of applications seems appropriate and should be fostered.

- Energy aspects of materials utilization and application for energy conversion should be recognized in several ways:

    a. Research programs and graduate education seem the most likely starting points for introducing curriculum changes related to energy problems.

    b. Attention should be paid to an understanding of the entire materials cycle, including the economic, environmental, and recycling factors. Development of thought of the materials <u>system</u> is encouraged.

    c. An interleaving of examples of materials applications related to energy should be made in existing courses.

    d. A new course (or a few) might be developed in each curriculum emphasizing the energy-materials interface.

e. Continued efforts must be made to provide more effective educational opportunity in materials applications to engineering students in design departments such as civil, mechanical, nuclear, industrial, and electrical engineering.

The response to energy-materials problems perceived appropriate varies among nations. We propose that the first response should be at the graduate and research levels. Not only would its impact be felt sooner than would be true of subject matter introduced earlier in the careers of students, but its nature could be more easily explored by students and faculty together in their research programs. In formal courses, energy-materials problems might be introduced in a variety of ways--but surely not by merely jamming more subject material into an already full curriculum or by replacing the basic subject areas by applications-oriented subjects. A better understanding of the entire materials system is appropriate, including the materials-energy factors. A further feature of concern to the Workshop was the growing recognition of the multiplicity of elements in the materials education matrix. Not only does our field span the range from the basic sciences of physics and chemistry to detailed materials applications, but it also encompasses a wide range of substances, not only metallic alloys and ceramics, traditional in our educational pattern, but also semiconductors, polymers, cement, and wood. Selection of subject areas appropriate to the country must be made.

Educational responsibility of faculty members in metallurgy, ceramics, polymers, or MSE departments is not limited to professionals in those departments. Education of students in the design departments, civil, mechanical, nuclear, industrial, and electrical engineering in the basic and applications-oriented properties of materials in design of structures, machines, and devices is of vital importance. Such educational ventures should be designed with care, with recognition that the classroom and laboratory needs of these students may be quite different from those of the professional MSE students.

- Interplay between the educational structures of our various countries, already strong in specific instances, must be further encouraged. Association of faculties and professionals in the materials field already exists in many instances. This has partly been channeled through existing professional societies in meetings devoted to research. It has also been fostered through exchange of faculty members (sabbatical leaves, short-term interchanges, tourism, and the like). It has also been fostered by exchange of students--generally students from countries with partially developed materials-education programs who have studied in countries with well developed educational institutions.

The last association, study of students abroad, has been remarkably successful in some instances. Development of education in materials in Japan has been aided remarkably in the last 30 years by its association with the United States and Western Europe. This assistance has become a highly effective two-way street. The Argentine experience is well known and the growing collaboration in education and research in Central and South America is impressive. Development of materials education in India has been enhanced by association with the United States and Western Europe. Commonality of thought between educators in Western Europe and North America has been enhanced by continual exchange of people. Exchange of students, faculty, and other professionals throughout Europe has had major impact there. Exchanges of students between other countries may have been extensive in some instances but they seem not to have had the same impact that these examples show. Workshop speakers emphasized that associations between professionals in developing countries need to be encouraged. The role of political climate is important in all past and future associations.

The environments in which interactions can flourish demands the coexistence of several factors. First, there must exist appropriate groups of persons in the nations embarking on the collaborative efforts. This means that the professionals must be not only interested in the association, but must also have enough professional and "political" influence in the educational (and perhaps governmental) structure of their own country to bring about needed changes. Secondly, development of the MSE structure in any country must be embedded in a generally perceived need in that country--that is, the educational goals must be appropriate for that society. Frequently, an important driving force for development or enhancement of an MSE educational system is strong support for a perceived national need. Thirdly, money must be available to support exchanges. The money should not be centralized in a single agency--pluralistic sources are desirable. Finally, mechanisms of association must be available and commonly known to faculty in the various countries. Professional societies are doing a good job of fostering association at the research levels but similar organizations at the educational level do not exist. Perhaps adequate institutions for materials education exist within nations (for example, the American Institute of Mining, Metallurgical and Petroleum Engineers, the American Society for Metals and the American Society of Engineering Education) have extensive educational facets within the United States but international associations are poorly established.

SUMMARY

Materials education around the world has great variety--some educational institutions and curricula are old and well-established, others new and seeking to find their appropriate place in their own society. Still, remarkable similarity of patterns and goals of materials education exists worldwide, partly because of a commonly accepted foundation of education in MSE, partly because of extensive interchange of students and professionals in the past. The impact of energy problems in materials utilization is gradually being assessed by the educational community. Curricula will undoubtedly assimilate this new parameter; the extent of the changes in present or planned curricula may well vary, country by country, but it seems to demand no overwhelming changes in educational style. The large-scale associations between professionals from various nations, of immense value in the past, need to be fostered further.

WORKSHOP 6

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE-ENERGY-EFFICIENT MANUFACTURING

James Mattice, Chairman
Charles A. Berg, Organizer
Mario Cellarosi, Rapporteur

The presentations of the workshop reflect the range of viewpoints and experiences of the authors; this range encompasses academic science, industrial research, government-sponsored development, manufacturing management, construction practice, and even political science. The workshop sessions were attended by participants from a variety of countries thus the general conclusions reached in the workshop reflect international professional perceptions of the issues discussed.

A major theme emerged early in the workshop and prevailed throughout the sessions. It is that the fundamental concern of manufacturing technology is the total cost of production. The increasing prices of energy impose additional direct and indirect costs on production. For example, direct costs for energy in manufacturing include heating, ventilating, and air conditioning (HVAC) of manufacturing space and indirect costs include the costs of energy required to process excess materials now required in manufacturing. It was emphasized that efforts to reduce the direct consumption of energy must be pursued vigorously; however, it was also emphasized that the costs of energy should not be considered in isolation from other costs of manufacturing. Comprehensive efforts to reduce total costs of manufacturing are required as a means of reducing both the direct and the indirect requirements for energy. The indirect requirements for energy (e.g., in waste material) are often far more significant than the direct ones.

Technical measures to affect the direct use of energy in manufacturing were discussed extensively. Many of these can be applied immediately to reduce costs of production. These include rigid control of air conditioning, ventilation, and lighting; retrofit of efficient electric motors to replace less efficient hydraulic servosystems; and similar steps. In general, these fall in the category of energy management. They can provide significant reductions in manufacturing costs; however, there are few instances in which materials science impinges upon energy management. One possibly important instance is the drying of paints, solvents, and resins (as in aircraft production). Removal of solvents from the air in manufacturing spaces imposes a substantial load on HVAC systems. Novel materials that might permit the applications of paints, etc. without evolution of noxious solvents could lead to manufacturing with greater energy efficiency and lower costs. The possibility that other modifications in materials might also relieve the direct requirements for energy, to remove harmful substances (e.g., welding slag dust, cutting oils, cooling mist sprays, etc.) from the air in a manufacturing space, was also discussed briefly.

The capacity of materials research to affect the energy requirements and costs of manufacturing in the longer term appeared highly promising. It was pointed out by several participants, however, that the existence of large stocks of capital equipment which embody conventional technology restrains the adoption of technical change. It is very difficult to adopt new technology that provides only a marginal improvement in costs over conventional technology. Thus, the new technology, through which improvements in energy efficiency and costs are to be realized, must offer truly compelling economic advantages over conventional practices in order to win adoption. This implies a strong need for the basic scientific research through which highly novel and advantageous technology may be found.

Some possible, and promising, directions for materials research as a basis for new manufacturing technology were suggested. For example, it was cited that with newly increased fuel prices the costs of transportation now represent 10-15 percent of the total costs of producing many of the products that are conventionally manufactured in large central plants; glass containers and specialty steel products are examples. Possibilities to devise new processing systems, which would permit one to produce these in smaller volume, closer to their point of use, were discussed. These included the use of glass sintering, powder metallurgy, and novel plastics. No definite conclusion could be reached regarding any single example, but the general sense of the Workshop was that research which could provide a basis for manufacturing on smaller scale to suit the present realities of transportation and distribution could prove very valuable.

The potential for more exacting use of materials was discussed at length. This could save energy and costs by eliminating present wastes of material in conventional manufacturing. For example, hot isostatic pressing, and other versions of "forming to shape," enables one to form parts with significantly lower (30-50 percent) total requirement for materials. These advanced forms of powder metallurgy can now be used only with certain of the nonferrous alloys employed in aircraft engines. Basic research to extend the use of such techniques to manufacturing with more common ferrous alloys might lead to great gains in energy efficiency and total productivity. The possible use of electroforming or spray forming in "forming to shape" with common technical alloys could also be of great potential value. Research in basic materials science (e.g., on the possibility of superplasticity in more common alloy grades or on direct electrodeposition of alloys) will be required to realize any part of these potential gains.

The use of lasers, microwaves, and other forms of "directed energy sources" received considerable attention in the Workshop. Laser hardening, laser glazing, and the use of lasers to compact powders were discussed as examples of the way in which directed energy sources can be used to reduce the total energy and the costs of processing. Some techniques of laser processing are already used commercially. Further R&D in the use of laser energy in processing offers the promise of substantial gains in manufacturing efficiency. In particular, further efforts on the use of lasers to condense powders, and research on possible combinations of laser processing with plasma arc reduction and alloying appear to be very promising avenues of materials research in manufacturing.

The use of microwave energy in polymer processing was cited in discussions as being one way to reduce the energy and costs of polymer molding. Examples of the current use of microwaves for this purpose were discussed; outstanding reductions of energy and costs have already been attained. Materials research, particularly on the electrical and electromagnetic properties of structural polymers and the response of these to electromagnetic effects could lead to even more significant gains in polymer processing.

In general, the exacting application of electromagnetic effects in materials processing and manufacturing appears to offer the possibility to circumvent the now irreducible costs of conventional technology. These costs arise through losses of energy, loss of materials via chemical effects, loss of materials as scrap, loss of the time required to complete diffusional processes (e.g., heating), and other such effects. As a class, many of the effects responsible for the irreducible costs of conventional technology stem from the lack of exacting control over the use of energy. Electromagnetic effects appear to offer the opportunity to remedy this. R&D toward a better understanding of the roles in which electromagnetic effects might be applied in materials processing and manufacturing would appear to be highly worthwhile.

The use of energy accounting methods as a basis for materials selection was advanced, however, it was pointed out in discussion that the data required for this are presently inadequate. In addition, it was pointed out that conventional energy accounting does not reflect the physical nature of the natural resource consumed for energy, nor does the technique indicate the value of that resource. The general concensus of the Workshop did not strongly support the use of energy accounting for the purpose suggested.

To arrive at new methods of manufacturing sufficiently advantageous to win industrial adoption, in the face of large existing stocks of capital equipment that embody conventional technology and slow (or negligible) growth of markets, will require a strong effort in basic research.

This effort will, in turn, require the application of all the intellectual resources available for such a task. The effort will require contributions from the basic scientific laboratories of the government, the universities, inventors and entrepreneurs, industrial laboratories, and those agencies of government responsible for technical development programs.

WORKSHOP 7

SCIENCE AND TECHNOLOGY FOR ENERGY-EFFICIENT MATERIALS FROM RENEWABLE RESOURCES

Robert Youngs, Chairman
James Bethel, Organizer
Marco A. Flores-Rodas, Rapporteur

INTRODUCTION

Those of us who are especially concerned with renewable resources from the standpoint of both materials and energy appreciate the opportunity offered by this Congress to consider materials-energy interactions in the renewable resources field with others here who bring to the Congress such a breadth of scientific discipline and experience. It is all too rare that specialists in wood science and technology exchange ideas with scientists and technologists specializing in other materials.

We who are concerned with renewable resources and with forest products in particular have something to offer you, as you do us. Our contribution is information on wood--an important material of the future.

This workshop dealt with several subjects of particular concern to the interaction of energy and materials in the context of renewable resources. Our emphasis was on wood, which does not imply that other renewable resources are less significant. Wood is a significant renewable resource that deserves consideration in this context. It composes 95 percent of the world's output of renewable industrial materials.

Our discussion centered around six principal issue presentations dealing with the supply and renewability of renewable materials, and various aspects of materials--energy interactions in processing and use. A few summary remarks that deal with just a few of the major issues discussed and points of concern follow.

ENERGY EFFICIENCY IN PROCESSING AND USE

Renewable wood-base materials have many inherent advantages in terms of energy efficiency in processing and in use. This has been quite dramatically brought out by some of the presentations in this Congress. In view of this we recommend that engineers, architects, and materials scientists become familiar with wood as a source of both materials and energy. Doing so will broaden their capability to deal effectively with a full range of materials and energy options--it will enlarge their bag of tools, so to speak. This is something that deserves attention but has been overlooked in Washington.

CONSERVATION

Important to the conservation and wise use of wood and wood-based materials are efforts to extend service life. Deterioration of wood by biological organisms is the approximate equivalent to the corrosion of metals. Greater use of wood may depend significantly on the development of improved wood preservation technology. This is particularly important in regions conducive to severe degradation, a characteristic of many of the developing countries particularly those in tropical areas. Better preservation is particularly important as a condition precedent to improving the serviceability of local woods for local use.

Many of the developing nations are amply blessed with wood. But they are finding real problems in using it effectively, and attention to increasing service life could greatly increase the utility of that material.

INVENTORY DATA

In our discussions of the supply of renewable materials it became quite apparent that reliable inventory data simply do not exist. Such data are basic to considerations of the wise use of resources for both materials and energy. One can find numbers throughout the world on inventory or renewable resources or particularly forest timber resources. However, the mere fact that there are numbers is misleading because some of these numbers are based on so little data that they are almost worse than meaningless.

The following five items are some specific activities that we suggest to improve the quality of these data bases:

- Develop improved applications of high altitude, remote sensing technology to forest inventory. We recognize that this is difficult to implement, however, it is the trend of the future and we suggest that it be given increased attention.
- We should base forest inventory on whole-tree biomass. The current practice is to base inventories on certain predetermined commercial designations of classes of material.
- We should develop periodic monitoring systems to estimate forest growth so that we can keep up to date with the renewability of this renewable resource.

- We need to institute international cooperation in forest inventory design so that meaningful comparisons can be made region-to-region and country-to-country. Forests, like most natural resources, do not respect national boundaries. We need, however, to be able to deal with them effectively on an international basis.

- An issue of concern is standardization of inventory technology so that when an organization such as the U.N. Food and Agriculture Organization accumulates worldwide inventory data it can do so on an additive basis.

TECHNOLOGY FOR ECONOMICAL HARVESTING AND TRANSPORTATION

An important barrier to the more extensive use of forest residues and to a wider array of tree species that make up the forest resource is the lack of adequate technology for economical harvesting and transportation. This problem received a great deal of attention in the Workshop and was pinpointed as one of the critical areas needing further study. Further attention also needs to be given to whole-tree harvesting as a means of maximizing resource utilization.

FUEL

Half of the wood removed from the world's forests is used for fuel. In many developing countries there is a critical need for fuel that could be satisfied with wood or one of its derivatives. However, much of the wood that is being used is not being used efficiently. It is important to improve wood combustion technology, including the development of more efficient stoves for domestic heating and cooking, improved industrial power plants, and appropriate power generation facilities for public utilities.

In spite of inadequacy in current technology, interest in wood for fuel continues to increase. To facilitate such use, one of the very practical needs that we see is development leading to the efficient drying of wood prior to its use for fuel.

ENVIRONMENTAL REGULATIONS

Further attention needs to be devoted to environmental regulations that more effectively take into account the combustion characteristics of wood fuel. Recognition of the nontoxic characteristics of wood could lead to broader opportunities to use renewable resources as alternatives to petroleum. The gaseous effluents of wood combustion are essentially free of nitrogen oxide and sulfur oxide compounds. If increased attention is given to the characteristics of wood fuel, it will be possible to use this renewable fuel source effectively without further deterioration of the environment.

UNAPPLIED TECHNOLOGY

There is a great deal of technology on effective use of wood as a material that is not being applied. This is characteristic not only of the United States but of the whole world. And there are some outstanding opportunities to conserve energy and scarce materials through improving the processing and use of wood as a substitute industrial feed stock and as an engineering material. Efforts to extend the awareness and the use of such technology could have substantive payoffs in terms of energy and material conservation.

DISCUSSION

- Present engineering data on wood as a design material is highly inaccurate because of the steady erosion of timber standards. And this problem, which arises in the wood industry itself is one that vitally concerns materials scientists throughout the engineering world. Nevertheless, there are continual efforts to maintain standards; this is one function that such groups as the forest products labatory in Madison, Wisconsin are particularly concerned with.

- What is the potential role of genetics in the development of species of wood to enlarge, enhance, and improve their performance as finished material?

  The workshop recognized and in fact discussed at some length the need for further work in genetics to improve the capabilities of wood as an energy source, and in some cases this could be done. The age-old question in this regard, however, is simply this: When those of us who are concerned with the effective use of wood approach geneticists with the question of how they can improve wood properties for particular uses, they always respond "Okay, you tell me what the use is going to be and I'll tell you how I can improve the properties." Usually we are stuck at that point because when we plant a stand of timber it is typically for many uses and the multiple use concept is broadly ingrained in the timber industry. It is difficult to say that any particular tree or group of trees will be used primarily for structural lumber, for pulp, for energy, or whatever. Any stand would provide some or all of these.

- What is the possible hazard of single-species growth and the vulnerability to blight?

  This question of so-called monoculture is often raised, but I think that the problem has been exaggerated. The variations even within a single stand are such that a true monoculture is simply not produced. It is something to be cautious about;

however, I do not think it is a serious danger to us if we manage forests wisely.

- Could you comment on oil farms such as Professor Calvin's?

  We certainly commend efforts of this sort to find additional energy sources among renewable materials. There are still many questions about the work that Dr. Calvin is doing. We are looking forward to further evidence of the feasibility of this approach. We certainly are not discrediting it in any way and yet we simply did not feel we were prepared at this point to raise it as a major consideration in this report.

- Regarding the extension of service life of woods, in the Netherlands a new method has been developed which is based in Germany, the United Kingdom, and the United States. It is concerned especially with the renovation of houses where the underside and the edges of the windows always deteriorate. The method consists of drilling small holes at a distance of about 180 millimeters, into which is put a small capsule that has a special absorption layer and contains insecticides and certain other fluids. The hole is plugged with wood, crushing the capsule, and the fluid is absorbed by the wood. Within three days it extends some 160 millimeters.

- The question of estate crops such as natural rubber was not discussed because the workshop did not happen to include people who were familiar enough with these subjects to discuss them well. There are many other possibilities in this field of tree-related renewable resources.

- Though recycling of materials contributes significantly to the amount of materials available, it too was not discussed, being left to other workshops.

WORKSHOP 8

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE-ENERGY-EFFICIENT TRANSPORTATION

I.G.C. Ogle, Chairman
Morris A. Steinberg, Organizer
Salomon Wald, Rapporteur

This workshop reviewed issues related to all major transportation systems--aircraft, railroad vehicles and powerplants, ships, automobiles, and buses, road and highway construction, and unconventional technologies such as electric vehicles. The workshop also discussed general problems relevant to all transportation technologies, such as the question of whether or not economy and energy efficiency can be reconciled in transportation, and socioeconomic constraints which can hinder the introduction of more energy-saving materials.

A clear interaction between energy-efficiency and materials utilization has been found in each transportation system although the tradeoffs and specific problems vary considerably between different systems. In fact, there is a large potential for energy saving through lighter and otherwise more efficient materials. This potential often reaches 20 percent in case of railroads, even 50 percent of present energy requirements. Thus, the drive to save energy is one of the main reasons for the R&D effort and for a very fast rate of technical change in practically all transportation systems. Some concrete examples might illustrate the specific issues of each transportation system.

MATERIALS ISSUES SUMMARY

In aircraft transportation, fuel represents 40 percent or more of direct operating costs and might even rise to 50 percent, which is more than in any other motor transportation technology. Thus, the need to reduce specific fuel consumption has pushed ahead the search for new airframe and engine materials; composites appear to be the most promising. Composites account for barely 1 percent of the materials in existing widebody jets, but this proportion is expected to rise to 20 percent in the late 1980s. The weight-saving achieved through composites such as graphite-epoxies will not only lead to fuel savings but to the resizing of entire airplanes.

Fuel costs account for only 6-7 percent of total operational costs in railroads, but as fuel costs rise, more attention is being given to better vehicle design, to improvements in rail technology, and especially to the replacement of wood ties by concrete. The latter is an expected consequence of environmental controls on the use of creosote. These and other efforts will lead to slow but useful reduction in energy requirements. The diesel locomotive, which is the prevailing railroad engine in the United States, is already quite energy-efficient and little immediate progress is expected in this field.

Road and highway construction and maintenance absorbs less than 2 percent of total U.S. energy. Still, considerable energy- and cost-savings will be achieved through the introduction of fly ash. Fly ash, a solid waste by-product of coal power plants, depending on its properties, is a substitute for Portland cement as a base course material.

In ship building, materials and design improvements are necessary and are actively pursued for four interrelated purposes: to increase loading capacity, to increase cruising speed while minimizing fuel consumption, to reduce the number of crew, and to reduce overall cost. These improvements require very complex, high-power machinery, among other things, for new concepts in welding of ship structure.

The design of automobiles and buses is being strongly affected by rising fuel costs. The main goal, to reduce weight, can be achieved through improved design with traditional materials, through improved properties, through new materials, or through entirely new design concepts. As far as materials are concerned, substantial improvements are possible and can be expected mainly through the use of plastics and high-strength steels. However, it is very important to keep materials options open, since substitution of any one material for another must be determined by an overall systems approach. In this respect, there is a clear requirement for technological pluralism. There is a need to examine the application of new materials and materials concepts for a vehicle system on the basis of total energy balance as the means to strike a balance between fuel savings resulting from materials substitution and optimum first cost or what the market will accept. In any event, materials R&D has many large tasks in the automobile sector.

Among unconventional transportation systems, electric vehicles for specific applications do exist and might in the future account for 10 percent of all automobile fuel consimption, at least in some European countries. Advanced batteries are at the test stage and further improvements, in durability, for example, are expected.

For many transportation systems, advanced materials and energy-saving technologies are, in principle, available, but have not yet been introduced. In many other cases, considerable additional R&D efforts are necessary to improve technologies. No simple generalizations are possible except perhaps in one respect: the private sector will remain the main developer of energy-efficient transportation systems, but it cannot do this alone. The market system will need some prodding and assistance from the public sector.

GOVERNMENT'S ROLE

There was strong rationale to indicate that governments must support longer term R&D associated with high risk technology, and that they should adapt taxation and legislation in a way that can promote application of better technologies, instead of hindering this application. However, governments should not subsidize the manufacturing of transportation systems.

SUBSTITUTION

The Workshop also discussed the contraints that can prevent or delay the substitution of more energy-efficient materials for ones presently used. Substitution is a very complex issue and it is often not dominated by energy considerations. To take the case of steel, 20 percent of all steel produced in the United States is used in automobile manufacturing, and any major shift away from steel toward plastics could have dramatic employment and corresponding political repercussions. Thus, it is important not to forget the political, labor, capital, trade, and environmental consequences of major shifts in the use of materials--consequences which could act as major constraints.

ENVIRONMENTAL REGULATIONS

A last question that was raised in the Workshop concerned the effects of environmental regulations on the energy and materials choices of transportation systems. Little discussion took place and no clear answer to this question was apparent.

DISCUSSION

- The auto industry consumes 20 percent of the steel and has many other ramifications. The driving force for change is a governmentally mandated fuel efficiency which does not directly say anything about the technical solutions, where to find them, or how to get this efficiency, but indirectly it mandates certain choices, or changes, especially weight reduction.

These are two ways for weight reduction, one is down-sizing which is unimportant in Europe because the cars are already fairly small, but important for weight reduction in the United States.

The other way to reduce weight is by using lighter materials. Use of lighter materials, can increase the number of basic types of materials from about three to about six. They include plain carbon steels; high-strength steels and aluminum alloys (both of which introduce various problems, particularly with respect to recycling); and plastics, which may be more or less homogeneous plastic but are more likely to be reinforced. There is currently very little use of reinforced plastics in automobiles, but in about five years there will probably be much more.

Plastics will create problems with respect to recycling and recycling of course does not only mean getting some values back but it means a disposal problem. We have barely solved the problem of disposal of the automobiles that accmulated in the early 1970s and there may be a new near crisis of disposal if we have materials like plastic that will be very difficult to recycle.

- Recently Ford Motor Company has gone through an exercise to lower the weight of a standard 1979 car (Granada range) simply to identify where the technological problems would lie if one wanted to replace conventional materials--steels aluminum, and possibly other components with composites in replacing every conceivable part of the car. Cost (about $3½ million) was not a consideration.

- When using a material with a high-energy content like aluminum, the energy consideration can be divided into two parts. The energy needed to operate the cars would probably be gasoline. But the energy content of the materials used for construction could be drawn from other sources such as the hydroelectric power developing countries could utilize to make, aluminum. In automobiles and other uses of composites, hydrid systems will make the cost possible because graphite is still $25 a pound. Glass is much cheapter. The all-carbon fiber car is nonsense on cost grounds. Also, the speed of manufacture is all-important, and unless there are resins developed so that hybrid composites can set as quickly as steel can be formed, even that is not a realistic possibility.

- The systems approach to materials utilization and materials replacement is an important issue in replacement of wood railroad ties with concrete ties, in light of current shortages of both domestic and imported cement. What impact will such a conversion have on the U.S. Cement and Concrete Industry and what timeframe should be expected for such a conversion? The switch to concrete is viewed at the present time as the only way of getting around the problems of using creosote on wood; creosote is outlawed for environmental reasons. The railroad industry adopted the first alternative of going to concrete, but there are still lots of technological and supply problems to be solved. Cement production itself has environmental problems.

- New materials development is a current need. The example is filamentary graphite composites, proposed in about 1963 in the Air Force project FORECAST. Almost a billion dollars has been spent in R&D to date and there still has been no large-scale application of composites. The Ford Motor Company, in their $3 million investment, has taken advantage of the billion dollars of R&D that has been accomplished to date. This is as it should be in regard to technology transfer.

Characterizing a material and putting it into commercial use is very costly. The manufacturers of materials, the producers of mill products, really do not want to do the necessary R&D for alloy development because of the difficulty in recovering investment costs. They cannot seem to get their investment back. The end users are now in the position of having to spend their own resources to do alloy or materials development for new applications.

One example, is changing the heat treatment of the 7000-series alloy 7075 from T6 to the T73 condition. To characterize this for application on a modern jet airplane costs over $1 million. One of the important things decision makers need to know is that the investment in alloy development for new materials is going to be very large over the next few years and it is going to take a very long time to get these materials into new hardware. This is particularly true for the development of new materials in the coal gasification and nuclear field, and for aircraft. Development of a better mechanism for informing decision makers what the real requirements are going to be in materials development should be a recommendation of this meeting.

- Fly wheels and hydrid propulsion systems are under development in various countries to some extent and presumably we will have a better picture of where the energy storage options are in terms of unconventional vehicles in the future.

WORKSHOP 9

MATERIALS SCIENCE AND TECHNOLOGY FOR NEW ENERGY SOURCES AND MORE-EFFICIENT ENERGY CONVERSION--NUCLEAR

J. Phillipe Berge, Chairman
Robert Jaffee, Organizer

The questions addressed in this Workshop concerned the role of materials and the need for more materials R&D related to the availability, cost, and safety of nuclear reactors and nuclear energy in general.

Issues in five areas were addressed: light-water reactors, gas cooled reactors, fast breeder reactors (especially liquid metal fast breeders), fusion reactors, and new materials for the nuclear industry.

LIGHT-WATER REACTORS

G. Ostberg, Discussion Leader
R. Smith, Rapporteur

Materials technology can contribute significantly to the safety assurance and economics of light-water reactor energy. International cooperation is needed to address problems and effectively implement solutions; materials problems encountered by any organization influence the rest of the light-water reactor community. Cooperative planning, research, and sharing of information are imperative to help solve the world energy need. Corrosion, fuel behavior, materials degradation, repair welding, and inspection are considered areas of beneficial collaboration.

Development of totally new materials is not expected to have an impact on the economics of light-water reactors, although improved heat treatment and processing can play significant roles. The key to reliability is to better understand and control current materials and the systems in which performance is required.

Light-water nuclear reactors represent a major contribution to the world's energy needs. Commercial boiling water (BWR) and pressurized water (PWR) equipment is deployed worldwide producing safe, efficient, and environmentally clean energy. Because both types of systems are developed technology, the principal efforts regarding materials center on two issues: safety and reliability.

Safety is requisite and commands a continuing effort to understand materials-systems interactions to improve conditions where needed, and to assure integrity. Postulated and real materials problems connected with manufacturing and operation have been the subject of intensive investigations. Due consideration is necessary for a number of related factors such as design, manufacture, control, operation, maintenance, and repair. Important research has been conducted to determine the role of heavy-section weld cracking, i.e., re-heat cracking during postweld heat treatment (PWHT); postulated loss-of-coolant accident (LOCA); and repair welding of pressure vessels. The effects of each of these items appears to be relatively well understood. As an example, recent results from the heavy-section steel technology program on large heavy-walled pressure vessels testing (nine vessels) has demonstrated a high degree of integrity for such vessels even when large flaws are present. Pressures nearly three times those permitted by the American Society of Materials Engineers (ASME) Section III code for Class-1 construction were required for failure of the vessels, including the case of large flaws located in the suspected zones of repair welds (half-bead technique without PWHT). Most important was a demonstration that analytical techniques could predict flaw behavior from a knowledge of materials properties and initial flaw geometry. Current safety research is actively studying related topics. Included are thermal shock of pressure vessels during LOCA; in-service materials degradation (irradiation); methods to predict flaw behavior for fully ductile conditions, including residual and thermal stress contributons; inspection improvements for both conventional and advanced techniques; and surveillance.

The materials role in the economics of energy production is overwhelmingly dominated by considerations of reliability. The materials costs for original construction represent a very small fraction of the cost of producing electrical energy. Thus modest savings through use of less expensive materials offers little incentive for research. The prime economic factor influenced by materials technology is the durability and reliability of equipment. The very high costs related to forced outage time, and difficult and resource-intensive repairs (personnel exposure) command a focus of materials technology development on reliability. The pay-off is through more fully understanding the behavior of current materials and the systems effects in which they must perform. Control of variability and appropriate qualifications are key items.

Most current research is directed toward problem solving. Corrosion control and necessary remedial activities are major concerns, chief among which are: denting and stress-corrosion cracking in PWR steam generators, stress-corrosion cracking of BWR piping, disk and blade cracking and pitting in turbines, and other forms of corrosion in balance-of-plant components. Corrosion fatigue, fabrication and repair techniques, and chemical cleaning are also areas of major activities.

Effective communication and cooperation among designers, architectural engineers, fabricators, and materials specialists are absolutely essential to reliable systems. No material can be expected to exhibit requisite durability for all service conditions. Most problems are system or configuration related or both. Solutions to these problems must embrace all involved sectors.

Inward creep of zincaloy fuel cladding is a concern related to pellet cladding interactions (heat transfer and rate of heat extraction during LOCA). Reactor testing shows fuel rod ovalization and line contact with fuel. Estimates are, that under certain conditions, contact can be expected in 2000 hours. The need is, again, a better understanding of this behavior including possible bundle movement which may result. Efforts are under way to develop a better heat treatment for zincaloy-4.

GAS-COOLED REACTORS
J. Barford, Discussion Leader
Per K. Korstad, Rapporteur

What are the prospects that materials performance will be better and systems reliability higher in gas-cooled reactors (GCR) than in LWRs? GCRs can be: carbon dioxide-cooled Magnox reactors, carbon dioxide-cooled Advanced Gas-cooled Reactors (AGR), helium-cooled High Temperature Reactors (HTGR), and Gas-cooled Breeder Reactors (GCBR), carbon dioxide- or helium-cooled.

There are three major differences between the GCR and LWR technologies: the GCRs operate at higher temperatures; the heat transfer medium is a single-phase gas; and the preliminary containment constitutes (at present) a prestressed concrete pressure vessel (PCPV).

Systems reliability for HTGRs is presently more difficult to evaluate. Experience with prototype or small-scale HTGRs Oragon (OECD), Peach Bottom (USA), AVR (Germany) has been good. The Fort St. Vrain Reactor has not yet achieved full power.

For more advanced HTGRs, gas outlet temperatures of 950°C are envisaged. This puts heavy requirements on materials, and there are several large materials evaluation programs to study these aspects. Probably new materials (alloys), tailor-made for this particular application will be desirable or needed. International cooperation in this field is highly desirable.

Prestressed concrete pressure vessels have many inherent advantages over steel vessels. This applies, for instance, to irradation damage. But a disadvantage is that they must operate at low temperatures; the existing AGR vessels are designed for about 60°C. This requires the steel liner to be cooled on the outside and insulated on the inside. So far operation has been good, but further studies of long-term effects of higher temperatures on creep and moisture migration, both for the loss of insulation, are desirable.

BREEDER REACTORS
Michael Weisz, Discussion Leader
J. E. Cunningham, Rapporteur

Future materials R&D needs were briefly assessed in terms of reducing construction and operating costs, increasing plant availablity, and upgrading safety and reliability. Potential accidents involving the reactor core that must be considered include internal plant failures (LOCAs, transients, etc.), external forces (earthquakes, floods, missiles, etc.), and sabotage. The major safety concern is release and transport of fission products.

There are notable differences between the LWR and liquid metal fast breeder reactor (LMFBR) systems that must be considered, such as: sodium coolant has excellent heat transfer characteristics; the normal coolant temperature is at least 800°F (444°C) below its boiling point; and the pressure of the primary system is low. The characteristics of the LMFBR system that raise concern are: the fuel contains highly toxic fission products and plutonium; sodium reacts vigorously with water or air; the core as normally constructed is not in its most reactive configuration--hence, rapid increases in power due to reactivity increases are possible should the core become compacted; and large oxide-fueled reactors have a positive sodium void coefficient.

Materials R&D needs over the lifetime of the system are summarized below:

Reactor Core and Fuel Element Parameters

- void swelling and irradiation creep
- compositional effects and phase stability
- pre- and post-mechanical properties to maintain structural integrity and stability under normal and transient conditions
- sodium compatability
- fabricability
- data assessment and performance behavior modeling.

Out-of-Core Components (Mainly steam generator)

- design/materials interaction
- differences from LWR due to higher temperature operation and operation in the creep regime.

FUSION REACTORS

R. R. Hasiguti, Discussion Leader

B. Frost, Rapporteur

At present there is no structural material that will satisfy the foreseen structural requirements for the first wall of a magnetically confined fusion reactor.

Also, there is no test facility that will adequately simulate the irradiation and temperature loadings of a fusion reactor. Furthermore, existing or planned research facilities that can provide useful information are few in number and have highly limited test volume. Therefore, international cooperation is a serious need.

The basic issue is to find a material that will survive the fusion environment of either magnetic or inertial confinement systems for a reasonable lifetime ($\geq$ 10Mw-yr/m^2).

dpa 100 - 200

He 1500 - 3000 ppm

A high-flux, high-volume test facility is required to develop a data base. Fission reactors can provide the test environment needed for alloys containing nickel. The Fusion Materials Irradiation Test Facility (FMITF) will provide verification of the design data base for these alloys. Near-term reactors built with alloys containing nickel, will probably include some kind of protection against plasma-materials interactions. Either a fusion materials test reactor (FMTR) or the Engineering Test Facility (ETF) will be needed for V-, Nb-, Ti-, or Al-base alloys. Either the FMTR or the ETF must have high flux, high fluence, and experimental accessibility (large volume).

The fusion program will be primarily a physics program until the key physics questions are resolved (c. 1985). At that point, the materials problems will be come the most serious problems in fusion. Until then, investment in fusion technology and the included materials development will remain modest.

Good international cooperation on fusion materials development has been established.

NEW MATERIALS FOR THE NUCLEAR INDUSTRY
S. Bush, Discussion Leader
A. Bement, Rapporteur

The selection and use of new materials for LWRs, the principal form of reactor for the next one or two decades, will be constrained by both technological and political factors. The following factors will control:

- Reliability to minimize lost revenues will dominate thermal efficience.

- The inherent conservatism in codes and regulations with respect to inspectability, environmental degradation, appropriate design procedures, and amenability to forming and joining will provide major resistance to changes in materials.

As for conventional materials, austenitic stainless steels in BWRs have relatively poor records due to many incidents of stress-corrosion cracking. Stress corrosion has also been a problem for austenitic stainless steels primarily at the secondary side of steam generator tubing and in large steam generator tubing and in large steam turbine disks.

Corrosion has also been a problem in substituting new materials. For example Inconel-600 has undergone stress corrosion cracking in BWR safe-ends and has a relatively poor record in PWR steam generators due to secondary side corrosion or primary side corrosion fatigue.

Additional considerations are:

- Section XI of the ASME Boiler and Pressure Vessel Code requires extensive in-service examination which to date has been accomplished by improved ultrasonic inspection in preference to changing materials.

- Improved joint design to reduce crevices, improve accessibility, and reduce stress intensities is a fertile field for reliability improvement.

- Since plant factor improvements have a bigger pay-off than limited changes in thermal efficiency, it is unlikely that reactor operating conditions will change sufficiently to require changes in materials.

- For reactor pressure-vessel steels, it is more profitable to control residual elements such as copper, phosphorus, and sulfur as a means of minimizing long-term degradation than it is to develop new materials.

As to more advanced systems, the following points were made:

- HTGRs do not have sufficient operational history to predict likely problems.
- Long-term creep and creep fatigue may pose problems in LMFBRs, however, behavior to date has been quite good.
- Conventional ferritic steels will see increased use in both PWRs and BWRs with and without overlay claddings, but may not do away with the stress corrosion factor.

The above remarks do not apply to fusion reactors, which are still in the conceptual research stage and which involve special degradation mechanisms that must be better understood.

<u>Converter and Burner Reactors</u>

- The tradition has been the adaptation of commercially available alloys that satisfy requirements of neutron economy, corrosion resistance, and fabricability. Radiation damage resistance has generally been of secondary importance. However, some customized materials have been developed to include the zincaloys, nuclear-grade graphites, and magnox alloys.
- Time-dependent property changes have been of concern primarily for primary pressure vessels, fuel cladding, and structural graphite.
- Long-term structural integrity has been a relatively recent concern in developing new technology.
- Plant factor and life-cycle costs are the primary incentives for improved materials development.

<u>Fast Breeders and Fusion Reactors</u>

- Time-dependent property changes are more critical.
- Property changes during service are more sensitive to alloy chemistry and microstructure.
- Greater fractional investments in the technology base are being made in alloy development, simulation testing, radiation damage characterization, and time-dependent mechanical performance matching.
- Beginning-of-life properties may no longer be a valid basis for design and safety confidence.

- There is no longer any safe ground for design conservatism.

Among the emerging materials technologies are the following: directed energy processing for modifying surface properties, rapid solidification processing, improved melt purification and casting methods for eliminating residual elements and segregated phases, and the control of lattice periodicity to achieve long-range order.

New design methods are expected to improve confidence and response time in making materials substitutions if needed. These include greater computational capacity through the availability of high-speed large-scale integrated circuits and inexpensive information storage; greater emphasis on life prediction modeling and time-dependent performance modeling; and developments in computer simulation, computer-aided design, and interactive and adaptive learning aids.

More emphasis will be given to "designed-in" as opposed to "tested-in" reliability, which by necessity forces a greater fusion between the design and materials communities.

General

Long-range ordered alloy $(Fe, Co, Ni)_3V$ allows:

- Superior high-temperature strength and creep resistance relative to nickel-base superalloys to 900°C.
- Improved swelling resistance from limited data relative to the more swelling-resistant austenitic stainless steels.
- Moderate ductility, weldability, and fabricability with high iron content.
- Good compatibility to lithium.

The expected application of this alloy would be high-temperature graphite reactors, LMFBRs, and fusion reactors. However, the lack of an intrinsic protective oxide former is a limiting factor for gas-cooled applications. Furthermore, irradiation at temperatures below 300°C can cause disordering and a loss of favorable properties. However, the compatibility of weldments of long-range ordered alloys must be carefully checked.

It can be argued that gelsphere-pac fuels are easier to fabricate, and perform better than conventional pellet fuel.

There are an adequate number of materials available for most of the nuclear applications, but weldments of these materials constitute a new material with highly variable properties. Therefore, the development of methods and selection of more formable materials to permit the fabrication of weldment-free complex shapes must be stressed. Duplex tubes, which have had success in fossil-fired steam plants, may have a successful future in nuclear plants. Weldments of austenitic stainless steel that undergo epitaxial grain growth are quite amenable to nondestructive ultrasonic testing.

Nuclear steel making materials have developed and improved: isotopic, high-strength graphite (Ceraphite) by sintering powdered carbon; sintered glass insulations; carbon-carbon composites; and high-strength superalloys with and without cobalt. For the latter application they have developed near-full density, self-sintered covalent compound ceramics (β-SiC, B_4C, β-Sialon) with significantly extended performance temperature ranges as compared with sintered compacts containing a glassy phase as a sintering aid.

DISCUSSION

In regard to international cooperation, it is important to make use of some international organizations and also to have some treaties on a governmental level between two or more countries. But, the most important point is that personal attitudes of the scientists on the committees. The scientists and everyone should make an effort to promote international cooperation especially in the case of nuclear energy development.

The recommendation for international cooperation should be forwarded to the U. N. International Atomic Energy Committee in Vienna which is able to develop international cooperation in specialized issues.

Latin America is trying to optimize the relationship between such agencies as the Organization of American States, and the U. N. Development Program. There is also a nondestructive testing institute in the Atomic Energy Commission of Argentina for the purpose of cooperating with the Organization of American States, on welding and nondestructive testing, two technologies that are important for safety and reliability of nuclear plants.

WORKSHOP 10

INSTITUTIONAL AND ORGANIZATIONAL PATTERNS AND STRATEGIES FOR INTERRELATION OF MATERIALS AND ENERGY RESEARCH AND DEVELOPMENT, TECHNOLOGY, PRODUCTION, COORDINATION, AND PLANNING

Rune Lagneborg, Chairman
Franklin P. Huddle, Organizer
Harold Bullis, Rapporteur
Michael Mathison, Rapporteur

INTRODUCTION

There appeared to be little question as to the need for some form of international body or institution for materials. Materials are intimately related to energy and environment. The global maldistribution of both supplies and consumption of materials implies a condition of global interdependence that increases as more and more nations move from the extractive to the manufacturing phase of economic development. As productivity increases, and processing of materials replaces extractive activity, the need for capital increases and with it the demand for more and better information to support international cooperation. However, no suitable institution exists to serve this array of needs, although the scope of a number of institutions with materials functions could be expanded to meet these needs.

Spokesmen from developing countries observed that those countries desire to extend materials processing beyond the stage of ore or concentrate to ingot to shapes, or even to finished products for export, but the adverse consequences for environmental quality and energy consumption generate local resistance. They want help in formulating policies and approaches to mediate this evolution to a more productive economy. There is a need to integrate policies for the environment, for energy, and for uses of materials. Even in the highly developed United States, materials policy is still being formulated; in the less developed countries it is far behind this point. Accordingly, an inventory of policy options or guidelines related to the several stages of industrial development is needed.

An international organization for materials might usefully inventory international activities, data availability, and publications. No one country's scientists can keep track of the great proliferation of research findings, especially with the language barriers. An explicit statement of goals of such an international organization must be formulated.

INSTITUTIONAL OBJECTIVES

Seven objectives were proposed (Table 1).

The Workshop participants promptly challenged these proposed objectives as being loaded with value judgments, not being objectives but only approaches or limitations, and so forth. The suggested revised objectives are listed in Table 2.

The need to address materials education was stressed, as was information about materials.

INSTITUTIONAL MODELS

As to possible forms of organization that might be appropriate, it was suggested that an international materials institution be non-governmental; highly professional; in close and effective communication with policy formers to provide them with facts, analysis, and options; perhaps based on the Pugwash model. In addition, the proposed organization should be a marshalling yard: to carry things a step further. We need to reinforce what is going on, but first find out what it is.

However, it might be too ambitious to attempt to encompass all materials matters on a global basis since there are already many organizations covering some parts.

The geographic scope was considered: should there be a single global institution, or a series of regional institutes feeding information and analysis upward to a global institution and perhaps also downward to national and even sectoral groups or organizations? In this context it was pointed out that one way of overcoming language barriers would be by employing a regional approach first.

A number of attractive models warrant further examination, including a proposed study of Association of Southeast Asian Nations (ASEAN) resources utilization, and the International Institute of Applied Systems Analysis (IIASA) concept of international systems studies.

POSSIBLE FUNCTIONS OF A COOPERATIVE ORGANIZATION

Seven concepts (Table 3) were examined.

DIMENSIONS OF THE ORGANIZATIONAL FORMAT

The consensus was that the organization should start in a rather modest fashion to be reasonably sure of a successful beginning. Furthermore, items should be picked that can feasibly be accomplished. Rather than working on completely fresh problems, it is preferable for an organization like this to pick up problems where it can start from a relatively high level of knowledge.

TABLE 1. PROPOSED OBJECTIVES OF AN INTERNATIONAL MATERIALS INSTITUTION

Create a mechanism with which to focus on selected common problems and opportunities.

Promote and catalyze international cooperation efficiently, economically, rapidly, and completely.

Provide a focal point for materials discussion, information exchanges, data collection, etc.

Provide, where appropriate, relevant materials information to political, economic, and technical decision makers.

Increase national and international public awareness and appreciation of materials science and engineering in all aspects of life.

Provide materials-oriented inputs to existing organizations to insure adequate consideration of materials science and engineering.

Use existing agencies whenever possible to undertake projects selected to promote a materials point of view.

TABLE 2. REVISED OBJECTIVES OF AN INTERNATIONAL MATERIALS INSTITUTION

Study the interface and interrelationships between materials technology and development.

Coordinate the activities of the research community, industry groups, and government agencies around common and unifying technical themes to mobilize the broader research community toward the solution of materials problems.

Address problems of interactions between materials technology, energy, and environment.

Increase understanding of materials issues on a global basis and, if possible, identify common problems and opportunities.

Promote discussions and studies on the interface of materials with other important systems parameters such as energy and the economy.

Promote education of qualified materials specialists for the energy, transportation, agricultural, and communications industries; and of technological manpower for the materials-related industries; and also general education for professional engineers and technologists; general education at the high school level, and continuing education.

TABLE 3. POSSIBLE FUNCTIONS

Provide a focus for international concerns in materials.

Motivate effective management of needed information about the materials cycle, and materials science and engineering.

Encourage analysis of materials information in order to

insure proper dissemination;

identify gaps to be filled;

establish priorities of international attention;

plan conferences; and

identify and suggest projects.

Assist decision makers and policy makers to make decisions to facilitate useful global interdependence.

Encourage cooperation and coordination in the field of materials.

Build up a coherent network of professional people with mutual trust and respect within the technical community of materials.

Encourage the development of national capabilities in terms of knowledge related to materials.

The organization should be nongovernmental rather than governmental. Emphasis should be on the analysis of technical information rather than the actual collection of information. The organization should motivate existing institutions to collect missing information, rather than itself undertaking the collection. Also, the situation should be:

technically and professionally oriented rather than economically and politically;

informal rather than formal; and

operational in the long term rather than the short term.

To begin with, the goals should be modest rather than grand and selective rather than comprehensive. With time, however, that may change. The emphasis should be on technical contributions and contacts and the bearing of technical questions on political issues. The results achieved should provide a basis for policy makers, but contacts with these policy makers should be a secondary and not a primary objective.

CONCLUSIONS AND RECOMMENDATIONS

The consensus on further courses of action to follow from this conference was first, that the International Advisory Committee appoint a comparatively small, continuing, working group. The group should be generally representative or characteristic of developed, developing, and intermediate countries, North-South and East-West. This working group, appropriately supported and funded, should be charged with three responsibilities, as follows:

Formulation of an evolutionary and progressive plan for a non-governmental materials organization of international scope and membership.

The planning and organization of another international congress or conference for 1980, 1981, or later as appropriate.

The assignment and planning of papers to appropriate representatives of the three levels of countries, to consider the scope, objectives, functions, structures, modes of operation, funding, and support of the proposed organization so that more specific action may be taken at that conference with regard to the establishment of an appropriate organization.

CONCLUDING STATEMENT

There were two concluding points: first, the workshop did not entertain the idea of encouraging the creation of some mammoth computerized center to collect, store, and dispense all knowledge about materials all over the world. It was concerned with the coordination of existing organizations in materials. Some organizations have developed effective programs to stimulate international collaborative research and advanced teaching. The proposed working group should make contact with, and consult with, these agencies. It should move promptly to take advantage of the knowledge and experience of these agencies in its coordination of the materials field.

Second, it should be made very clear that when we talk about an institute, and institution, or an organization, we do not think in terms of bricks and mortar, but of people. This is a proposal calling for people in organized, systematic, useful, and amicable contact with people. It is people that comprise our organization, not inanimate structures.

DISCUSSION

The discussion opened with an objection that the Workshop had addressed itself to institutional questions without taking note of existing unbalances in the allocation of resources to technological programs within individual programs.

Attention was also called to a U.S. plan for an International Institute for Scientific and Technological Cooperation and to a similar Canadian program started earlier.

The question of funding was raised. That had been recognized as a necessary subject for attention but the Workshop had held the view that what was envisioned was a modest program not requiring major outlays. The World Energy Conference was then cited as a possible model--a parent body or institution without a large secretariat or organizational apparatus.

One participant in the Workshop recalled that the consensus had been that a major function of the proposed international institution would be interdisciplinary meetings of representatives of member countries, looking at the "total systems situation" but with materials as the focus, to keep the international discussions from being "lost in too broad a sea of vagueness."

After further discussion of the vexing problem of internal misallocation of funds in the R&D budgeting process, discussion again turned to possible actions in response to the Workshop recommendations. Plenary approval of the Workshop's list of functions of the institution was suggested, and then the adoption of some kind of preliminary machinery to "get the thing going."

Morris Cohen (MIT) announced that the National Materials Advisory Board was prepared to respond to a request to serve temporarily as secretariat "to get this organization underway" (including correspondence and exchange of documents). William Prindle (Executive Director of NMAB) added that, of course, some sort of funding arrangement would be necessary for NMAB to serve in this capacity, particularly if the activity went on for some time.

The Workshop 10 recommendations appeared cogent: that international cooperation in materials is necessary, that some form of institution is needed to effect it, but that in an era of "organizational super-saturation," it is desirable to avoid hasty additions to this overload. The Workshop 10 report recommends a step-by-step planning approach, with, first, another conference in two or three years while a small standing group or committee continues to attempt to solve the practical problems and report to a plenary session of the next international materials congress. With this comment, which appeared also to reflect the sense of the plenary session, the discussion ended.

It was urged upon the conferees that there be discussion of basic fundamental points about the objectives and goals of a possible international materials institution. How might it consider the relationship between the developed and the developing world? Before the considerably wide representative audience at the Congress, there was an opportunity to consider how best to deal with controversy and conflict in the global management of materials, however the absence of representation from many centralized-economy countries was noted.

Classification of nations might also take account of the fact that there are two classes of nations with undeveloped technology--those with energy resources and those without. Another classification system might cut across national boundaries, addressing the three materials groups of "producers, consumers, and conservers." The producers tend to be mainly in the developing countries and the other two classes in the developed countries.

The question was raised as to the practicality of an international institution for materials: what issues could it effectively address? One example was the impact of the rising price of energy versus the low price of raw materials in the oil-deficient developing countries. Another topic might be the examination of the entire materials cycle in its interactions with energy, environment, and quality of life.

The interaction of materials with technological decisions and economic decisions called for participation in the deliberations by politicians and economists as well as materials scientists.

GENERAL DISCUSSION

At this session the attendees were invited to comment in general on the Congress and its results, and on what issues it would be worth convening a group such as this again.

The following thoughts were expressed:

- The field of materials is one of the main interactions between the developed and the developing world. Within this field there are many controversial aspects and many conflicts. Therefore this audience, consisting of many people from all around the world is a good group in which to discuss the fundamental objectives and goals of a possible materials institution and how it could consider the relationship between developed and developing countries in the field of materials, rather than trying to resolve details of implementation which can be analyzed at another level.

- In an international materials organization it would be well not to consider the usual groupings of "developing" and "developed" countries, but rather three groups--the ones that have both materials technology and energy, the ones that do not have either, and the ones that have energy but not technology.

- As another grouping, there are producers, consumers, and conservers. The producers are people who dig up the resources and want to sell them; they want to create markets and get the highest prices; they are a horror to the conservers. There are the consumers who want materials at the lowest possible prices and at the right delivery times. The third group is the conservers who are really worried about the limitations of this planet. The materials producing countries, in general, are the so-called "third world" or "developing" countries. The consuming countries and the conservers, in general, are the western world. Within this framework there is much room for intense discussion on the generation and use of the world's materials resources--a real problem in the world today.

- The very critical situation in which the oil-deficient developing countries find themselves must be addressed. A compromise must be found between the price of energy and the price of raw materials in the world market. Such a compromise may be the best solution to the problem of rising oil prices.

- Regarding the creation of a new international organization, caution should be the watchword because bureaucracy is the great "growth industry" of our age. Of the objectives laid out in the workshop on institutions, some focus inward on common problems and others look outward toward influencing society, e.g., providing data for decision makers. This illustrates a dilemma. That is, that decisions in most of the fields discussed at this meeting are not made primarily on a materials science basis at all. Whether or not we build high-temperature engines which are more efficient is determined by cost effectiveness and the market for the product; whether or not we appear to run out of oil quickly or slowly depends on a political decision in Saudi Arabia; whether nuclear power is a helpful contributor or not depends on social acceptance. Therefore, a forum to consider such problems must include not only materials and energy scientists and engineers, but also economists, politicians, and others involved in the decision making and implementation process.

- The question of topics for future international materials congresses is important. Is there a focal point two or three years ahead which would merit people's finding money to travel from all over the world to meet to spend time deliberating it? Suggestions from developing countries are desired. One suggested theme of mutual interest is technical aspects of trends, or apparent trends, in the world distribution of the manufacture and utilization of materials.

- Another suggested theme is the processing of minerals from mining to finished products with energy as one consideration and mining, including the beneficiation of low grade ores, as the other. This is a topic of interest to countries at all levels of development and which has interfaces with energy, environment, and the quality of life.

- The unique feature of this Congress was the combination of interest in materials and energy. It is an important and interesting theme which could well be continued. It may be that there could be more emphasis on energy through studies of materials at the next one--as compared to energy impact on materials. The process of changing resources into reserves and production is a sociotechnical process with economic and organizational aspects as well as technical, therefore all of them must be included.

- Within two years, the United Nations is going to hold a conference on energy. It would be well for any continuing group arising from this Congress to keep in touch with the planners of that meeting to assure that the scope includes the materials aspects of energy technology.

- With regard to world representation in future congresses, it is important that a better mechanism be developed to invite and attract fuller participation by the Eastern European countries and by mid-East and Black African countries.

- Except for the above noted needed improvement, it was generally agreed that the assembly of people at this Congress in terms of diversified experience, interests, expertise, and nationalities is unique and valuable and should be continued.

LESSONS FROM THE CONGRESS: CONCEPTUAL AND TECHNICAL

Morris Cohen

It is evident from this International Materials Congress that the materials of mankind constitute a world system that ties nations and economies not only to one another, but also to the very substance of nature. Of course, there are other essential elements in this partnership, such as living space, food, energy, and knowledge. All of these five areas of endeavor and inquiry are vast, complex, and interdependent.

To make life worthwhile over the decades and centuries to come, it will be necessary for society to strengthen its partnership with nature; in simple terms, this means to understand nature ever more thoroughly and to use it ever more prudently. In that grand process, materials science and engineering have a central role to play because they are society's intellectual approach to the field of materials.

Nevertheless, materials still remain largely hidden from public view, or general appreciation, like the foundation of a skyscraper or the semi-conductor in a computer. National goals and societal needs are usually not stated in terms of materials, even though they constitute the very stuff that man uses for making machines, structures, devices, and all manner of products. Inasmuch as society now perceives energy as an especially critical problem, this Congress has sought to examine the interplay of materials and energy in response to pressing human needs. Yet, it was only during the past few years that energy per se became so "visible" to society. Although mankind has long wanted food, shelter, goods, transportation, conveniences, etc., the energy requirements were generally ignored or taken for granted--until the sudden price rises in Middle-East oil highlighted the basic role of energy in human affairs. We can expect that materials will also achieve a more exposed place in the scheme of things when materials shortages (not necessarily due to their scarcity in the world) begin to propagate shock waves around the materials cycle.

Materials technologists have become skillful in responding to societal demand, whether for automobiles, aerospace, military hardware, communications, and now to the impact of energy. In fact, as we have seen this week, materials and energy are so intimately related that almost any technical materials research can be described (and often justified!) in the language of energy units or petrodollars. Our workshops have disclosed an extremely broad spectrum of opportunities for making, fabricating, and using materials with reduced energy consumption; generating energy with less expensive or waste materials; and improving the efficiency, reliability, safety, and cost-effectiveness of virtually all high-technology energy-conversion schemes. The discussions have ranged from the making of biogas from cow dung to the prodigious materials requirements for the first wall of nuclear fusion reactors. We can anticipate that, in response to this overall societal pull, the field of materials will make major contributions toward alleviating the energy impact. And it appears that such progress will comprise the integrated effect of many incremental advances on many fronts. At the same time, we are beginning to see that energy is but one of the cost factors that enters into decisions around the materials cycle.

We are facing an era of intense and varied activity in the field of materials research, development, and innovation. In that dynamic, even turbulent, situation, we are likely to find that our greatest shortage in the materials system will lie, not in the materials themselves, but in the human intellect that can generate, disseminate, and use <u>knowledge</u> about materials. Surely, then, education in many forms will be one of the continuing themes of future international materials congresses.

There is a kind of theorem that can be applied to fields of knowledge and human endeavor, somewhat as Godel rigorously proved for branches of mathematics; that is, the foundations and validity of any system can not be truly tested within itself--instead, the proof must be sought in a still larger framework. The comprehensive field of materials, as dealt with at this first International Materials Congress, is so deeply embedded in human affairs that society at large must become the test-bed.

LESSONS FROM THE CONGRESS: EMPHASIS ON SOCIETAL ISSUES

Hans L. Landsberg

Every profession has its detractors. Economists have nothing but, and the latest definition I heard of an economist is a fellow who, if you have forgotten your telephone number, is willing to estimate it.

It is in that spirit that I shall try the impossible task of summarizing and drawing lessons in 15 minutes from what has been said in three and a half days. I shall try to draw a few generalizations and relate some of the points made during the three days to these generalizations. Let me start with one that is probably quite noncontroversial: I think it is an excellent idea to mix engineers, scientists, and economists. I have heard that comment from several people--it was even mentioned today--and I think the mix has contributed substantially to the intriguing features of this kind of conference. I hope that in the future, whatever organization emerges, there will be room for social scientists not only to run alongside the train and be lifted into it once in a while and then be kept running beside it, but really to become passengers. It is an excellent idea, and I think it has paid off here.

My second generalization goes to the place and role of the "technical fix." Quite naturally, by the composition of this group, most of the things that have been said in the last three days were to a greater or lesser degree technical. But, on the whole, there has been a real recognition of the fact that the technical fix is really only one of a large number of inputs, and that it lives in a kind of matrix. The technical fix is what is doable, but we also have to know not only what is doable but what can be done. And what can be done lives in the world in which incentives and institutions play prominent roles. Of course, I am more familiar with those features than I am with composites, fractures, stresses, and the like of which we have heard in these least few days.

The awareness of the role of the technical fix came out in several points during these days. One participant talked about the difference between physical and market availability--a crucial distinction. In other workshops it was said that physical resources are not the "show-stopper." That is quite true, but they do have to be translated in time and at tolerable cost, whatever that means, into supplies and be at the right place. Nonetheless, it is important to repeat that physical availability is not the major issue, else we focus on the wrong problem. It struck me that the point was extremely well made. Another one was the role of composites in automobiles. They exist, but in terms of cost their introduction and spread may take more time than some people would like to see in terms of their usefulness.

A related point was that higher prices will exert great pressure toward greater efficiency. As I went through these various panels, maybe my ears were more receptive to that tune because it is a view that I hold strongly. That is, to preach, exhort, and threaten to achieve high efficiency, without letting prices do much of the work, is a very, very difficult, probably impossible, and surely frustrating venture.

The tendency for governments is to consider prices as a problem and not as a solution. That creates its own set of problems, not only in the short term but also--and especially--in the long run: if you feed both consumers and producers wrong price signals, you will have to suffer the consequences. This conference seems to have been singularly free of this error. There is a further point that I should like to make, one that has been alluded to by several discussants; that is the question of institutions. A good example is the report from the workshop on more energy-efficient buildings (No. 2). There, it is quite obvious that the peculiar nature of the building industry requires specific incentives, and if they are not there, there is not very much you can do about energy efficiency. There is the materials producer who sells to the builder; there is the developer, the realtor, so to speak, who deals with the builder; there is finally the renter or the buyer. Each actor has a different incentive to be materials efficient, materials conserving, energy efficient, energy conserving. There is no one way in which any single incentive or any single change in incentives can work unless one is quite aware of what the institutional barriers and structures are.

Another field that also came through in terms of the importance of institutions was R&D. Here again, institutions and the incentives are supremely important. For example, what is the role of government versus that of industry? Many industries in this country at least, have been accustomed to doing R&D in a set-up and for products in which government is mostly the specifier, the buyer, and the consumer-i.e., space, defense, and the like. Whereas, in the field of energy and materials, more generally, neither the space nor the defense kind of structure prevails, but rather, the product, whether it is a process or a piece of hardware, has to prove itself in the market. It must be competitive. Once you are in that position, the roles of government and industry as institutions become quite different. In the last five years of energy R&D we have seemed to struggle very poorly in finding ways of achieving cooperation or coordination between government and industry. Not that we might not eventually stumble into something that will work, but for now we are simply carrying the eggshells of the R&D experience, as it has worked out for so long, in matters like space technology and defense technology.

In summary, the question in the framework of incentives and institutions is: What is salable? What will make its way in the marketplace? And not what is doable. What is speculatively and imaginatively possible is the stuff that the media loves. They will feature it, and yet in the end it will just make a day's headline or will raise false expectation and will create, as we have seen in this country, cynicism as to promises of accomplishments.

To close, let me return to the beginning of this congress: the difficulties of making progress by way of good policy in the energy field. Let me try my hand at a very quick tour de force and give you my definition of the energy problem. While I shall use the United States as my example, the approach is largely true for other countries as well.

I see these tasks as the crucial ones in facing the energy problem: adjust to high and rising cost of energy; move to a different mix of sources of energy; move to reduce the rate of growth in energy use; cope with insecurity of supply; and, the most difficult of all, do all of the above in ways compatible with other societal objectives. That, I think, encompasses most of what we have come to know as the energy problem, and I call your attention to the fact that I do not use the term energy crisis. It is not a crisis: it is a problem punctuated by crises but it is a problem like health, education, defense, or what have you, a problem with which we are going to live for a very long time. If you think of it as a crisis, you are likely to create wrong remedies.

This is one side, one dimension of the matrix. The second one consists of the goals that would intersect the first. Let me name a few of those goals, and I must warn you that this list is heavily U.S.-oriented.

First there is economic efficiency; then, environmental preservation; equitable impact among income groups, between producers and consumers, and so forth; international harmony; the welfare of future generations; and maintenance of national security. These are only six--you could easily extend that list. Now these are two sets of objectives, of elements that have to be made compatible. But there is yet a third one that intersects: and that third one is institutions, a long list of institutions in a rather broad sense--federal government, in this country subdivided into the Congress, the Executive branch, and the courts, state government, local governments, labor urban minorities, racial and ethnic minorities, the aged, the handicapped--I can go on and on. Moreover, the number of special groups and institutions keeps growing. At the heart of the energy problem, then, lies the task of making energy objectives, other societal objectives, and the use of existing or newly invented institutions all compatible with each other.

With the energy problem thus defined, our friends abroad who have often wondered why it took the U.S. Congress 18 months to finally put together an energy program (and at that only half of what the

Administration had asked), occupying most of the time of an entire Congress, may have a satisfactory answer. Any one of you who has been immersed in the energy problem probably understands how you enter a house on which it says "energy," but once you are in it you discover that it is not energy at all; it is a sort of large experiment in group therapy for the whole country! Had the current Administration's first act not been energy but health or welfare, we would probably have got into the same kind of problem; but it happened to be energy, and we acted out all our frustrations, all our aspirations, and all our competing objectives in that particular field.

Materials is not yet in that position and I hope it will not be. I differ somewhat with Morris Cohen on the seriousness of the outlook for materials but, in any event, we ought to learn enough from how we have mishandled the energy problem. I say "mishandled" while fully aware of the difficulties facing establishment of a national energy policy. Perhaps our greatest mishandling is trying to have a comprehensive national energy policy in the first place, all put in place in one move. It may be too big a thing to handle. It overloads the circuits and we short-circuit. That seems to me a useful lesson of the 1976-1978 U.S. legislative experience.

Nonetheless, looking at the problem from the three vantage points I have described illustrates what a new organization like the one that we hope will emerge from this congress might well consider as a framework within which it poses what could otherwise by purely technical issues. Purely technical matters live in a world which is not quite the real world; they need to be related to that real, multidimensional world. This group has been extremely successful in moving in that direction. Its main message is that we have to be realistic. We have to think of how technology and the technical fix lives in society; otherwise, we shall encounter a situation that is reflected in the story of the woman who came to the butcher and wanted lamb chops. He said, "They're $4 a pound." She said, "That's terrible. There's a fellow down the street who sells them for $2." And the man said, "If I didn't have any, I'd also sell them for $2 a pound." Let us not get into that position, where we advertise what we cannot sell.

FUTURE INTERNATIONAL ACTIVITIES IN THE MATERIALS FIELD

N. Bruce Hannay

There is no need to persuade this Congress of the international nature of materials. The uneven distribution of resources around the world and the central position of materials in the economic development of all countries establish this beyond any doubt.

At this Congress there has been an admirable mixture of participants and interests. It seems probable that the lack of a clear discipline-based coherence among people interested in materials is responsible for the paucity of international materials meetings of this kind, prior to this week. No technical society, and no single organization, would have felt prepared to assemble such a group. We have needed a focal point and a forum for discussion of materials-related subjects, in the broadest terms. Indeed, that was what led us to the idea for this Congress some time ago.

We would have liked to have planned it internationally, but in the absence of an international organization that could undertake that planning, we decided to expedite things by taking the lead here in the United States and asking only for cooperation on an international scale. We are pleased at the success of this.

The question that obviously needs to be raised is what comes next? If you judge this conference to have been a success, we then ask whether it should continue? Should there be a second conference? What mechanism can be instituted for the continuation? Those matters will be discussed tomorrow by the International Advisory Committee.

Certainly we could imagine extensive forms of cooperation, and Workshop 10, in its report, mentioned a number of such possibilities. I think it is probably premature to contemplate most of these in the near future. Prominent among the things that were mentioned in that Workshop, was the subject of communication, and it would seem sufficient and quite enough of a challenge to agree to a mechanism for achieving continuity in communication before we leave here tomorrow. Other things might follow eventually if the means of communication are firmly established. The most straightforward way to promote such communication would be through a follow-up conference, and from comments from a number of you, I believe there is much sentiment in favor of this.

Even that brings many questions. What should be the conference theme? We have not been able to address that directly, but certainly there were a number of suggestions implied in remarks of various delegates to this Congress.

What about the format? This one emphasized workshops, but there are obviously others to be considered.

What kind of committee will plan such a Congress and who is going to be on it? Who will convene the Congress and where and when will it be held? Who will fund it? Certainly there are many questions, and we are not going to resolve all of these questions easily. They will be discussed further tomorrow, and I hope that from that discussion there will be agreement on how to move toward this very important goal. Once we leave here and are dispersed, it is going to be very much harder to institute any kind of planning mechanism for a second Congress.

The organization of an international conference always involves much effort by many people, even when the conference is only one of an established series. But a great deal more effort is involved when it is the first in a series.

There are many people who participated in the organization and the planning of this Congress, and they should be thanked. I am only going to mention two of them by name: Dr. Wachtman, who is the Chairman of the Congress, and Dr. Claassen, who chaired the Program Committee. Between them, they carried much of the burden. The staff of the National Materials Advisory Board played a major part in both the planning and the management of the Congress.

I particularly want to say that the response to our invitation from other countries was most gratifying to all of us. We felt at the beginning that this Congress should have a very broad international participation if it were to be successful and achieve its purpose. We had many useful proposals from other countries for the program and speakers. And we have had an excellent international participation. This reflected the international concern for resource problems and demonstrated that we have a great deal to say to each other.

With this start we feel confident that we can attempt the next step, and use this conference as a starting point on which to build a mechanism and a plan for continuing international communication in materials-related areas. We should be prepared to deal with a wide range of subjects and to involve the broadest possible international participation.

The conference itself has been very well summarized in the workshop summaries and by Professor Cohen and Dr. Landsberg, and you need no more words from me on that subject. Thank you all for coming and for your part in making this conference a success.

CLOSING REMARKS

Gunnar Hambraeus

The time has now come for me to adjourn this conference. As an engineer, I have enjoyed this conference thoroughly. We have talked about all things technical and scientific. Of course, I was in the beginning a bit disturbed by economists mingling with us, and even more troubled by the talk that politicians might meddle in this beautiful world of high technology of energy and materials.

Sitting here as chairman in this final session and listening to the reports, I realize that through history it has been the search and quest for materials that has moved the world. When the argonauts set out for the golden fleece, it was materials they were seeking. Marco Polo went to China for silk, and the conquistadors, of course, were out for gold.

It is not only the precious materials that have been quested after. Even more, the common materials like copper, tin, iron, mast timbers, and dyes have been the causes and the objectives of wars, conquests, conflicts, negotiations and treaties.

Thus materials have been at the center of world politics throughout the known history of this world. Is it not a nice thought that they who command the materials are in a strong position indeed. If we gang together we might rule the world or, more humbly, at least serve the world.

On this optimistic note, I conclude the conference and thank again all who have contributed to it, both in discussions, and as chairmen, observers, reporters, and organizers.

We are looking forward to meeting again in a year or two for another of these congresses.

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MEETING OF THE INTERNATIONAL ADVISORY COMMITTEE

March 30, 1979

The International Advisory Committee, consisting of leading scientists and engineers actively concerned with materials and related science and technology in 30 countries, was formed to fulfill three major functions with regard to the International Materials Congress: Materials Aspects of World Energy Needs. Those functions were:

- Comment and advise on the proposed program.
- Provide names of individuals in their own and neighboring countries to be invited as key participants.
- Provide a post-Congress forum to evaluate the meeting and to develop further action that might be taken, including consideration of continuing mechanisms for general international exchange of materials science and technology.

The first two functions were ably accomplished prior to the Congress. They were the key factors in obtaining the broad international participation in the International Materials Congress.

The third function was accomplished at the post-Congress meeting of the International Advisory Committee.

At this meeting, several general impressions and ideas were expressed and specific actions were taken to assure that the momentum for international communication generated by this Congress would be retained and expanded.

GENERAL IMPRESSIONS

There was unanimous agreement that this Congress was highly successful in bringing together a diverse international group of knowledgeable people, that many useful contacts and exchanges were made, and that communication should be maintained.

With regard to the mechanism for continuing the communication established, there was a clear indication that a large, permanent organization was not needed and should be avoided. However, there was a solid consensus that a Second International Materials Congress should be held and that it should take place in about two or three years.

In general, the opinion of the Committee was that the scope of the next meeting should be narrower than this one, but that it not be so narrow as to be highly specialized.

Although there was strongly expressed opinion that the next Congress should continue consideration of the materials-energy interface, the majority favored the selection of some other materials topic of broad international concern. Several topics were suggested. Among them were:

Materials and Renewable Resources

Materials and Nonrenewable Resources

Education in Materials Science and Technology

Role of Materials Technology in Prevention of Depletion of Materials

All agreed that even broader international representation should be promoted, especially from the Arab world, black Africa, China, and Central Europe, and that attendees should again be technology based, but policy oriented. The members felt that participants should be in touch with policy makers in their countries and that the results of this and future Congresses should be used by policy makers at high levels.

Increased involvement of scientific and engineering academies and professional societies should be sought, both for cosponsorship and for implementation of findings.

SPECIFIC ACTIONS

In order to implement its consensus, the Committee took the following actions by formal vote.

- The present International Advisory Committee was renamed the International Materials Congress Committee (IMCC) and established as a continuing informal body.
- The purpose of the IMCC was defined: The primary purpose of the International Materials Congress Committee is to organize the second International Materials Congress and to conduct any additional related functions, such as determining how to improve the geographical representation at the next Congress.

- A small, representative Steering Committee was established to act in the name of the IMCC between meetings, develop rules of procedure for the next Congress, and present them to the full IMCC. It was also empowered to try to find a few more representatives for the IMCC to cover a broader geographic coverage and report back to the IMCC.

- The following Steering Committee was designated:

  Representative for Europe - G. Hambraeus, Sweden (Chairman)

  Representative for North America - N. Hannay, United States (Vice Chairman)

  Representative for Far East - R. Hasiguti, Japan

  Representative for Latin America - C. Martinez-Vidal, Organization of American States

  Representative for South Asia - M. N. Dastur, India

  Representative for South East Asia - D. C. Salita, Phillippines

  Representative for the Arab Countries - I. H. Abdel-Rahman, Egypt

  Representative for Black Africa - A. Afonja, Nigeria

- The National Materials Advisory Board (NMAB) of the U.S. National Academy of Sciences was asked to serve as interim secretariat to the IMCC and the Steering Committee and agreed to do so.

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APPENDIX A

PREPRINTS

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PLENARY SESSION

CHAIRMEN

JOHN B. WACHTMAN (U.S.)
RICHARD S. CLAASSEN (U.S.)

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Perspective From A Developing Nation: Overview Of The Materials-Energy Issue

LUIZ C. CORREA da SILVA
Coordinator For Special Projects
Fundacao Centro de Estudos do Comercio Exterior
Brazil

I. INTRODUCTORY REMARKS

The issue dealt with in this Conference is a "fall out" of the profound changes (political, economic, social) which took place in the decade just ending. Unavoidably, we must from now on look at the science and technology of materials in a broader perspective, so as to identify problems and pursue solutions of greater relevance to our communities, societies and nations. We must widen the examination of factors and options, of problems and opportunities, with even greater imagination.

The initiative of the National Academy of Sciences and the National Academy of Engineering is appropriate and timely: both in substance (the theme chosen) and in spirit (international cooperation). We must all be grateful to our American hosts.

2. THE SETTING

A number of changes took place in the decade just ending which will have a decisive impact on materials availability, technology and cost:

- Developing countries (Dg.C.), as a community of nations, became fully aware of their true problems and opportunities. (V.g., the "Lima target").
- Dg.C. have acquired essentially the capability for autonomous decision, at the economic and political levels.
- The OPEC decision of 1973 was an instance of the newly found independence in the economic and political areas. Dispassionate and fair analysis shows that the decision had an overall positive effect.
- In the decade it became clear that developed countries (Dd.C.) and Dg.C. will have to face jointly serious problems relating to: exhaustion of natural resources; ecological disruption; urban deterioration; energy dependence; complexities inherent to the functioning of pluralistic societies.
- The international monetary, financial and trade structure has reached a point of crisis which will only be effectively

resolved after full recognition that two new strong "currencies" are now dominant: energy and technology.

3. ISSUES: PROBLEMS AND OPPORTUNITIES

The first issue (and problem) at hand is the imperative need to decrease energy "cost, content and claim" of capital goods, consumer products and services.

The second issue is the need (and opportunity) to move towards increasing use of "renewables". We must look imaginatively and in depth at the extraordinary potential of photons and genes. Photosynthesis and gene-synthesis constitute the great challenges to the coming generation. Dd.C. have, in the last 100 years constructed a civilization based on non-renewables. It is a thought, a hope, that in the next 30 years Dg.C. might lead the way towards a civilization based on "renewables".

The third issue is the need to develop novel materials and "encoded microstructures" (of type LSI, v.g.) for an entirely new pattern of supply/demand and availability/cost of energy/materials.

4. THE METHODOLOGY

To cope with the issues, in terms of materials science and technology, ways and means must be found or developed commensurate with the problems and opportunities involved. The following priorities are suggested:

- Development of a comprehensive methodology to handle quantitatively the technological input/content/output involved in social and economic development.
- Development of a suitable methodology to handle problems related to energy exploration, generation, conversion, distribution and application. In the case of materials: must develop analytical "machinery" to handle energy "cost, content, claim and credit".
- Promotion and expansion of international cooperation in matters relating to the new problems and opportunities in the materials sector. A follow up effort to this Congress is highly desirable.

5. CONCLUDING REMARKS

Will mention briefly: the Workshop agenda items; the question "Can Dg.C. participate effectively in the effort required?"; the spirit and substance of the work during the Conference.

Environmental Constraint And Energy Conservation In Japanese Iron And Steel Industry

TOSHIHARU UCHIDA
(General Manager, Environmental Control Dept.
Nippon Steel Corporation)

The Japanese steel industry's investment for environmental protection during the past 8 years totaled over $5,000 million or 15% of its total investment for plant and equipment. With a new steel mill, environmental investment can rise to well over 20% of the total construction cost. Annual environmental cost is now estimated at over $2,500 million.

Nearly 100% of COG and over 50% of the emissions from sintering plants are being desulfurized, while use of low-sulfur raw materials and fuels has been pushed to the practicable limits. The atmospheric concentration of SO_2, a typical index of air pollution in the neighborhoods of Japanese steel mills, cleared the world's most stringent ambient air quality standard, less than 0.04 ppm per day.

Our all-out endeavors to install, and improve the performance of dust collectors, aimed at the target "visible zero," have reduced the amount of dust fall in the steel mill vicinity to less than 10 $t/km^2/month$, a level comparable to that of a rural environment. The recirculation rate of process water now exceeds 90%. The COD level in sea areas adjoining the industrial zones has improved sufficiently to clear the water quality standard of 8 ppm maximum.

At the same time, however, pollution abatement has changed the energy consumption pattern, and caused a surge in consumption. A switch to higher grades of energy is in progress, from high-sulfur oil to low-sulfur oil and then to LNG. Electricity used for environmental control now registers approximately 100 KWH per ton of crude steel, which is estimated to amount to some 16% of the total electricity consumption.

The Japanese steel industry's energy consumption in 1979 is down 10% from the level of 1973. Many world records have been achieved in BF fuel rates. Production by continuous casting, which cuts energy consumption by about half compared to the conventional ingot route, now accounts for 46% of the total production. This percentage is more than twice the world average. BF top pressure power generating units in commercial operation are expected to total 22 within a few month. The rolled steel product yield is as high as 87%, about 15% higher than the level in the United States. Improvement of this yield, 6% higher than the level of 1970, means the saving of some 8 million tons of crude steel. Energy savings effected during the 5 years from 1974 are estimated at about 15 million tons in heavy oil equivalents.

The prime future needs are the development of environmental technology compatible with energy conservation and the effort to attain international harmonization of environmental policies.

Materials and Energy in the Economy: Comparisons and Interrelationships

S. VICTOR RADCLIFFE
(Senior Fellow, Resources for the Future)

Over the past decade, there has been an increasing advocacy of the idea that materials use and energy use are strongly interdependent. Yet, in fact, there has been little quantitative comparison of the actual characteristics and interrelationships for the requirements for materials and for energy in a national economy, as opposed to their use in specific technical activities within limited sectors of the economy.

At the level of a particular chemical reaction or physical process, it is true that theoretical relationships between materials and energy are defined precisely by the laws of thermodynamics. However, in practice, the totality of technological activities that are used to provide goods and services in a modern economy are comprised of a wide variety of such reactions and processes. Are there also meaningful, and useful, interrelationships between the corresponding requirements for materials and energy? In the absence to date of supporting or contrary evidence, the existence of such connections can only be considered as moot.

Yet knowledge and understanding of the comparative behavior of materials and energy use in relation to economic activity over the history of industrialization might indeed be important as a potential guide to their behavior in the future. It would be helpful to know whether significant coupling between the requirements for materials and for energy can be discerned at the national level, or whether it is restricted to specific sectors of the economy. For example, does coupling become close only at the level of the materials-producing sector itself? To what extent do changes in energy demand, or changes in the mix of energy resources in use, really influence materials requirements, and vice versa? Does materials-energy behavior differ greatly among countries?

Inevitably, the world patterns of energy supply and use will continue to change over the next several decades. Consequently, clear answers to such questions are desirable for both industrialized and developing countries if they are to correctly assess the likely consequences for the requirements from and for materials. Likewise, the answers are needed to assist in setting priorities for research and development activities in materials science and technology that are intended to meet the particular problems of individual nations as producers of energy or of materials, or as competitive manufacturers of goods for the domestic and world markets.

This paper is a preliminary attempt to tackle such questions. It first examines the nature and inter-connections of the national requirement of materials and for energy in the United States since the beginning of the century. The United States appears to be the only country for which such long-term historical statistics exist. However, some relevant information of a more detailed nature for the past two decades has become available recently for several industrialized countries, including the United States. Consequently, it has been possible to explore the corresponding interrelationships for both aggregate requirements and those in several of the major sectors of the economy. These long-term and cross-country analyses identify the extent to which materials and energy exhibit useful interrelationships at particular levels within a given economy, and how the relationships vary from one country to another.

Finally, the paper applies the resulting understanding of materials-energy patterns in selected national economies to the matter of analogous interrelationships at the level of the world economy. In particular, it examines the implications for likely future trends in use patterns and requirements. Consideration is also given to the problem of corresponding priorities of attention for activities in materials science and technology.

ENERGY SOURCES AVAILABLE IN THIS CENTURY

S. WILLIAM GOUSE
Chief Scientist
The MITRE Corporation

ABSTRACT

For a period of the order of several decades, there is no physical shortage of resources which have energy of sufficient thermodynamic availability to make them economically interesting. They are primarily fossil energy resources, oil, gas, coal, shale, tar sands, peat, etc. The distribution of the known reserves is not uniform and leads to difficulties in security, balance, and development aspirations. In simple terms, the world is sufficiently well endowed with resources to permit a reasonable transition from present patterns of energy use to some pattern as yet undertermined, presumably relying more heavily on renewable resources via solar energy or nuclear resources via fission and fusion.

The world could face a much more serious problem with respect to fossil energy utilization than fossil energy resource availability; the unknown, but to some extent likely to be adverse, effects of carbon dioxide buildup in the atmosphere.

Fairly conservative definitions of the reserve base indicate that on a global basis there is no absolute supply availability crisis for the next several decades. However, the difference between what is potentially available because it is in the ground and what is available for actual use at end use in finished fuel form, is considerable. Examination of the U.S. shows how difficult this problem can be. We have enormous resources of coal, oil shale and probably unconventional gases. Our inability to achieve expeditious resolution of conflicts between various national goals, has led us into a situation where we are unable to use what is physically in place. In addition to conflicts between various goals, in particular social goals, we have not as a nation been willing to face the fact that new domestic supplies of energy will cost us more than we have been accustomed to paying, more than imported oil. These higher costs involve significant questions of equity and the distribution of the resulting costs and benefits among various members of our society. Finally, the time constants for implementation of most concepts to exploit domestic resources are long compared to several decades.

Under normal circumstances the order of exploitation of energy resources having attractive thermodynamic availability would be to proceed from conventional oil and gas to more unconventional sources of oil and gas, including the gasification and liquifaction of coal, exploitation of heavy oils, conversion of shale to liquids, etc., in order of increasing cost of producing end use fuels. Since the supply price-curves of the various sources overlap, it is reasonable to believe that depending on richness of deposit, location respect to end use, detailed characteristics of particular resources, etc., one would find a number of these more expensive supplies exploited in parallel. The implications of such a path of exploitation on world material policy, at least from the point of view of the U.S., would not be extraordinary. One can foresee that higher prices of energy and more processing of lower quality materials, could lead to greater demands for high temperature materials but does not appear to require any major breakthroughs.

One can conclude that the world is relatively rich in terms of sources of energy. While the distribution of various forms is not uniform, there is in principle no insurmountable barrier to reasonable access. However, the potential for mismanagement by governments is large and the probability for that mismanagement taking place is sufficiently high that it would be wise for all to have developed, early, extensive contingency plans. The behavior of the U.S. in the last five years in trying to come to grips with the energy problem facing the country does not leave one with a warm feeling.

WORKSHOP 1

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE ENERGY EFFICIENT MINING, PROCESSING AND RECYCLING

CHAIRMAN: DIETER ALTENPOHL (SWITZERLAND)

ORGANIZER: CARL RAMPACEK (U.S.)

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Energy Conservation in Mining

THOMAS E. HOWARD
(JOY Manufacturing Company)

Viewed basically, mining is simply a process involving the application of energy to a material (ore) to accomplish the separation and removal of all or part of that material from its place in the crust of the earth. It follows then that there are two basic avenues for improving the process. The amount of energy required can be reduced; or cheaper forms of energy can be used.

The evolution of today's mining technology, has, with few exceptions followed the latter or cheaper energy route. Cheap mechanical and chemical energy has been substituted for more expensive human energy. To be sure the machines that have increased labor productivity have been made increasingly efficient, thereby saving energy; but the overriding emphasis has been toward larger and larger machines that can apply more and more energy per unit of time, thus decreasing the amount of human energy required to control them.

The result of this path toward more and cheaper energy has been that from an energy use standpoint, mining technology has become increasingly inefficient. The amount of energy required per unit of metal or other valuable minerals produced, is far greater now than it was prior to the introduction of mass mining and milling by D.C. Jackling in the early 1900's.

The mining technology of the nineteenth century obviously is not applicable today. The high-grade deposits from which the bulk of the production came prior to 1900 are generally depleted. However, the principles upon which the underground production methods used by the nineteenth century miner were based, are still valid and can be used to point the way toward a new energy conserving mining technology.

Basically, the nineteenth century miner broke as little waste as possible. And the waste he had to break he moved a minimum distance. He worked only in ore where he could. Where he had to break waste to provide working room he blasted and moved away some of the hanging wall before blasting the vein. He sorted. And he disposed of his waste as close as possible to the face.

This same minimum energy approach to mining can not only reduce energy consumption today and tomorrow, but also offers promise for improving the economics of production and reducing the size of the environment preservation problem. If the amount of waste that must be broken and moved to extract a given amount of metal from the ground can be reduced substantially, then the amount of energy that will be required for grinding and processing will also be reduced and production costs should be lower. And the difficulty and cost of waste disposal is directly related to the amount of waste produced by the mill.

Opportunities exist, within the framework of present mining technology, for moving toward the goal of minimum energy mining, which could be realized with a suitably directed program of research and development. For example, selective mining could be more widely and efficiently applied with an ore guidance technology that is faster, more precise and more accurate than the "eyeball" and physical sampling methods presently used. Similarly mechanical sorting and disposal of waste close to the mining face could result in substantial savings in energy and costs for some types of deposits, if improved sorting technology and means for sizing the sorter feed in the mine were available. In-the-mine beneficiation technology that would produce a bulk concentrate and a tailing that could be discarded near the face, or even used for backfilling underground openings as part of the mining process would be a substantial step forward in both energy conservation and production economics. The Research Organization of the Chamber of Mines of South Africa has been conducting research for a number of years aimed toward such technology.

In summary, identification of some of the best opportunities for saving energy in minerals production requires that the mineral production operation be viewed as a single process which begins at the mining face and ends in the concentrate storage bin. Potential energy savings not apparent from consideration of mining or beneficiation as discrete and separate operations, become evident when studied from the perspective a single integrated mining and processing operation.

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Energy and Minerals Beneficiation

P.G. KIHLSTEDT
Royal Institute of Technology, Stockholm, Sweden

The techniques of mineral processing are mainly a product of this century; the full emergence of the mineral processing was reached in the period between the second world-war and the Korean crisis. Before that time the material sciences were particularly based on steel and other metals which were extracted from rich ores commonly by melting. For some metals also leaching methods were used early, for example cyanidation of gold and roasting-leaching of pyrites. The ores were often treated in lump form as they came from the mining operations. Smelting in shaft furnaces or reverberatories was the usual preparation. During the first part of the century however, the knowledge and the technique of treating fine ore particles advanced as an independent science between mining and metallurgy.

Behind the modern technique of fine particle separation lie crystallographic phenomena in the mineralogy of rocks. The ores are composed of different minerals, on which the elements of the ore are distributed in accordance to crystallographic laws and chemical equilibria. The present fresh ore minerals have been developed during an immense period of time and at higher temperatures. The distributions of equilibrium thus have developed with a sharpness which is superior to those in technical slags and precipitations. For heavy metal ores the minerals thus are separated into high grade minerals containing the total heavy metal content of the ore, and in barren gangue minerals mostly without any heavy metal content. Such material separations can never be reached by conventional metallurgical methods.

In mineral benefication these distinct minerals have to be separated and extracted after they are liberated from each other. Such treating methods were cheaper and had much lower energy consumption than the direct smelting of the raw ore. In course of time they were able to produce rich concentrates out of lean ores when the richer orebodies were emptied. As the matter of fact the new beneficiation processes could separate away one ton of barren rock from the metalbearing mineral with an energy consumption less than 10% of the energy required by smelting away the same quantity of slag.

About half of the energy consumed in such a mineral beneficiation process is used for the liberation comminution on the minerals. The sizes of the mineral crystals and the structure of the bonds are mainly dependent on the minerals' surface energies and their relation to each other. The average crystal size is statistically about 1/4 of a millimeter. The cleaner concentrates and better recoveries requested in the separations the more complete liberation of the crystals is needed.

The problems of grinding and separation may be illustrated by the calculation that the liberation grinding of one cubic meter of a normal sulphide ore gives a number of about $1x10^{16}$ particles, which have to be classified and separated into clean mineral concentrates. There are different unit-operations for the separation process based on density, magnetism, electrical attraction etc. but there is no doubt that selective flotation is the most elegant and generally applicable of the methods. The surface energies of the minerals, modified by different chemical adsorptions, are used to separate the crystals. The particle transportation is made by air bubbles, which carry the wanted minerals from the water suspension. Recoveries and concentrate grades may be very high. To-day a good copper flotation has 95-99% recovery and a concentrate has less than 10% of mineral impurities.

In order to save energy on the way to the complete separation we have to successively take away already liberated particles from the grinding as well as already cleaned minerals from the separation processes. This is done step by step in open or closed circuits both by changing grinding machines with the product size and by stage cleaning of the concentrates. One successful method has also been collective-selective separation. By coarse grinding and simple separation most of the gangue is there taken away cheaply. The difficult separation is then performed after fine grinding of a smaller quantity of minerals.

It is sometime said that also the modern communition processes work with exceptional low efficiencies. The actual fact is that most of the crystalline rocks have very different compressive and tensile strength. Normally the rock in big scale crushing breaks first at about 20 times greater compressive strain than the neccessary tensile strain. In mineralogical tests sometimes one crystal is pressed between two plates. This gives, however, in reality a tensile strain on the free crystal sides, and breakage is already achieved at a pressure representing about 1/20 of what is normal for that breakage pressure when crushing rock masses. Big scale crushing with rapid free blows also gives lower energy consumption in some cases. In the same time the liberation of the crystals is often promoted when the shock wave passes the minerals.

To-day fine grinding of minerals is often carried out longer and longer. That means particle size distributions from earlier 80% finer than 150 μ to now sometimes 80% finer than 20 μ. The energy consumption in the grinding is then about 2 to 3 times higher. On the other side the concentration units are much bigger, which gives scale benefits by using big diameter mills. This is particularly supported by the techniques of autogenous grinding in open circuits with finishing grinding in closed circuit with small balls. In order to save energy consumption in metallurgy the concentrates are also today made cleaner and cleaner.

Here has mostly been spoken about beneficiation of ores and metallic minerals. During our long period of low-cost energy supply we have been accustomed to an extensive use of metallic materials in spite of their high energy content. The production of steel ingots requires about 300 000 MJ/m^3 and aluminninum ingots about 430 000 MJ/m^3. Construction materials based on steamcured building materials, have, however energy contents of about 2 000 - 5 000 MJ/m^3 but have hitherto spent a research life in the shadow. Now when the total global value of these materials has passed that of the metals we have to pay more attention to their production nature, which is different from the ores. The beneficiation of industrial minerals means altered unit operations, processes and techniques.

Beneficiation

I. E. NEWNHAM

(Commonwealth Scientific and Industrial Research Organization)
(Australia)

Improving the efficiency of comminution and flotation can have only a marginal impact on the energy efficiency of mineral processing. The following Table gives an abridged summary of some of the results of work sponsored by the United States Bureau of Mines. (Battelle Columbus Laboratories, 1975)

Table 1.

Energy Required per net ton of Product.

Million BTU

Percent of total.

	Comminution	Flotation	Total
Aluminium	.22	-	243.9
as %	*.09*	-	*100*
Cement	.431	-	7.65
as %	*5.6*	-	*100*
Lead	3.28	1.18	26.78
as %	*12.2*	*4.4*	*100*
Zinc	4.23	1.76	60.17
as %	*7.0*	*2.9*	*100*
Copper	30.09	12.24	112.29
as %	*26.8*	*10.9*	*100*

Table 2.

Energy Required to Produce Annual U.S. Consumption.

Trillion BTU

	Comminution	Flotation	Total.
Aluminium	1.27	-	1408
Cement	38.5	-	688
Lead	2.92	1.05	23.9
Zinc	6.44	2.67	92.0
Copper	59.2	24.09	221

Although these figures refer specifically to the U.S. industrial scene of 1973, we can base some general conclusions on them. As far as beneficiation is concerned, the only areas in which a major saving of energy could be effected are the comminution of copper ores, the comminution of cement and the flotation of copper concentrates. A similar analysis of the capital employed to install the plant that consumes the energy would doubtless indicate the benefits of any improvement in efficiency which gives greater throughput for the same energy input.

Three projects have been selected to illustrate Australian work that may make for more energy efficient processing. The primary objective of the first of these is to develop procedures by which optimum rock breakage by explosives may be achieved. It is being conducted at the University of Queensland under the total sponsorship of the Australian Mineral Industries Research Association (AMIRA). It relates to open pit and underground operations and involves

- the development of a practicable technique to utilise in-situ seismic measurements in order to predict fragmentation characteristics of rock masses and discrete hard strata in overburden;

- the development and implementation of a technique for determining the size distribution of rock fragments produced by explosive breakage (techniques in use at present are inadequate for handling large volumes of rock);

- the use of the above techniques to achieve the optimum fragmentation for specific mining operations.

Once these techniques have been proved in field trials, experimental blasts will be designed on the base of local rock mechanics properties. The long term aim of this work is to develop mathematical models of the explosive rock breakage process; these in turn should enhance the possibility of optimising the process.

If all this helps to ensure a better feed size to the primary crusher, it will make for more energy efficient processing.

The second project, which is jointly sponsored by AMIRA and CSIRO, aims to characterize the mineral intergrowth properties of parent ores and flotation products. The resultant estimate of comminution and flotation characteristics and of ore grade will lead to an optimised balance of energy usage and other costs against improvements in final grade ore yield.

A computer controlled scanning electron microscope provides mineral image maps which are stereologically interpreted. At each of the raster of points corresponding to the image area, mineral composition is defined by the intensities of back scattered electrons and of the elemental x-rays generated by the electron beam.

From the resulting digital images, the natural grain sizes, amounts, and types of association of the minerals present in sectioned whole rock samples can be estimated; these data will be applied to predicting the likely response of the ore to various beneficiation treatments.

For individual whole particles deriving from comminution or flotation processes, the intergrowth distributions (for definition of jargon terms, see Grant et al, 1977) can be derived, and the size distributions of the component minerals dispersed throughout the sample of composite particles estimated. Persistent mineral associations can be determined as a function of particle size or of processing stages. Ultimately the project will quantify the required fineness of grind or regrind, the selective response in flotation, and the degree of mineral liberation.

The third project conducted collaboratively by Hamersley Iron Pty.Ltd. and CSIRO aims to control the comminution process so that less energy is used in the unproductive recycling of oversize and the wasteful production of fines. A computer at Paraburdoo gathers plant data over a wide range of feed conditions, particularly during special test runs on certain crushers, scalpers and screens, and monitors tonnages treated and power consumed by individual crushers and screens.

This provides the basis for empirical models of the complete plant and phenomenological models of the crushers and screens. The statistically based plant models have allowed screen, scalper and crusher sizes to be optimized for the whole plant so that less fines are produced; the more basic models have improved the understanding of the relation between the individual items of equipment and the materials they process.

At the same time, simulation studies have demonstrated that the recycled oversize can be reduced by performing most of the crushing in secondary rather than tertiary machines. This approach requires new control systems for crushers which can react quickly to overload conditions, despite the presence of time delays and the lack of on-line measurements of ore-size.

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Recent Energy Saving Trends in Mineral Processing

Professor ERKKI LAURILA
(Academy of Finland)

The total energy consumption in industrial grinding processes has been estimated to be 3 - 4 % of all electric energy developed in the whole world. Cement alone requires close to 1 %-unit. The major others in the order of importance are grinding of wood, iron ores, coal, non-ferrous ores, and wheat.

In investigations related to grinding of ores and minerals, the role of classification has been largely neglected. Classification is the process by which the fineness of the ground product is controlled in closed grinding circuits, both wet and dry.

It is surprising that even today the sharpness of size separation in all industrial classification processes has remained low. However, it has proved to be extremely difficult to develop new industrial classifiers, wet or dry, where the sharpness would be materially improved.

Practically all industrial classification processes are performed in one stage. It has now been shown that by applying two-stage classification the sharpness of size separation can be raised to values unknown to the mineral industry. By this basically simple change the capacity of the existing grinding machinery can be increased as much as 25 % while the energy consumption at the same time is reduced up to 20 %. A number of fringe benefits will automatically follow.

Two-stage classification by present industrial classifiers cannot be readily accomplished. To overcome the difficulties, new industrial classifiers have been developed in Finland for wet classification, for dry classification and for production of dry micropowders. All these classifiers can be operated either in one stage or in two stages, even in multiple stages. As a result , practical means for a major reduction of the energy reguired by various grinding processes have now become available.

The new ways for two-stage classification, wet and dry, seem to give the practical answers to the following three key questions:

1. How to produce (with a given mill or mills) the maximum tonnage of final fine material that meets a given size specification (such as 95 % -x µm) ?

2. How to produce the said fine product to have the lowest possible specific surface area (in other words the steepest possible size distribution curve and the minimum of extreme fines) ?

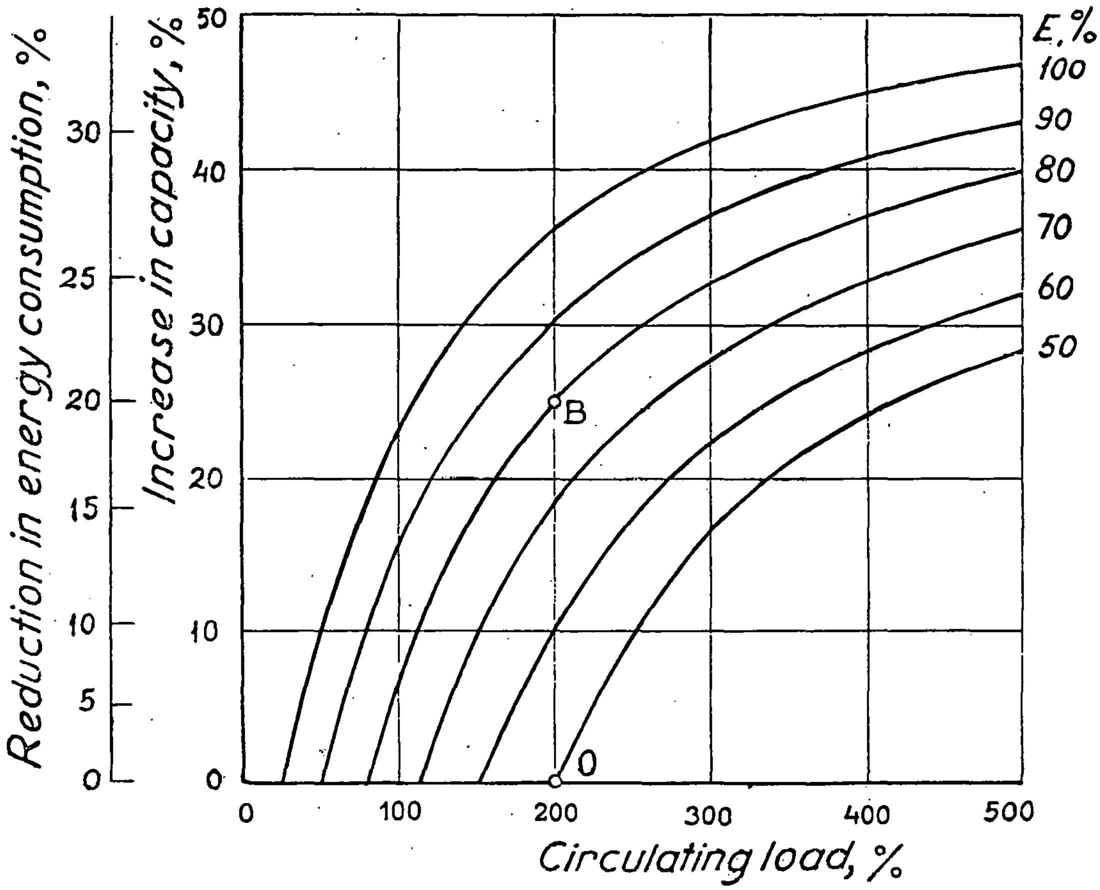
3. How to produce the said fine product at the lowest possible energy consumption ?

In mineral concentration the flotation process is one of the key operations. The main requirements call for excellent metallurgical results at a low energy consumption. In these respects the new OK-flotation machines developed in Finland seem to be the world leaders of today. The heart of the development is the entirely new energy saving mechanism which allows fool proof operation in small units and in big units, even in mammoth size units 38 m^3 (1350 cu.ft.) in volume equipped with a single mechanism, only. All this has fully changed the architecture of the flotation plant. Earlier, there were large grinding mills and tens or hundreds of relatively small flotation cells. Today, you can observe small grinding mills (yet of the same size as before) and only a few huge flotation cells. It is natural that the capital costs and the operating costs are now substantially lower. Furthermore, supervision, instrumentation and automation have become far simpler than before.

The conventional way to dewater wet mineral concentrates includes three steps: thickening, filtration and drying to a desired final moisture content. Today, water removal by drying is an expensive process because it is based on evaporation by heat. Drying, however, has remained an unavoidable step because the conventional filtration process has not been effective enough in lowering the moisture content of the cake produced. A new approach applied in Finland to simplify the dewatering process is to use new automatic pressure filters which in a number of cases can replace all the earlier three steps by a single-step operation, and in all cases minimize the heat energy required in the drying step.

It seems surprising that discussions on mining and processing of sea-bed nodules have overshadowed another field of great potentiality, i.e the dry processing of minerals. Extensive mineral resources known and unknown, exist in arid countries with limited or no water supply at all. In all cases of dry concentration the every-day practical difficulties relate to proper preparation of the feed to the various processes, and especially to sharp dedusting on an industrial scale where the present means have proved to be sadly inadequate. With the new pneumatic classifiers mentioned above it has now become easy not only to obtain well dedusted fractions at a high production rate but also to extend dedusting to the range of micropowders never before practiced in industrial mineral processing operations.

With growing interest in dry mineral processing new developments such as new high intensity - high gradient magnetic separators provided with energy saving permanent magnets must receive growing attention. Perhaps there might even be a chance to solve the concentration of the hematitic taconites the dry way.



Curves showing the relationship between circulating load, sharpness of size separation, increase in capacity and reduction in energy consumption, in comparison with performance data for a conventional industrial closed grinding circuit with E = 50 %, CL = 200 % (point 0).

Some Aspects for Saving of Energy in Mineral Beneficiation Technology with Special Reference to Iron Ores

Dr. T. R. Boulos
Associate Professor, Central Metallurgical Research and Development Institute, Cairo, Egypt

The present world energy status represents a penalty imposed on the development of metallurgical industries in general and on mineral beneficiation technology in particular. The result of such an abrupt increase in fuel prices will be a decrease in the acceleration of development in industrialized countries and the inability to achieve modest levels of development in many oil-deficient countries.

The conceivable effects of this crisis on the development of the iron and steel industry may be much more substantial. The introduction of "giant" blast furnaces in the steel industry and the remarkable development of the direct reduction methods in this domain may be responsible, among other technical and economic factors, for the present situation in the iron ore market. Lower coke consumption through improved reduction properties and optimization of slag composition have made fired agglomerates, rather than lump ores, the "best seller." Irregularities in ore characteristics due to different gangue minerals are now intolerable in view of the impending increase in coke prices which were doubled since 1972. Meanwhile, the development of the direct reduction technology (depending on the application of natural gas for steelmaking) in comparison with the conventional LD, LDAC blast furnace operations may explain the current situation towards the depletion of the world's demand for high-phosphorous lump iron ores.

The requirements raised by such development in steel production due to the increase in energy costs, will affect the technology of ore beneficiation for agglomerates production. Sophisticated concentration flowsheets may be an unavoidable alternative to fulfill such a target. But how could that be achieved in view of the present situation, a question which might find various answers in the Congress.

The interrelationship of the three main processes, viz. mining, beneficiation and extraction represents, in fact, the principal route for "amplification" of any saving of energy in plant. A perfect mining plan will afford lower comminution expenses, and a precise concentration flowsheet will effect a notable decrease in the energy consumed in smelting. However, saving of energy, in this domain, may follow either direct or indirect routes to satisfy the following requirements:

A. A flexible mill design with a perfect layout to afford maximum use of equipment at the lowest maintenance cost and with the optimum automation technology.

B. Minimum comminution energy consumption through perfect control of the mill-run-of-mine input, ultimate increase in machinery throughput with the maximum reduction in lining and grinding media wear and the media wear and the minimum recirculation of products. Due consideration should be given to the mining operations aiming at quality control of run-of-mine at an optimum production rate.

Constant uniformity of feed may represent the successful step for saving of energy in the pulverization section. Selection of the proper crushing and grinding units is, in fact, the prime element for indirect saving of energy via maximum throughput and minimum wear. This may be done with appropriate consideration to grain size, capacity of the preceding and subsequent equipment in both the preconcentration plant and the main plant, and to the concentration target as well.

Ultimate increase in unit throughput may be the best route for both direct and indirect saving of energy. Relatively lower speeds in huge mills will also affect the grinding media rate of wear. Care should be taken when choosing the material and profile of the mill liner.

It is important to refer to the limitation or even elimination of material recirculation in the plant which amplifies any original disturbances in the mill on the prejudice of extra energy consumption.

C. Maximum concentration ratios at the optimum mill throughput via the shortest route to the target. This may be accomplished by adoption of innovative procedures, rather than conventional ones, in both the preconcentration plant and the main beneficiation plant. Application of huge units in this respect, represent the simplest way for indirect saving of energy. One may mention the introduction of 1000 cubic feet flotation cells, the application of the Reichert Cone (75-100 t.p.h.) or the utilization of the Jones magnetic separator (120 t.p.h.) in modern concentration flowsheets. The development of pneumatic preconcentration methods for the treatment of porous iron ores or the application of selective flocculation processes for the treatment of finely disseminated taconites represent a real breakthrough in iron ore beneficiation technology.

Low temperature roasting of mangniferous iron ores or mixed iron ores prior to low intensity magnetic separation processes may be an alternative for saving of energy at relatively high temperatures. Avoidance of the formation of Mn-Fe solid solutions at these high temperatures is a property of this former technique.

D. Minimum fuel consumption for thermal treatment of concentrates, through the application of other cheap energy resources e.g., solar energy, wind mills or other solid fuels like anthracite coal or coke breeze. A considerable replacement of conventional fuels by coal or lignite in the sintering or pelletization processes of fine iron concentrates may be of extreme importance to reduce the energy consumed for the preparation of these special quality products. However, technical mastering of the firing circuit in these operations proved to reach a record of 5 l.p.t. at LKAB, Sweden.

Some Developments Related to Materials for More Energy Efficient Mineral and Metallurgical Processing in Israel

by
A. METZER
IMI, Institute for Research and Development, Haifa, Israel

The purpose of this presentation is to describe several new developments, where materials are an important factor in the reduction of energy requirements. These include :

1. Controlled dry-grinding of phosphate rock.
2. Use of Solar Energy for concentration of hydrometallurgical solutions.
3. Development of magnesia whiskers for high temperature insulation.
4. Production of high purity periclase for efficient lining of steel furnaces.

1. Controlled Dry Attrition Grinding of Phosphate Rock. (Work in Development Stage)

In almost all known methods of size reduction, breaking forces are applied indiscriminately on particles of the material. Efficiency of the operation is generally measured in terms of new surface produced per unit of energy input. However, when the main purpose of comminution is the liberation of valuable constituents of an ore, the efficiency concept should also include a measure of the degree of liberation achieved. In other words, comminution should be considered as an integral part of the process of separation, and its efficiency judged accordingly.

These principles were applied to the comminution of a sedimentary ovulitic phosphate ore from Israel containing 21% P_2O_5. The crypto-crystalline apatite ovulites (100-800μ in size and containing 35.5% P_2O_5) are embedded in a matrix of larger calcite crystals (up to 10μ which is softer than the ovulites. When the rock is crushed, fracture cracks propagate mainly through the boundary between the matrix and the ovulites, setting them free. The -20+200 mesh fraction, enriched in ovulites, contains only 24-25% P_2O_5, due to the fact that many ovulites are still bound to the calcite and to the presence of non-disintegrated calcite particles.

In order to increase the degree of liberation, two methods of controlled dry grinding (by impact and shear) are under development. The first consists of a steel ball mill with rubber balls of medium hardness (such as used in prevention of blinding of shaking screens).

The resilience of the rubber on impact or shear protects the ovulites from breaking. The best results were obtained when the -200 mesh produced was continuously removed, for instance in an air-swept mill. Under these conditions, the -200+200 mesh fraction could be upgraded to approx. 28.5% P_2O_5. From the preliminary results obtained it is apparent that this method is quite effective, and further work should be concentrated in determining the optimum properties of materials for the grinding media (size, density, resilience, etc.).

The second method under study consists of a fluidized bed of ore into which mechanical energy is introduced by means of a rotor, which disintegrates the particles by impact and attrition. By this method, a -20+200 mesh concentrate containing up to 32.5% P_2O_5 and 55% recovery, was obtained.

2. Use of Solar Energy for concentration of Solutions. (Research Stage)

In many hydrometallurgical processes, where dilute solutions of metal salts have to be concentrated by thermal methods, solar energy could be used in arid areas by means of evaporation ponds. Applications include concentration of dilute copper solutions obtained by acidic leaching of lean ores, crystallization of alkali salts obtained in chemical processes, etc. The main problem in the use of this process, is in sealing large areas of ponds to prevent seepage. Present methods in use are of two main kinds : the more expensive uses plastic sheets suitably protected, and the cheaper is based on the use of various kinds of clays (e.g., bentonite) to seal the ground. However, these are not completely satisfactory, and the development of better and cheaper materials and methods is required.

3. Magnesia Whiskers for high temperature insulation (Development stage)

Prevention of heat losses in high temperature metallurgical processes can be obtained by the use of special insulating refractories. A variety of refractory fibers are available today for this purpose, but only two of them can stand temperatures above 1600°C, namely Al_2O_3 and ZrO_2.

A new process for producing MgO whiskers, which can resist temperatures above 2000°C, is under development. These whiskers are 1 to 3 mμ in diameter and up to 5 mm long.

4. High purity periclase for lining of steel furnaces. (In production)

A new generation of refractory products based on high purity, high density periclase was introduced in 1975. This periclase is produced by thermolysis of Dead Sea brines rich in $MgCl_2$, contains more than 99.0% MgO and only about 50 ppm Boron, and has a density of 3.45, which is close to 97% of the theoretical. Its main application is in Oxygen Converters (BOF) for steel, in the slag contact area, where their resistance to chemical attack and mechanical strength are of importance. Substantial energy savings are obtained by increasing the number of furnace heats before relining, or in other words, by a decrease in the refractory consumption per ton of steel produced.

Uranium Enrichment with Low Energy Costs in Remote Areas

FRITZ HINZNER
(Comisión Chilena de Energía Nuclear)

The increase of energy costs since 1973 and the continuous growth of energy demand has contributed to introduce nuclear power as an alternative source of energy to satisfy the world's needs. Nuclear energy will become more important at the end of the century with an installed capacity of 1.500 GW, of which light water reactors (LWR) are the most important. In 1979 out of 126 GW in power reactors, 106 GW are LWR and at the end of the next decade out of 600 GW, 560 will be LWR (OECD, Dec. 1977). Since LWR's use enriched - uranium as fuel, there will be an increasing demand for enrichment services. Considering present supply for enrichment, plants planned and in construction and expansions in U.S.A., it could be concluded that at the end of the next decade the demand for enriched material may not be met by the existing plants (OECD, Kovan, Smith, 1976).

Of the three industrially used enrichment techniques, the only one that does not require much energy is the centrifuge process. From the energetic point of view, this method is attractive, but it is technically sophisticated, a large number of centrifuges are required and wear out fairly quickly. Considering the whole centrifuge process including the plants for building the centrifuge accessories, it may require perhaps as much energy and materials as the diffusion technique which is energy intensive but a well proven process.

Since enrichment with the diffusion or nozzle technique are energy intensive processes with a low material flow, it seems reasonable to use low cost hydro power which may be found in remote areas. Africa, South America or Canada have abundant unused hydro power at very low cost. Due to its high maintenance requirements, the centrifuge process will not be suitable for such a place, therefore the present analysis will only consider the diffusion and nozzle techniques.

In order to assess the possibility of enrichment in a place with low cost hydro energy, the internal rate of return (IRR) was calculated for the different alternatives, under the following assumptions:

- Energy requirements: for diffusion 2.500 KWh per separate weight unit (SWU); for nozzle 3.000 KWh/SWU (Kovan 1976, Becker 1976).
- Low cost hydro energy in remote place 9 to 12 mills per KWh.
- Transport of UF_6 to a remote area, 30.000 Km both ways, \$ 5 per SWU.
- Investment: \$ 230 to \$ 320 per SWU/Y for diffusion; \$ 270 to \$ 380 per SWU/Y for nozzle, plus 10% for transport to remote area and 80 million for infra - structure.
- Interest: 9% to 11% per year for loan and construction period.
- Operation extrapolated from 1974 considering escalation, \$ 6.1 per SWU for diffusion; \$ 7.6 per SWU for nozzle (Braun et al, 1974).
- Selling price of SWU: \$ 80 to \$ 100.
- Inflation: 6% to 8% construction; 3% to 5% energy; 7% to 9% operation; 3% to 5% price of SWU.

For a price of \$ 90 per SWU a diffusion or nozzle plant could be installed in a remote place with an energy cost of 9 mills/KWh and inflationary conditions, obtaining an IRR of about 12% for nozzle and 20% for diffusion. Since the value of SWU during the second half of the next decade will be at least \$ 150, an estimate was made for this price, obtaining an IRR of about 20% for nozzle and 35% for diffusion for an energy price of 30 mills/KWh.

In order to compare an industrialized area with a remote place, it was assumed that the energy of the industrialized area has an escalation of 4% per year. Since hydro energy of the remote place is only a function of the initial investment, the energy price should not increase with time. The additional transport and infrastructure expenses were deducted for a plant in an industrialized place. On this basis the IRR was calculated as a function of the energy price for 90 and 150 \$/SWU. For 90 \$/SWU the installation of a nozzle or diffusion plant would be more attractive in a remote area, if the energy in an industrialized area would cost more than 13 or 17 mills/KWh, obtaining an IRR of 10%. A remote place would be more attractive for 150 \$/SWU, if the energy in the industrialized place costs more than 27 or 34 mills/KWh for nozzle or diffusion techniques, obtaining an IRR of about 25%.

The above analysis shows that it may be possible to install an enrichment plant in a remote place with low hydro energy costs. However, due to the very high investment, of the order of 3.000 million excluding hydro power stations, and considering that these techniques are still classified, the whole idea looks like "science fiction". The fantastic increase in energy prices during the past five years and the subsequent changes in energy policies, make it difficult to predict what may happen to vast hydro resources that are at present flowing into the ocean. Enrichment of uranium is nothing else than concentrating energy in a solid to release it later in a reactor with very low transport cost. Probably, the energy situation in the world must become much more dramatic before countries that have the know-how of enrichment techniques and the financial means, make use of low-cost energy in remote places.

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Unconventional Resources

RALPH C. KIRBY
U. S. Department of the Interior, Bureau of Mines

This Congress is focusing on the new challenges and opportunities for materials science and technology to help nations cope with the specific aspects of problems most important to them as producers, importers, or exporters of materials or as energy producers. The issue addressed by this workshop is materials science and technology for more energy efficient mining, processing, and recycling. This part of the workshop addresses specifically the use of unconventional resources.

The role of the Bureau of Mines is "to assure the continued viability of the domestic minerals and materials economy and the maintenance of an adequate minerals base so that the Nation's economic, social, strategic, and environmental needs can be better served." This mission has lead to the Bureau's programs of research on low-grade deposits, complex ores, and unconventional resources for the recovery of metals and minerals. The following are examples of unconventional resources that the Bureau of Mines is investigating. They can provide us with a starting point for further discussion.

Alumina from domestic nonbauxitic resources. The United States presently imports over 90 percent of its bauxite and alumina requirements for producing aluminum. From the standpoint of national interest, there is an urgent need to advance a technology that will allow the U.S. to make use of its ample domestic resources for aluminum production. There are more than 160 billion tons of alumina in the U.S. in sizable deposits of anorthosite, clay, laterite, shale, and low-grade bauxite. A series of miniplant investigations are testing and developing the most promising technologies for producing alumina from such abundant domestic resources as clay, anorthosite, alunite, and dawsonite. A contract study by an engineering/construction firm led to the selection of the process having the greatest potential for supplying alumina from a U. S. resource from among six alternate raw material/process technology options. The preliminary design of a possible pilot plant based on that process is now underway. Studies have shown that processes for treating nonbauxitic materials require more energy than the Bayer process. The hydrochloric acid/clay process requires 21 million Btu per ton Al_2O_3, while the Bayer/bauxite process uses about 15 million Btu per ton Al_2O_3.

Recovery of tungsten from Searles Lake brines. Current domestic production of tungsten fulfills less than one-half of our domestic consumption. A large resource, estimated to be 135 million pounds of dissolved tungsten, is contained in the brines of Searles Lake, Calif. If the tungsten could be recovered from this source, domestic tungsten reserves would nearly double.

A technique capable of removing tungsten from the complex Searles Lake brines has been demonstrated by the Bureau of Mines. The tungsten is sorbed on a specially synthesized ion-exchange resin and stripped using a weakly alkaline solution. Tungsten can be recovered either as a marketable iron-tungsten product or as tungstic acid concentrates. The key to the technique is the unique resin developed by the Bureau. Although a variety of commercial ion-exchange resins are available, none proved effective for recovering tungsten from the alkaline brines. The resin is produced in the form of beads rather than by a less efficient crushing and screening method initially tested. Current research is directed toward providing information for operating an expanded-scale process development unit and appraising the process economics.

Geobrine mineral recovery. Exploitation of minerals in geobrines could provide added incentive to the development of geothermal power. These brines contain such valuable minerals and metals as potash, manganese, lithium, zinc, lead, and silver. Flashing steam from high-temperature, high-salinity brines usually results in the precipitation of scale-forming minerals which coat heat-transfer surfaces and could plug injection wells. Recovery of these brine constitutents could add to the resource base as well as alleviate severe materials problems of scaling and corrosion. Development of California's Imperial Valley geothermal resources alone could provide enough potash to eliminate U.S. imports and even allow exports by the latter half of the next decade.

Recovery of chromium from laterite processing residues. The United States is dependent on foreign sources for chromium. While large low-grade chromium resources exist in such places as the Stillwater complex of Montana and the nickeliferous laterites of Oregon and California, it is not presently economic to treat them. The Bureau of Mines is investigating the recovery of chromium from the domestic laterite residues from nickel/cobalt processing. The method makes use of a material that would not normally be considered a resource for chromium because it contains only 2 or 3 percent chromium. Since this material already will be mined and available as a residue, the effort to develop the technology to recover chromium as a byproduct is warranted.

Accessory mineral recovery. Although much is known about the composition and character of feed materials entering the metallurgical system, information and data on the final disposition of the elements and compounds that make up the feed is, for the most part, limited to those that are recovered as marketable products. The elements and compounds of concern are normally produced incidental, thus accessory, to the main output from a processing sequence. They are not by-products inasmuch as they are not now being recovered. Since they are only accessory, too little attention has been given to their origin and fate--they often escape and may be harmful. The development of technology to recover these accessory materials would result in a substantial measure of conservation and, perhaps even more important, would constitute an effective way within the metallurgical system of controlling pollution. The Bureau of Mines program is concerned with increasing our understanding of the fundamental physical chemistry of metallurgical reactions by determining thermodynamic data for minerals. Examples of projects related to the recovery of accessory minerals from mineral processing streams include recovery of vanadium and uranium from Western resources, lithium and accessory minerals from clays, particulates from mineral processing wastes, and accessory minerals from copper slags and lead and zinc process wastes. The particulate mineralogy unit will provide identification and analysis of mineral particulate, especially asbestiform minerals, derived from mining and mineral processing operations.

The Future Availability of Aluminum in Mexico

Gabriel Torres-Villaseñor
Centro de Investigación de Materiales, Universidad Autónoma de México
Apartado Postal 70-360, México 20, D.F., México

Mario López Buizan
Depto. Ciencia de Materiales-ESFyM, Instituto Politécnico Nacional
Zacatenco, México, D.F., México

Mexico is a Country where aluminum is an importation product. Al consumption in 1977 was 90,000 metric tons. 50,000 tons are transformed in Mexico from alumina obtained in the U.S. and the other 40,000 tons are imported as Al mill products and sundry other forms. The cost of aluminum products transformed in Mexico is 22% higher than in the U.S., this is due mainly, to the higher cost of electricity and importation costs. On the other hand the recovery of aluminum from scrap, which is an important and cheap source of supply in other countries is not very cheap in Mexico. A kilogram of aluminum scrap cost only 20% less than a kilogram of primary aluminum. For which reason, energy savings obtained by this method do not compensate its use.

The studies made in Mexico by government entities show that bauxite the richest source of aluminum, oxide, doesn't exist in our territory. We have instead vast quantities of other aluminous ores, sufficient to sustain the industry for hundreds of years. The principal ores are the Kaolinic clays, alunites, gibbsites and nephelines (SiO_4AlNa).

The problem we now face, is not one of literally running out of aluminum, but one of availability under conditions which may be acceptable to us, there is a limit as to how much money and energy we can afford to pay for them. The basic question is: how can we satisfy our aluminum needs while at the same time consuming less imported alumina and energy? The answer to this question has three components: recycling, substitution and development of new and more efficient methods for the extraction of alumina from domestic ores.

We should forget for the moment about recycling as a secondary supply of Al, because of the present high cost of the aluminum scrap. In contrast, the replacement of aluminum-rich alloys by alloys with low content of Al is a real possibility in Mexico. The replacement of Al-Si-Mg alloys in building and construction with Al-Zn alloys, will reduce the aluminum consumption and will allow the use of the excess of Zn that Mexico has. Building and construction absorbed 30% of the total national aluminum consumption last year, so an alloy

Al-Zn with more than 50 wt % Zn, will leave free more than 15,000 tons. of Al to be used in other applications without increasing aluminum production.

Suitable alloys for this replacement are those with 17 to 40 wt % Al. The properties of these alloy are currently being studied at the Centro de Investigación de Materiales. These alloys have an acceptable density value of 3.5 to 6 gr. per c.c., and a strength similar or better than the conventional Al-Si-Mg alloys. The corrosion behavior is satisfactory and the alloys can be hot worked at 260°C. This represents an energy saving because Al-Si-Mg alloys at the present time are hot worked at 450°C. Mexico produces 270,000 tons of Zn per year since 1975, and the domestic consumption is of some 70,000 tons, so we have an excess of nearly 200,000 tons of Zn, some of it is sold to other countries at a very low price. So this type of substitution could be favorable to Mexico because we are using a low cost material produced by the country and the energy consumption required for its production and transformation is less than that of Al alloys.

Another answer to the problem is to design a more efficient method for the obtaining of alumina from clays. This means that with the same amount of energy we can get more products. A promising prospect lies in a method which extracts alumina from clay and at the same time it is possible to obtain other products such as cement and fertilizers. The method has been used during the last 10 years in some socialist countries as Poland and Russia, and it seems to be good because the U.S.S.R. and the U.S. were the leading producing nations of primary aluminum in 1975. The process starts with 4 tons of any aluminous ore with at least 30% of alumina mixed with 7.5 tons of lime stone. The energy source is fuel oil and the resultant products are 10 tons of cement one ton of alumina and one ton of soda.

Plants of this type are working at Groszowice (Poland) and at Picaloba (USSR). Of course the socialist point of view of the energy;s cost is quite different to that of the capitalist world so it is not easy to say if the method is convenient energy-wise; we can only observe that for these materials this method is cheaper than the Bayer method. This process is under study at the Materials Science Department of the Instituto Politécnico Nacional, in order to determine if it is convenient for Mexico, under its present energy generation conditions.

Another promising prospect lies in the chloride reduction process currently being tested by several industries of the world. A variation of this method has been tested at the Centro de Investigación de Materiales by F.Goldis. In his method he recirculates part of the aluminum which in turn is oxidized in the process, raising the temperature of the system enough to produce the chloride reaction.

With this method it is expected to obtain one ton of aluminum from

5 tons of Kaolinic clays and 4 tons of coal. If successful, this process may be able to lower energy demand by as much as 30% from today's most efficient Hall cells.

Energy Considerations In The Production Of Aluminum In The Developing Countries

R. ANDREW BLELLOCH (Louis Berger & Associates)
and
CHRISTOPHER NIEMCZEWSKI (Centaur Associates)

The purpose of this paper is to identify the sources of bauxite and energy in the developing countries and to investigate the potential for siting aluminum production there in order to meet expanding world demand. The necessary conditions for the healthy development of an aluminum industry - from the points of view of both the sponsoring firm/agency and the host country - are discussed. The intent of the authors is not to advance one particular view but to provide the basis for workshop discussion.

Aluminum is an attractive, lightweight material. However, its production, which has been increasing at an annual rate of 5%, may be limited by its energy intensiveness. Approximately 15,000 kwh of electricity is needed to smelt one ton of primary aluminum. Production has been concentrated in industrial countries close to major markets and, at the same time, near sources of low cost energy - hydropower, fossil fuel or nuclear. The disappearance of low cost energy in developed countries is acting as an increasing constraint on expanding production there. Even current production is largely dependent on electricity bought on long term contracts at prices much lower than today's opportunity costs. These prices and the consequent costs of aluminum production are likely to increase significantly when contracts expire.

Developing countries, on the other hand, have the bulk of the bauxite reserves and vast untapped sources of energy in the form of undeveloped hydropower and flared natural gas. (The latter is a by-product of oil production which in certain countries is currently wasted for lack of a market).

There are three principal considerations in the development of an aluminum industry in any given country - existence of bauxite reserves, the availability of low cost electricity, and the existence of a significant domestic market. For primary aluminum production to be viable, at least two of these factors,(i.e., bauxite and energy, or energy and a domestic market), are probably necessary. Developing countries meeting this criterion are identified. The cost of aluminum production and electricity generation are discussed with a view to identifying necessary economic conditions.

In addition to purely financial questions, the goals of the host country, the need for foreign investment, risks of expropriation, possible ownership/management arrangements, technology transfer, and marketing must all be considered. As the overall needs of the industrialized nations for new sources of primary aluminum seem to be generally compatible with those for industrialization of the developing countries, it is hoped that workshop discussions will help identify the basis for meeting them.

Some Aspects of Energy Saving in Ironmaking

S. DAS GUPTA
(M.N. Dastur & Company (P) Ltd, India)

Iron and steel is the largest single energy-consuming industry of the world. In 1973, it accounted for about 11 per cent of the total world energy consumption. Of the different stages in producing steel from ore, the maximum energy is consumed at the ironmaking stage. In this paper, a brief review of energy savings in the blast furnace and direct reduction processes is presented.

Blast Furnace

The coke consumption in the blast furnaces in selected countries has reduced by 25 to 55 per cent between 1960 and 1976. This has been brought about by technological improvements such as the use of enriched ore feed, closer sizing of burden materials, higher usage of agglomerates, higher blast temperature, oxygen enrichment of blast, auxiliary fuel injection and higher top pressure. Use of pre-reduced material produced from plant wastes has also helped in lowering the coke rate. Besides, increases in the furnace size have also brought some savings in energy consumption by reducing the heat losses.

Use of higher top pressure in blast furnaces requires supply of blast at higher pressure and this in turn results in increased energy inputs. About 25 per cent of the energy consumption in blowers can be recovered from high top pressure furnaces.

Efforts in energy saving in ironmaking are continuing and it is expected that by the mid 1980s coke rates of about 400 kg per ton hot metal may be achievable in countries like Japan compared to coke rates of 430 to 600 kg per ton obtaining in the principal steel producing countries of the world.

Direct Reduction Processes

The energy situation in the direct reduction processes is discussed citing the two gaseous reductant processes namely the HyL and Midrex which have found greater industrial application. The natural gas consumptions have been reduced by about 30 to 35 per cent. This has been achieved by using better burden materials such as pellets instead of ore, and recovery as well as utilisation of waste heat.

Recycling of Waste Materials: Yes, But . . .

Alberto Bonfiglioli
(Science Policy Research Unit, University of Sussex)

Waste is an improper name for a resource. Like any other resource, it may or may not be a useful reserve of materials, depending upon a complex of factors: cultural, political, social, economic, technical.

Waste is produced as a consequence of all types of process or activity, taking place in a given environment. Perhaps the best known case of producing unavoidable waste is the conversion of heat into mechanical work. In other processes theoretical efficiency cannot always be estimated. But no sophisticated thermodynamics is necessary to realise that the efficiency in using resources can be greatly improved, and consequently the amount of waste produced can be significantly reduced.

Efficiency does not have an absolute meaning. Cost efficiency in production of goods and services does not necessarily imply efficiency in using physical resources, however valuable they may be for society, mankind, and future generations. Instead, efficiency in costs frequently involves great inefficiency in using cheap energy, cheap raw materials and in taking maximum advantage of the cheap services provided by the environment (such as disposal or dispersal of residues). As a consequence, huge amounts of by-products are produced, which are cheaper to throw away than to use for any other purpose (precisely the economic definition of waste). At the present time, countries that produce fuel and raw materials are seeking more equitable conditions of exploitation of their resources, and expenditures aiming at a less predatory use of the common environment are increasing considerably.

Thus, many things are now less cheap to throw away than in the past. Within this context, recycling of waste materials - which has always been practiced in human societies as well as in nature - becomes a central issue, widely publicised as an imperative to conserve materials, to save energy and to reduce stresses on the environment. The effectiveness of all this, however, cannot be taken for granted in general. Realistic assessments can essentially be made only for particular situations.

Three kinds of situations may be distinguished, according to the form in which waste is produced and managed:

1) Waste, relatively homogenous and produced in huge amounts in restricted locations as a result of extracting or processing other resources; (e.g. colliery spoil, gangue in ore extraction, ash or SO_2 from power stations; red muds from Bayer processing of bauxite; new metal scrap not re-processed within the factory where it is produced);

2) Waste produced as in the above situation but recycled at the place where it is produced in order to contribute to the economics of the process, as well as to reduce problems of pollution or disposal; (e.g. recycling of water in various processes - paper or sugar production, mineral dressing, coal washing, etc.; re-combination of chemicals to reconstitute reagents; treatment of fumes produced during the smelting of aluminium, with recovery of fluorine compounds; new metal scrap recycled within the factory where it is produced.

3) Waste, mostly heterogeneous, produced in relatively small amounts in dispersed places, needing an extensive recollection procedure; (e.g. domestic rubbish, scrapped house appliances, scrapped cars).

The above distinction is necessarily schematic, but it is suitable as a reference framework for the examples to be discussed in this paper. All of them concern aluminium, which is a major metal appropriate for illustrating some situations that may originate from the use of waste materials.

Waste, as in situation 2 above, is essentially controlled within the confines of specific organisations (the firm, the plant). Recycling of water, recombination and recycling of reagents in chemical processes, recycling of new metal scrap, are all current standard practices that, certainly, need to be improved. But the technical changes that may be required in order to face new situations at local or international levels (environmental regulations, increases in prices of energy and raw materials), can be decided within the context of those organisations. This is illustrated by the measures taken within primary and semis aluminium plants in order to reduce scrap production and increase efficiency in recovering metal from their home scrap (Flemings et al, 1974; O.E.A., 1978). Another example is the concept, already adopted in primary aluminium smelters, of using a raw material of the process (alumina) to capture pollutants and recycle valuable products (fluorine products). (Cochran, 1974; Dumortier, 1978). Such a concept merits exploration in order to evaluate further possibilities in other industrial processes.

Unfortunately, many other waste materials are embedded in a more complex context. The potential use of colliery spoil and fly ash as a source of alumina (Christie and Derry, 1976; Burnett et al, 1977; Bonfiglioli et al, 1976) illustrates that the use of some waste materials can create a significant extra demand for energy and does not necessarily remove stresses on the environment; instead, stronger ones can be created. Moreover, different industries, so far mostly independent from one another, should harmonise their technologies, markets, and general interests (eventual connections between alumina production, coal mining, power stations fired with pulverised coal, and the cement industry may well illustrate the point).

Another useful example is secondary aluminium. This is produced from scrap within a scheme well differentiated from primary and semis production. The total estimated energy requirement for producing secondary aluminium is generally higher than 5% of the primary requirement (a figure usually quoted). Moreover, as efficiency in management of primary home scrap increases, the average quality of scrap available for secondary smelters becomes lower. As a consequence, both energy requirement and production costs of secondary aluminium are increasing (O.E.A., 1978). It remains, however, less capital intensive and less energy intensive than the primary metal and, in general terms, it is highly advantageous to increase the uses of the former as a partial substitute for the latter. This requires a much better management of old scrap. This resource is generally dispersed, their characteristics vary within a wide range (depending upon the whole history of different scrapped products), and their availability can only be estimated through models based on more or less crude assumptions concerning product lifetimes (Chapman, 1975a, 1975b). Thus, patterns of production, consumption and disposal need to change in order to incorporate the concept of materials conservation. Technical changes aiming at a more efficient recycling have to be introduced from the very conception in product design and development.

Recycling of materials waste, as any other process or activity, requires energy and produces effects on the environment. The extent to which conservation of some materials involves conservation of other resources, is more a question of appropriate management (which includes opportune technical changes) than a consequence of conservation itself. Such management becomes extremely complex when conservation involves many different sectors, whose interests can easily be in conflict.

Necessary changes at different levels of society, allowing a more efficient use of resources, do not seem likely to occur spontaneously, without well defined and appropriately implemented governmental policies.

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Recycling of Material Wastes

R. G. W. LAUGHLIN

(Ontario Research Foundation, Ontario, Canada)

The recycling of material wastes is important both because of the finite nature of our mineral resources and because of the contained energy in the material which, in many instances, can be conserved by reuse. A third consideration is the minimizing of environmental damage both in the disposal of waste materials and in the winning of raw materials and energy.

The scarcity, environmental damage, and degree to which energy can be conserved varies greatly from material to material. In a recent Ontario Research study (Brown et al., 1976), on reuse of post consumer materials as feedstocks for the production of paper, steel, aluminum and glass, the potential for energy conservation was shown to range from 14% for glass to about 95% in the case of aluminum.

The best approach to recycle is direct reuse, as in the case of returnable bottles, since this is when the maximum in materials, and energy savings can be realized. This is not always practical, particularly in industrial recycling, so that, in most cases, reprocessing is needed prior to reuse. In either case, whether the direct reuse or reprocessing route is followed, one of the first requirements for effective recycle is to know where the material can be reused. One approach which has been utilized in recent years to identify potential match-ups between generators and users of industrial waste materials are Industrial Waste Materials Information Exchanges. Following an extensive study (Golomb and Laughlin, 1977) of Waste Exchanges operating in Europe, and just beginning in the United States, Ontario Research Foundation established a nationwide Canadian Waste Materials Exchange. The project, which is being sponsored by Fisheries and Environment Canada, began in January, 1978, and has been fairly successful in achieving waste transfers through its first year of operation. Of 772 industrial wastes listed on our bi-monthly bulletins, 553, or 72%, were of sufficient interest to generate at least one enquiry. By the end of 1978, we had recorded 62 waste transfers which approximate to a total of 44,000 tons/year of material with a value of about $1.5 million.

The benefits of the Waste Exchange concept are twofold: firstly, the direct benefit of having many companies aware of a particular waste being available, thus multiplying the chances of thinking of a use for the material; secondly, the Waste Exchange has a more subtle impact in educating people to think more about reuse opportunities.

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Materials Science and Technology for more Energy-Efficient Mining, Processing, and Recycling: The French Effort in Recycling

ELIANE MORIN
(French Scientific Mission)

Like Japan and some other industrialised countries in Europe, France is very dependent on imports of energy and mineral resources. In 1976, energy imports amounted to 61 billion francs (12 billion dollars) up from 16 billion francs in 1973; mineral resources imports came to 15.8 billion francs (about 3.5 billion dollars), up from 4.7 billion francs in 1971. Mining production in France supplies only 13% of the total consumption of non energetic materials (not taking into account recycling), and national energy sources only 24% of the primary energy consumption.

This great dependency on foreign countries led the French Government to create two agencies responsible for reducing consumption of energy on the one hand, of materials on the other. The Délégation aux Economies de Matières Premières (Agency for Mineral Resources Savings) was set up in April 1975 within the Ministry of Industry, and l'Agence pour les Economies d'Energie in November 1974. The objective of the Délégation aux Economies de Matières Premières is to reduce imports of mineral resources by 5 billion francs sometime between 1980 and 1985. The result will be greater autonomy, lower energy consumption for metal processing and reduced environmental impact of production and wastes.

Five different methods are being implemented to reach the 1980 goal:

1. Reduction of the weight of some products such as reduction of the thickness of copper tubes or reduction in the use of resources such as phosphates in fertilizers.

2. Substitution of a more abundant resource for a scarce one such as aluminum as compared to copper.

3. Modification of processing methods to reduce the use of materials and diminish wastes (mechanical or electrical industry).

4. Increase in the lifetime of products and their reliability (appliances, automobiles).

5. Increase of recovery and recycling (copper, paper, glass).

Because France has few resources of its own, the thrust behind this effort was to reduce consumption and promote recycling in the sectors where imports are high: copper, paper, rubber, plastics. Also, the emphasis was put upon the use of municipal wastes and the reuse of glass. The goals are:

- To reduce copper imports by 50,000 tons per year by 1985 (330,000 tons imported in 1976) mainly through increased recycling (in 1976, only 35% of copper products were recycled as opposed to 61% in the US).

- To recycle 2,300,000 tons of paper a year by 1980 as compared to 1,800,000 in 1975.

- To reuse 600,000 tons of glass a year by 1980 compared to only 115,000 tons in 1975, through recovery of 100 million glass bottles.

- To recycle 25,000 tons of PVC a year by 1980 and 40,000 tons by 1983 compared to 400 tons in 1976, again through recovery of bottles.

- To use municipal wastes from 10 million inhabitants (18% of the population).

The energy savings resulting from reduced consumption or increased recycling of materials are limited if expressed in percentage of total consumption, but not so much in dollar value. Recycling copper or aluminum means 5 to 10% savings in energy consumption for processing, recycling iron scrap for steel production reduces energy consumption from 4,720 kWh/ton of steel to 1,660 kWh. The objective of glass recycling for 1980 should result in a fuel economy of 120,000 tons of oil equivalent per year and that of PVC recycling in an economy of 60,000 tons of oil equivalent in 1983 (a total of 70 MF at the present price of oil).

To promote increased recovery and recycling, the Délégation pour les Economies de Matières Premières has helped finance a few pilot plants (recovery of copper used for cables for example or the sorting out of metals, paper, glass, textiles in municipal wastes) and research in areas such as reuse of copper with impurities. Also the Délégation has been conducting comparative studies of the use of various materials for a few products such as packaging of bottles (cardboard and plastic) and car bodies (aluminum, steel and plastic). The results of those detailed studies will be presented.

In the sector of transportation particularly, any weight reduction leads to decreased energy consumption during the lifetime of the vehicle. So light materials and alloys deserve special consideration, and are being given much attention in France for use in cars, and rapid trains.

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FRACTURE LIMITATIONS TO MINING

K. BURNS and V. WEISS
Syracuse University

The recoverability of known coal reserves is sometimes limited by the occurrence of roof failures. These collapses make coal mining hazardous and in some places completely uneconomic. To improve the recovery rate in these areas, it is necessary to determine the mechanisms responsible for these roof collapses to permit the development of methods for early prediction of the conditions ahead of the mine face and the development of alternative mining methods to circumvent or to control the problem. The magnitude of the problem is illustrated by the South Maitland Coal Field in New South Wales, Australia, where approximately 70% of the known resource (10^9 tonnes) is irrecoverable with present mining technology and operations on the field are terminating.

The cause for these instabilities are pre-existing systems of cracks that penetrate the coal seam. This leads to uncontrollable roof failures or catastrophic face collapses. Statistical analyses of the phenomena show that the mining problem is connected with the presence of only particular kinds of fractures, i.e. those showing oblique slip movements on the fracture faces.

This, then, represents a problem of fracture mechanics of inhomogeneous geological materials. Recent advances in fracture mechanics research may well be able to point towards methods for prediction and control. Moreover, adaptation of non-destructive testing techniques commonly used in quality control and failure analysis, such as e.g. crack detection and residual stress measurements, may also be useful towards the solution of the problem where mining is fracture limited.

"Cost" Assessment Methodology in the Primary Mineral Industry

By

Iraj Zandi
University of Pennsylvania
&
S. David Hu
TRW Energy Systems Group

Introduction: This paper presents an analytical assessment tool which allows 1) the quantification of the "cost"/benefit associated with various technological-managerial energy saving options in a given primary mineral industry and 2) the estimation of the cost/benefit to the industry where government alters its environmental, resources, and/or tax policies. "Cost" in the context of this paper implies a broader meaning than dollar cost alone. It represents dollar cost as well as all physical costs.

Methodology - The methodology combines the econometrics of a target mineral industry with a resource assessment model (resoumetrics). Resoumetric is basically a process oriented book keeping methodology which keeps track of "costs" within a given industry. It is unique in the sense that it considers each plant individually. Information about every single mine, mill, smelter and refinery in the industry, and business structure of each company is woven into the model. At the present time we have constructed the model for copper.

The methodology assesses the implication of policy alteration by computing quantities which characterize the performance of the industry "before" and "after" the change. These quantities are identified in terms of supplies, cost, prices, material, energy requirements, water needs, and environmental changes. Governmental policies impact the assessment through input parameters to both econometric and resoumetric. For example, taxes, depletion allowance, or environmental standards are input to resoumetric and any changes in their values reflects in the operational pattern of the companies involved.

Initially, the econometric model generates information about market prices, demand, supply, and generation of scrap of various copper products for the entire industry. Secondly, a historical average profit in percentages is estimated for each company based on published or other available financial information. The differences between the prices and this profit establish the first approximation of the products' cost for each company. Thirdly, the cost function for each company developed in the resoumetric model is used to estimate the quantity of production for each company at the calculated cost level. The sum of these productions, estimated in the above manner for all of the companies active in the industry, should be about equal to the production level estimated by the econometric model. If there is an unacceptable level of discrepancy, a systematic adjustment of profit levels must be made to bring these two quantities close to one another. Finally, production functions developed in the resoumetric model are used to estimate the amount of energy needed by each company. The summation of this estimated energy yields the total energy need in the industry. This is the quantity that governmental policy attempts to reduce.

Since most energy conservation measures will increase the cost of pro= duction, it may be convincingly argued that the Government will only successfully administer this policy if it somehow compensates the industry for any additional costs incurred by energy conservation. Some alternative Governmental actions that can be used for this purpose are: 1) additional percentage depletion allowance, 2) corporation income tax rebate or tax rebate or tax amortization for the installation of energy saving devices, and 3) subsidies or aids in the form of governmental contracts and floor price purchase agreements, etc. The problem is then estimating the degree of change of these policies that would produce benefit to companies equivalent to the cost of the desired energy conservation.

Using the resoumetric model, we can input a certain percentage of tax reduction, for example, and calculate the credit that would result for each company. Also, through the resoumetric model, we can calculate the amount of energy saved through the expenditure of this tax credit by each company on energy conserving equipment. The sum of these energy savings for all the companies active in the industry can be calculated and compared with the desired level of conservation. If this does not meet the desired goal, the size of the tax incentive will be reassessed and the calculation will be repeated until an acceptable overall energy saving is achieved.

In general, such an iterative procedure can be used to quantitatively estimate the level of changes required for each Governmental policy option (some of which are enumerated above) to produce the desired energy savings. In the real world, however, the best decision normally will not be associated with change in a single option. Very likely the most desired action will be a composite of various measures. The problem of determing the combination of these measures which will satisfy the interest of the decision maker while producing the desired level of energy conservation in the given industry remains. This is accomplished through hierarchical analysis.

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WORKSHOP 2

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE ENERGY EFFICIENT BUILDINGS

CHAIRMAN: L. W. MASTERS (U.S.)

ORGANIZER: ELIO PASSAGLIA (U.S.)

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Materials Science and Technology for More Energy Efficient Buildings

The Building Envelope

DONALD E. HIPCHEN
(Jim Walter Research Corp.)

The materials used in the building envelope - walls, roofs, floors - constitute an important opportunity for achieving more efficient use of energy. A substantial portion of all energy consumed is used to control the climate in buildings. The materials used in the building envelope are vitally important to energy efficiency because of how well or poorly they resist the passage of heat. The materials which are presently in predominant use can be categorized as wood, mineral, bituminous, metallic or synthetic in nature. They have been selected primarily for reasons of strength, durability and cost with minimal concern for their resistance to the passage of heat, or energy efficiency. Insulation in buildings is a relatively new innovation achieving only significant use since the mid twentieth century. The predominant materials in use in building envelopes are poor in resistance to thermal transfer. However, the insulating products developed in modern times offer high resistance to the passage of heat. Historically, construction materials evolve and change slowly. It is reasonable to assume that man must continue to depend upon available materials, supplemented by a modest number of improved materials, for many years to come in providing his shelter. From the standpoint of materials used in the building envelope, in order to achieve more energy efficient shelter, it will be the task of the construction industry, government and scientific and technical communities to incorporate existing and new materials into more energy efficient building systems with emphasis on greater use of already available insulating materials. New construction must employ new systems. Yet systems must also be developed to retrofit virtually all structures which have been produced up to the present time - a time when energy was abundant and inexpensive. This will be a complex and difficult task. It goes well beyond the selection of materials and systems by the engineer, architect and builder. Government must contribute by fostering higher standards for every efficiency coupled with reasonable regulation of combustibility and environmental impact. Testing technology - how we measure energy efficiency of materials and building systems - must be advanced substantially. Tradeoffs will have to be considered - cost vs. efficiency, efficiency vs. combustibility, efficiency vs. durability and cost, etc. Lastly, the materials considerations of the building envelope must be integrated with other factors which will affect the energy efficiency of buildings - cost of energy vs. time, type and configuration of structures, heating and cooling systems, etc.

Results of a Study of Cellulosic Insulations*

D. L. McELROY and W. W. HARRIS
(Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830)

D. W. YARBROUGH
(Tennessee Technological University, Cookeville, Tennessee 38501)

Commercially available cellulosic insulations consist of macerated newsprint with 15 to 35 wt % chemical added to meet fire and safety specifications. Because this insulation has good thermal resistance properties, and is inexpensive, it is widely used in retrofit installations for attics and walls. There are about 700 producers in the U.S., few of which have R&D laboratories. Material specifications for this insulation have been changing, and published property data are limited.

To improve our knowledge and strengthen the data base supporting specifications, DOE, in 1978, initiated a study of commercially available cellulosic insulations that involved contributions from eight organizations. The study has yielded results on most of the properties appearing in the product specifications. Data were obtained using 51 samples procured by the Consumer Products Safety Commission (CPSC) as duplicates for use at ORNL and the CPSC Engineering Laboratory. The study included about 30 additional samples tested by others for certain properties.

The Settled Density governs coverage. Results for this property obtained using a simple blower/cyclone/shaker technique were within 6% of values by the National Research Council of Canada, using a 28-day temperature/humidity cycle test called for in current GSA specifications. Using the B/C/S technique, the 51 CPSC samples showed an average settled to blown density ratio of 1.38. Subsequent tests were done at the measured settled density.

Radiant panel tests by CPSC show that 37 of the 51 samples (73%) passed the Critical Radiant Heat Flux test by showing no evidence of flaming, and exceeded a CRHF of 0.12 w/cm^2.

*Research sponsored by the Division of Building and Community Systems, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

The Smolder Combustibility test uses 8" × 8" × 4" cans of insulation, conditioned at 23 C and 50% relative humidity. The insulation materials were tested by igniting a cigarette that was inserted vertically in the insulation. A failure is defined as evidence of flaming or weight loss of more than 15%. Only 14 of the 51 samples (27%) passed the smolder test. The cellulosic insulations that passed the smolder test had passed the CRHF test.

A test of Corrosiveness involved exposure of Al, Cu, and steel coupons to wet cellulosic insulations for periods of 7 and 14 days. For the set of 51 samples, 28 (55%) passed the 7 day test and 8 (16%) passed the 14 day test.

Both insulation and light fixture producers caution consumers not to cover Recessed Light Fixtures with any type insulation. Field data, however, show clearance violations in many houses. Laboratory tests on attic mock-ups employing nine fixture types showed temperatures above 200 C when fixtures are overpowered and covered with cellulosic insulation.

Observations resulting from the study include:

- Strengthening of the data base for cellulosic insulations is needed.
  — What would encourage such efforts?

- A significant fraction of the cellulosic insulations tested failed to meet three important criteria in the current specifications. Only 3 of the 51 samples passed on three tests.
  — Is the specification too rigid or the product inadequate?

- Excessive operating temperatures were observed when cellulosic insulation was misapplied around recessed light fixtures.
  — How can this problem be avoided?

Wood Construction for Energy Efficiency

R. L. YOUNGS
(U.S. Department of Agriculture, Forest Service
Forest Products Laboratory, Madison, Wisconsin)

The prevailing American housing technology is light-frame wood construction. As used in buildings, wood is largely a natural product rather than a man-made material. Its applications in energy-efficient construction will have to be based on a better understanding of its in-service performance rather than on the modification of its properties by industrial processes.

Common construction assemblies contain materials of widely differing properties. The performance of such assemblies is determined by interactions between a variety of load and response factors. Study of the thermal performance of materials is inseparable from that of assemblies and entire buildings. Construction and design must be integrated for the most advantageous yearly balance between heat losses to the ambient environment, and heat gains from the sun as an alternate energy source.

Wood systems lend themselves to modifications in design to take advantage of passive solar concepts. However, these modifications are not commonly recognized. Further work is needed to better define the advantages of passive solar design in wood construction and to make such concepts available to the design profession.

Traditional passive solar design concepts have stressed the use of large physical mass for thermal storage and temperature stabilization. Observations of wood-frame structures, on the other hand, suggest that they are performing better than would be predicted by traditional analytical approaches. New design criteria must be developed to allow more reliable prediction of the response of a wood building to a passive solar design environment for different construction types in different climate zones, and under lived-in conditions. Further field studies must cover energy usage and temperature variations to permit formulation of the needed criteria.

Considerations of thermal performance are inseparable from those of moisture control. Reduced air leakage rates in better-built homes have led to the possibility of increased indoor relative humidity levels without added humidification, and to an increased hazard of damage from concealed moisture condensation in walls and roofs. For control of visible condensation on glass, builders are beginning to advocate elimination of the ceiling vapor barrier to permit moisture movement into the attic. The validity of such practices, however, will have to be decided on a regional basis. Studies are needed that determine the moisture content in these cavities while exploring the interactions between indoor relative humidity levels, outdoor weather conditions, free water accumulation, and vapor barrier placement in various construction types.

While it is well known that light-frame wood technology allows construction of highly energy-efficient buildings, research is needed to better understand the interactions between different performance aspects.

Materials Science and Technology For More Energy-Efficient Building Systems

GERALD C. GROFF
(Director, Research Laboratories)
(Carrier Corporation, Research Division)

To examine the opportunities for energy efficiency improvements in the various systems which are used to heat, cool, light and provide other necessary services in residential and commercial buildings, it is helpful to categorize these systems in terms of function: energy transport, energy conversion, and energy use.

In this manner, subsystems and components used to transport electricity, heat, light and fluids can be segregated and examined. Similarly, equipment and devices used to convert energy from one form to another and to provide the end use energy application can be identified. With the myriad of energy use functions which may be found in most buildings, it would seem that the suggested breakdown would lead to an extensive list of potential energy efficiency improvements and opportunities for materials science and technology contributions. While this is undoubtedly the case, it will better serve our immediate purpose to distill from such a list certain generalized observations.

If we look at the systems and equipment involved in transport of electricity throughout a building, and the various motors and lights which are served by the electrical energy, the opportunities for efficiency improvement lie, primarily, in reducing resistive and reactive losses in the electrical systems and devices. There are ample opportunities for development of better conductors and motors and lighting components. These are well known and deserve little further comment here. It may be more appropriate to focus on the utilization aspects of these systems, instead.

Motors, for example, use significant amounts of energy in large buildings in the operation of pumps, compressors, fans, elevators, and business machines. Significant reductions in energy use can be achieved through the development of higher efficiency motor designs and more efficient applications. There are great opportunities for new materials and materials applications to reduce mechanical losses from friction and wear through improved bearings, seals, gears and lubricants. Also, flow losses found in fans, pumps and compressors can be reduced through improved designs of flow passages. Materials and processes which permit incorporation of these improved designs are required.

The very great opportunity available for energy savings resulting from improved overall design and operation of the major electrical, mechanical and space conditioning systems in buildings has been purposely omitted in this discussion, since this has only indirect implication on opportunities for materials research contributions. Thus, if we reduce the quantity of air or water circulated in our systems, or reduce heating equipment operating time by use of night set-back, or reduce lighting levels, we can conserve considerable energy without need for particular materials advances for the system components. It is important, in this area to reconsider carefully what the functional objectives are for the system itself.

Two specific areas for materials research and development offer great potential for improving energy efficiency. First, the development of materials for heat exchangers which will be cost-effective and reliable in corrosive fluid environments, such as for handling condensing flue gases in high efficiency combustion heating equipment, and for heat recovery from cooling towers and other wet or corrosive exhaust streams. The other area is in development of high heat capacity materials suitable for use in thermal storage and transport of heat and cold. While thermal storage is of considerable interest with solar and other non-conventional systems, such materials may also offer highly significant energy savings opportunities with conventional building space conditioning systems, and may be of particular value in reducing peak energy demands on the power companies.

In the areas noted here, and in many other areas of building systems and components, there are excellent opportunities for application of advanced materials technology. A structured approach to the examination of energy usage and losses in the various building systems may help identify areas and establish priorities for development and application of advanced materials technology. However, basic systems functions must first be defined and operating control options must be considered.

Integrated Systems for House Heating

RUTGER A ROSEEN
(Studsvik Energiteknik AB, Sweden)

We have to utilize our energy sources more efficiently. By increased use of low temperature heat we can save an enormous amount. If the house is designed for a low temperature heating system low grade waste heat from industries and power plants, solar energy, heat pumps and low grade geothermal energy could be used. In our surroundings there is more low temperature heat than the society's total heating need. But the problem is to utilize this energy in an economical fashion, because the supply is often out-of-phase with demand and at a distance from it.

In Europe low temperature heat is used in district heating schemes, where hot water is distributed to houses by buried insulated pipe systems.

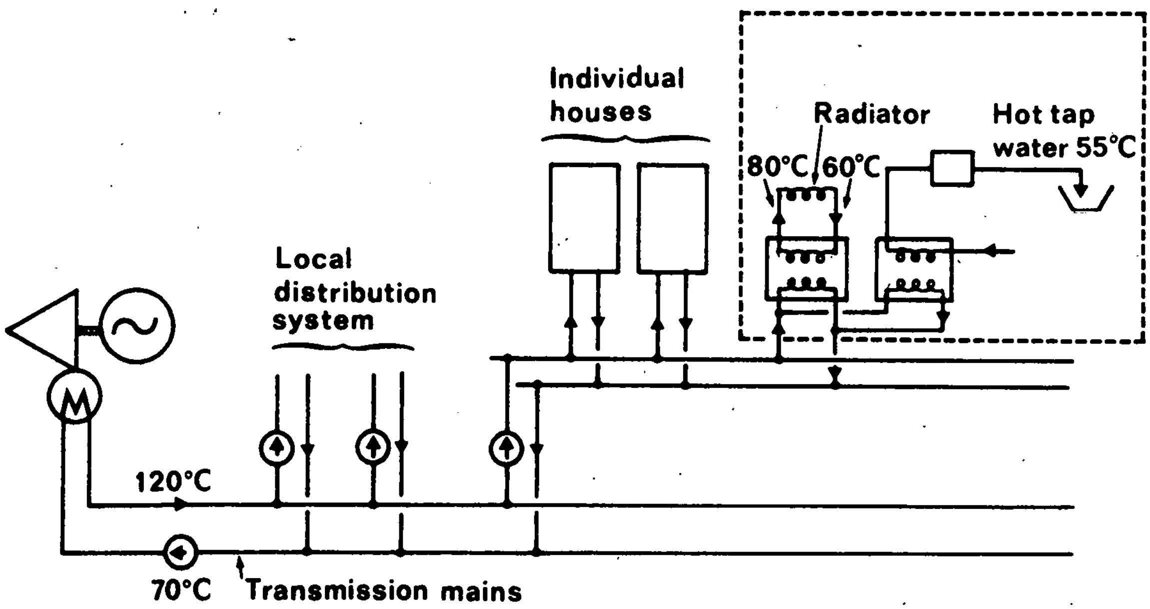

Fig 1. Conventional district heating scheme.

Unfortunately the system is designed for a high primary temperature, 120°C, which is too high for the use of low grade heat. In each house there is an heat exchanger which lowers the temperature in the radiator system to 80°C with a 60°C return.

If we instead design a scheme for lower temperatures it is possible to utilize a combined system for both heating and tap hot water at 50-65°C.

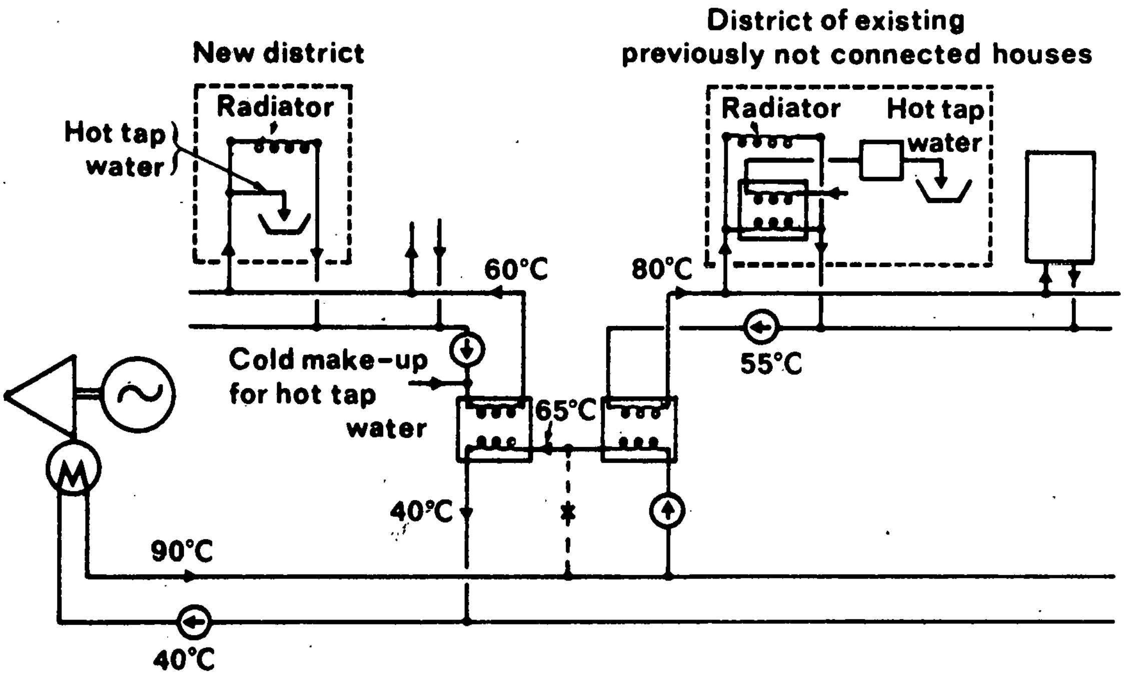

Fig 2. Low temperature heating system.

In this scheme we can utilize lower temperatures and save the expense of the heat exchanger and boiler. However, we have to increase the pipe diameter which will increase the cost if the same pipeline system is used. The challenge is to find better materials and techniques in order to lower the investment cost in the distribution system.

The characteristics of the materials in the pipelines are:

- Strength and toughness.
- Corrosion resistance, no need for corrosion protection.
- Flexibility in small dimensions, easy to coil and possible to use without fixed bends.

- Low weight, easy to install.
- Low volume price.

The normal pipes of steel suffer from bad corrosion resistance and cannot be used in integrated systems. Copper- and stainless steel pipes are too expensive. The lower temperatures open the field for plastics pipes, which could satisfy the demand but there are also some problems to be solved.

- The complex interaction of temperature, time and environment with respect to 50 years life.
- Large initial deformation and creep.
- Need for reliable antioxidant additives.
- Permeability of oxygen, which makes it necessary to use corrosion resistant components even in closed systems.

There are possible materials under test in our laboratories at STUDSVIK; cross linked polyethylene, fiberreinforced plastic, polybutene etc. The work has been in progress since 1974 and the results are very good. The introduction of plastic pipes insulated with loose PUR-blocks will lower the total installation cost with 40% compared to normal pipelines.

We can use this new distribution system in connection with industrial waste heat, reject heat from cogeneration and large heat pumps, but what about solar energy? The problem is to store heat from summer to winter at least in the northern part of Europe and America. This can be performed by a chemical store, an aquifer or a pit type hot water magazine. For the time being pit magazines seem to be the cheapest and most flexible solution.

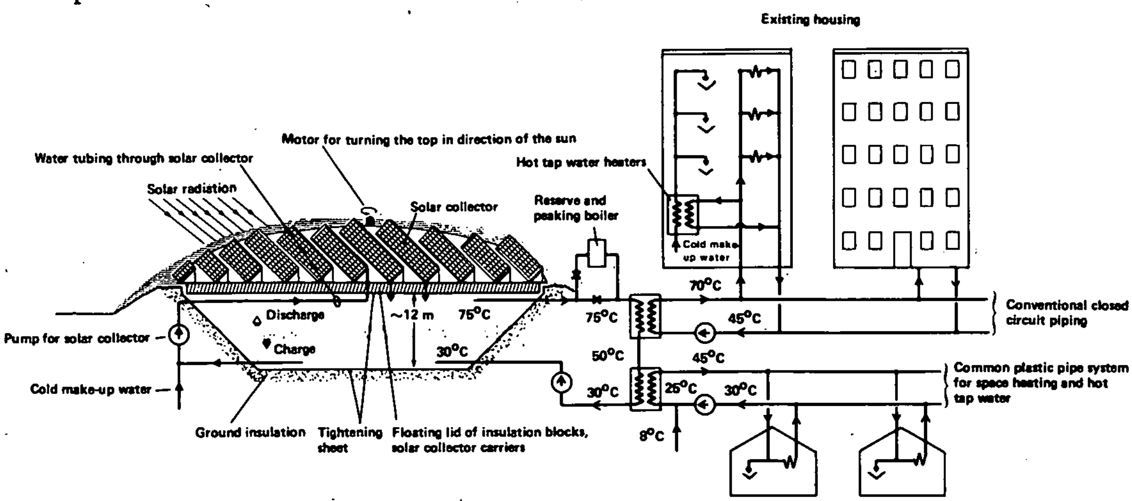

Fig 3. Central solar heating plant.

The excavated pit is thermally insulated and covered with a membrane. The lid floats on the top of the water and the solar collectors are integrated into or placed onto the insulation which rotates and follows the sun in order to increase the efficiency of the solar collectors. A central solar heating plant is in operation in STUDSVIK.

In order to increase the thermal capacity a heat pump could be introduced.

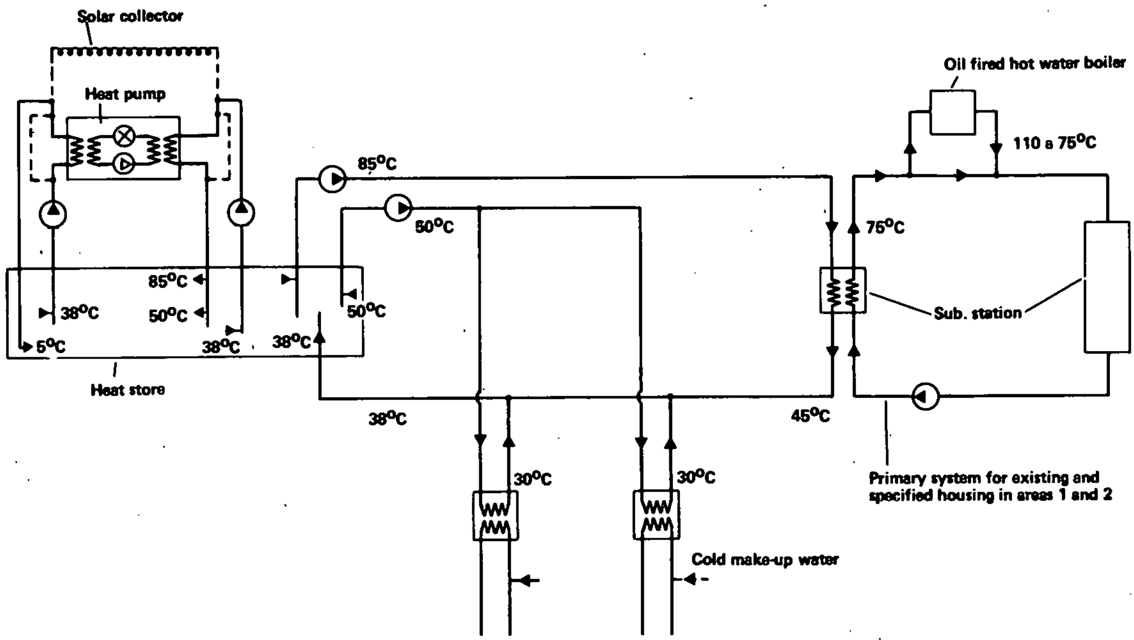

Fig 4. Central solar heating station with heat pump.

The material challenge is to find a good thermal insulater, which could resist high hydrostatic pressure and humidity. The membrane must be chemically and mechanically intact 20-50 years at 95^{o}C. The water permeability must be low and the ductility good enough to take up the ground movements.

An even larger material challenge is the lake magazine, where we dont have to excavate the pit.

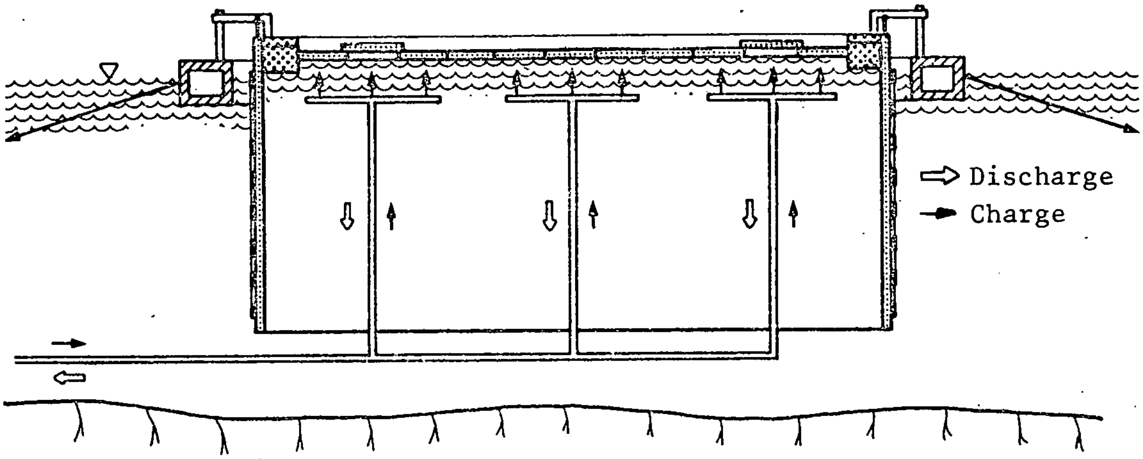

Fig 5. Lake magazine.

The examples I have given indicate that there is a very large material challenge in the energy saving integrated systems. By introducing lower temperatures, cheaper and more economical materials like plastic and composites giving cheaper system solutions can be used, but lot of research is necessary before the long life reliability is high enough. However, the work is in progress.

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Improvements to U.K. Housing Stock

RAYNER M. MAYER
(Temporary address: Cavendish Laboratory,
University of Cambridge)

There are c. 19 million houses in Britain, which consume for space heating during the winter about 20% of the total primary energy requirement. With the present building regulations for a standard house (3-bedroomed, semidetached) the heat loss has been estimated by Heap (1978) to be 6.2 kW for a temperature difference of 20K. This could readily be reduced to 3 kW by fitting of additional insulation and reducing the ventilation.

Improvements to the existing housing stock fall into two categories: (a) economic at current energy prices, (b) economic at some future time when energy prices have risen. For the latter, Fisk (1976) has argued on economic grounds (and this could be extended to include social) that it is important not to foreclose options, which might be required in the future, e.g. installation of sufficient insulation where access to the loft is not possible.

Since the mean lifetime of a house in the U.K. is c. 100 years, the greatest saving of energy per house could be made by suitable retro-fitting of the oldest housing stock as these are renovated. It is important to attempt to optimise the following energy saving measures of these houses because of the large number involved: (a) insulation of the solid walls - for which condensation is a problem if an inner skin is fitted and wear if an outer skin is added, (b) reduction of the ventilation due to wear to sash windows and normal subsidence and shrinkage. Whether these renovations should be adopted depends upon the assessment of the future energy situation.

For newer houses with cavity walls, filling of the cavity with a suitable plastic foam (such as urea formaldehyde) does improve the thermal insulation but can lead to water penetration in areas where prolonged periods of driving rain are encountered.

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ENERGY CONTENT OF CONSTRUCTION MATERIALS

ANGELA M.T. SOUZA

In the areas of civil construction, efforts have been made in order to make the buildings more efficient in respect to the energy necessary to their operation (illumination, cooling, heating, etc.). There is, however, an indirect energy consumption in buildings, represented by the energy used in the production of the construction materials, which has not been studied or quantified, and which represents a considerable energy consumption.

In this work, the most important materials normally used in civil construction in Brazil were analysed on the grounds of the energy required in their fabrication processes. This allowed the assessment of the total indirect energy consumption of a building (taken as an example), and to analyse the influence of the materials selection on its energy content. The data obtained are a further criterion to be adopted by the construction designers to make the construction more energy efficient. This can be accomplished by selecting the materials not only by their price and quality, but also avoiding the use of those which would result in a bigger energy consumption.

The energy sources used in the fabrication process were identified and quantified, and energetic indexes (energy contained in a unit weight of the material) were determined. These indexes vary from low values like 1.0 kcal/kg for gypsum plates, to values like 24,000 kcal/kg, as in the case of aluminum.

From these energetic indexes, the energy content of the materials (energy contained in one cubic meter) was determined and the contents of several materials of similar application were compared. Tables 1 to 4 show comparisons among several types of roofs, floors, coverings and walls, where it can be seen that a material with the smallest energetic index is not always the one with the smallest energy content.

Finally, the total energy content of the house shown in Figure 1 was calculated for the two alternatives indicated in the figure. The total energy contents resulted in, respectively, 49.5×10^6 kcal and 24.0×10^6 kcal. The difference corresponds to 28,000 kWh or to 2.7 metric tons of petroleum, due mainly to the substitution of ceramic bricks by concrete bricks (22.5×10^6 kcal).

A better view of the difference can be obtained by noticing that, if population of Brazil were grouped in families of 6 to 7 persons, 18,500,000 houses of this size would be necessary. If these houses were constructed, the energy contained in all petroleum consumed in Brazil in one year (50 x 10^6t) would be spent to cover the difference between the energy content of the two types of houses.

TABLE 1

COMPARISON AMONG DIFFERENT TYPES OF COVERINGS

Material	Energetic Index (kcal/kg)	Energy Content (kcal/m^2)
Ceramic covering	589	25,735
Tile	2,573	28,036

TABLE 2

COMPARISON AMONG DIFFERENT TYPES OF FLOORS

Material	Energetic Index (kcal/kg)	Energy Content (kcal/m^2)
Ceramic	589	32,970
Glass	5,641	250,443
Marble	345	25,888
PVC (Vulcan)	148	564

TABLE 3

COMPARISON AMONG DIFFERENT TYPES OF ROOF TILES

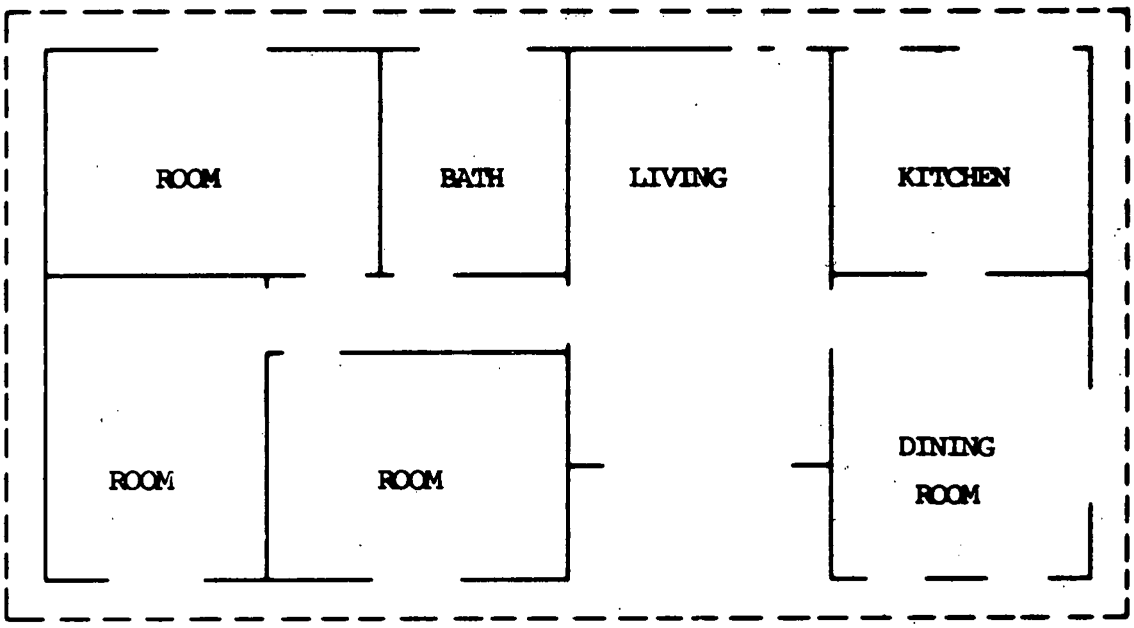
Material	Energetic Index (kcal/kg)	Energy Content ($kcal/m^2$)
Glass	5,595	131,493
Ceramic	735	22,877
Asbestos cement	940	12,373

TABLE 4

COMPARISON AMONG DIFFERENT TYPES OF WALLS

Material	Energetic Index (kcal/kg)	Energy Content ($kcal/m^2$)
Dividers	5,000	50,650
Ceramic air brick	752	203,130
Concrete air brick	103	18,638

HOUSE USED FOR TOTAL ENERGY CONTENT COMPARISON



		FIRST TYPE	SECOND TYPE
Bricks		Ceramic	Concrete
Roof Tiles		Ceramic	Asbestos cement
Covering	Bathroom	Tile	Ceramic
	Dining room	Tile	Ceramic
	Kitchen	Tile	Ceramic
	Living room	Ceramic	Paint
	Rooms	Paint	Paint
Floors	Bathroom	Ceramic	PVC (Vulcan)
	Kitchen	Ceramic	PVC (Vulcan)
	Dining room	Ceramic	PVC (Vulcan)
	Others	Parquet	Parquet

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WORKSHOP 3

MATERIALS SCIENCE AND TECHNOLOGY FOR NEW ENERGY SOURCES AND MORE EFFICIENT ENERGY CONVERSION--FOSSIL FUELS, GEOTHERMAL, AND SOLAR

CHAIRMAN: ROBERT I. JAFFEE (U.S.)

ORGANIZER: ROBERT I. JAFFEE (U.S.)

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Interpretation of Failure Statistics to Improve Weak Areas in Power Plants

Dr. L. HAGN
"Allianz Zentrum für Technik GmbH"

Summary:
The increase of reliability of power plants is the foundation of the economical calculations for the electricity supply industry (utility). Since the world of modern technics has come to the point where we are harshly reminded of the limits of our natural resources the efforts to improve the energy output of existing power plants have to be intensified.

For the individual power plant, it seems to be rather simple for the staff to oversee and detect the weak components because of the daily experience within the plant. Thus the failure free operation of these parts can be increased due to regular maintenance and inspections and thus as a last resort the strain on the material can be reduced. On the other side, in order to replace a failed component with an improved construction, the manufacturer can utilize the experience which he has gained by examining faulty operation and causes of damages of his own products /11, 14/. He should make use of approved construction possibilities and materials which are on the present state of the technique.

For the future changes and new construction methods within fossil operated power plants, one prerequisite is the compiled statistics of the damages of the past in order to get new impulses /8/. Besides technical associations of users /7, 3/ and the public inspection authorities /12/, large insurance companies, which insure technical plants, have detailed and neutral failure and reliability statistics derived from an heterogeneous collection of a great number of damages from almost all branches of technology and manufacturers. For purposefully applied loss prevention measures and improvements these statistics should give information about weak areas within the plants, name the components which have the most damages and the causes of failures.

Thus for e.g. the statistic of the Edision Electric Institute /4/ published 1973, gives the general view that the higher the energy output of a plant the more the operational reliability will be decreased. Main reasons for downtime within the power stations can be attributed to failures in the steam generators, followed by the steam turbines and condensers. This tendency remains the same even if the energy output of the plants is increased, but then in addition other weak points like the electrical generator become important.

In the latest detailed statistics /1/, written by one of the largest technical insurance companies in Europe – 16 ooo failures compiled within the years 1969 to 1974 – the causes which technical installations are endangered are subdivided into three main groups: product faults, operational and handling faults and external influences. They show the steps that can be taken to avoid future mistakes.

The general view of constructions and the detailed failure statistics of the single components within the power plants give the information that product faults occur the most with steam boilers and fluid-flow machines /1, 9/. Operational faults follow on the second place. The product faults include errors in planning and design, incorrect use of materials, processing faults and faulty materials. Faulty materials occur approximately 3 to 1o % of the time.

Operational and handling faults, which occur the most within condensers include loosening parts, failure or non-response of protective devices, serving faults and damages arising from wear, corrosion, erosion and ageing.

Going back the path of statistics to the real reasons for failures and taking into account the frequency the same failure occurs in one component, is the logical way to come to solutions for reliable constructions. Therefore it is important that the statistics are made available for the public, especially for the manufacturers and that these are openly discussed by the experts at technical conferences.

Because of the different evaluation concerning the causes of damages, changes should be made within planning and design, production and choice of material as well as operating procedures. Some examples will be mentioned: damping of turbine blading by connections /2/; installation of fitting impact, guide and separation plates on the steam side of LP- and HP-preheaters /5/; proper feedwater conditioning and steam quality control /11, 13/; combined oxygen/ammonia conditioning of water-steam circulation systems in power plants with once-through boilers /6/; accomodation of the condenser tubing material to the cooling water chemistry /1/; use of materials for turbine blades resistant to pitting corrosion.

In spite of all possible improvements, it will be necessary in the future to continously watch over and regularly check the components within the plants in order to increase the operational life span of the power plants. The aim is to increase the scheduled part of the non-availability in order to reduce the forced outages of a plant.

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How can current plant performance and reliability be improved through better materials and processes?

J. BARFORD, D. B. MEADOWCROFT
Central Electricity Research Laboratories,
Central Electricity Generating Board,
U.K.

Electric power utilities are frequently criticised for the thermal efficiency levels commonly attained with conventional plant. The top ten most efficient stations listed for 1977 by "Combustion" showed nine to have higher operating pressures than those often regarded as "standard", i.e. about 165 bar/565/566°C, but none had higher temperatures. Despite these figures, it is noticeable that in the last few years over 70% of plant orders in the U.S.A. have been for standard or lower steam conditions. Presumably this came about because of the relatively poor availability of plant with advanced steam conditions. However, it is not immediately obvious if this is due to shortcomings in materials behaviour or a lack of flexibility arising from design reasons. I note that U.S. data published by EPRI for units in the range 200 to 500MW shows forced outages with once-through boiler, whether super or sub-critical, to be about twice those for drum boilers.

It is difficult to judge these figures in the absence of operational data on the degree of two-shifting or part load operation which can often lead to abnormal temperature excursions, etc. However, a recent C.E.G.B. Research Division exercise indicated no fundamental difficulty in materials behaviour to prevent a modest uprating, say to 165 bar/595°C or, perhaps more attractively, to 240 bar/565°C to give efficiency increases up to about 0.7 percentage points. I should be interested to hear delegates' views.

In the longer term, further increases in fossil fuel efficiency, together with reducing emissions, indicate the use of coal gasification/combined cycle. This should have a greater potential for future development than pressurised fluidised bed with its limited combustion temperature. However, there are a number of fundamental system and materials problems to answer and the following examples illustrate some points on which comments would be appreciated.

1. For entrained bed gasifiers there will be a materials limitation as the required operating temperature of the heat exchanger is increased, but what efficiency and cost penalty is involved in using steam generating tubes instead to extract the heat from the hot gas? This will be an easier materials requirement to satisfy.

2. How clean can the gas be economically made, both in terms of chemical impurities (e.g. Na,K and Va salts could be increased by some sulphur clean-up systems) and particulates. Erosion/corrosion in the gas turbine must be avoided so gas cleanliness defines what blade metal temperatures and materials can be considered.

3. Are worthwhile efficiency gains necessarily achieved by increasing the inlet temperature to the turbine of a gasifier/combined cycle system? The novel blade systems under development will require extensive effort to be successful and in addition to the fabrication problems there will be several life-limiting difficulties. Prime amongst these are the thermo-mechanical interactions arising from the severe temperature gradients (particularly for two-shifting use), and deposition/erosion.

In summary how soon can a compromise be reached between system design and material requirements to define the most effective system likeliest to be successfully developed within, say, 10 years?

Will Materials Be A Barrier To The Design, Construction, And Operation Of Plants For The Conversion Of Coal To Clean Fuels

W. T. BAKKER
(U.S. Department of Energy)

Conversion of coal can only be considered successful when the coal derived fuels can compete economically with other fuels, suitable for the same application. This is not so at present. One cannot rely on the increase in price of oil derived fuels alone to make coal derived fuels competitive in the future. Thus, technology must be developed to reduce the production costs of coal derived fuels. Some of the goals of such a development project are:

- o Improve coal conversion efficiency
- o Reduce capital costs
- o Reduce operating costs
- o Maximize plant availability

Materials technology is necessary to achieve these goals. Processes considered thermally more efficient quite often also require more severe operating conditions. For instance, production of synthetic natural gas (SNG), using the flash hydropyrolysis process requires a very high mass flow of particulates and corrosive gases at a temperature above 1900°F and a pressure of 1500 psi. Materials engineering will be critical here and the application of corrosion/erosion resistant coatings may be needed. Similarly, the economics of advanced liquefaction process using $ZnCl_2$ as a catalyst, in which coal is directly converted into gasoline, is critically dependent on the almost complete recovery of the catalyst. This occurs in a high temperature recuperator, experiencing severe corrosion. Again materials technology must come to the rescue.

Materials technology can help reduce the capital cost of coal conversion processes in several ways. Examples are:

- o Development of less expensive materials. An example is the development of a Fe-Cr-Al-Hf cladding material for gasifier internals which has the same or better corrosion resistance as an existing 50Cr-50Ni alloy.

- o Aid construction of large size process equipment. For instance pressure vessel technology developed in the nuclear field can be applied in coal conversion to build larger reactor vessels and thus reduce the number of process trains.

- Improve fabrication technology. At present field fabrication of large pressure vessels requires manual welding. DOE now sponsors a program to develop automated field welding techniques, which will decrease construction time significantly and also improve weld quality.

- Reduce component redundancy. In each plant, fast wearing components must be duplicated or even triplicated to avoid plant outages. Development of better materials systems can reduce redundancy requirements and thus lower capital costs. Examples are the development of more wear-resistant valve seats and pump liners.

Materials technology can probably make its highest contribution to the economical success of coal conversion through the reduction of operating costs and improvement of plant availability. Projected selling prices of coal derived fuels are generally based on a 90 percent availability, generally achieved in relatively mature processes, such as catalytic cracking of crude oil. This cannot be taken for granted in emerging technologies. It has been shown that the cost of coal derived fuels increases about 18 percent for each 10 percent decrease in plant availability. Thus, cost of SNG from a plant, designed to produce SNG for $3.50/1000 cft at 90 percent availability, will rise to $4.80 if the total downtime is 30 percent instead of the assumed 10 percent. Materials and equipment breakdowns are major contributors to forced plant outages. Thus, the rigorous application of the latest materials technology during all stages of plant design, construction and maintenance is an absolute necessity. In addition, a strong supporting materials R&D program must be carried out to provide the required materials performance data needed for design purposes to develop materials specifications and to develop new materials or upgrade existing materials for those applications, where this is economically advantageous. DOE, EPRI and GRI are presently engaged in such a program. Major activities are:

- Evaluation of existing materials in critical applications such as gasifier internals, refractories and valves in the SNG gasification area, and letdown valves, slurry pumps and pressure vessels in the liquefaction area.

- Development of fabrication technology for pressure vessels and piping, such as narrow groove field welding techniques for extra thick vessel walls.

- Development of new materials for critical areas, e.g., high temperature corrosion resistant coatings and claddings, valve trim, pressure vessel steels and abrasion/erosion resistant steels.

- Exposure of materials in pilot plants and analysis of failed components.

In this manner, a materials data base for the emerging coal conversion technology is generated already during the pilot plant stages of the various processes. This data base will provide invaluable input to the design of future commercial plants. Thus, reliability will be designed into the plants to assure minimum downtime.

In summary, materials are not considered a barrier for the development of coal conversion systems. On the contrary, the systematic application of materials technology during all stages of coal conversion plant design, construction and maintenance is expected to be a key requirement to assure the future economic success of the production of clean fuels from coal.

MATERIALS FOR COMBINED-CYCLE POWER PLANT

Bernhard Ilschner
Institut fuer Werkstoffwissenschaften,
Universitaet Erlangen-Nuernberg,
Federal Republic of Germany

1. General Situation, Comparison with other Gas Turbines

The term "Combined Cycle Power Plant" (CCPP) describes a combination based on a gas turbine, the exhaust heat of which is used to generate steam which, in turn, is the propellant for a steam turbine, and is in some cases even further used for industrial or home heating. The obvious advantage of this combination is its high thermodynamic (Carnot) efficiency, since very high maximum temperatures in the gas turbine (eventually 1600°C) are matched by low cold end temperatures of the steam turbine. Fuel efficiencies of 44% have been reported, and values as high as 55% are envisaged. Thus, CCPP appears to be an effective means to keep the cost of electric energy low in spite of rising fuel prices, and it makes possible the use of "clean" (= expensive) fuel, considering economic competition.

Conception and development of this sophisticated type of electric power generating equipment appear to be typical for the situation in highly industrialized areas with a high density of population. The question is open whether less vulnerable, more standard types of equipment with correspondingly lower investment cost are more adequate for other areas until these have reached a similar level.

Particular materials requirements for CCPP are related to the gas turbine section. Development of gas turbines has several roots, in particular, gas turbines for aircraft (and more recently, rail and road vehicle) propulsion, and gas turbines for medium scale electric energy generation. There exist essential differences between these two types:

- gas turbines of the first type (i.e., components of "jet engines") are characterized by: Small size - maximum thrust per unit weight of engine - short mission cycles with numerous rapid changes of power level - moderate total service life.

- gas turbines of the second type in conventional application can be characterized by: Moderate to large size (300 MW) - high economic efficiency - intermediate mission cycles with slow rate of change of power level - long total service life.

In contrast, according to contemporary ideas,

- gas turbines for future advanced CCPP will be characterized by: very large size (500 MW and more) - maximum economic efficiency (i.e., highest possible temperaature) - steady state service mode over long periods - extremely long design life.

The large-size criterion and the length of total life time from a link to the modern conventional steam turbine, while, on the other hand, temperature range and corrosive environment are widely different. Therefore, advanced CCPP equipment and materials thereof have to be developed along particular lines, using experience from all the other fields mentioned, and from fundamental research.

2. Materials Requirements as Linked to Design Concepts.

2.1 High Temperature Strength of Crucial Gas Turbine Components

The conversion of the kinetic energy of the hot gas stream into kinetic energy of the rotating turbine wheel is effected by a combination of vanes and blades in the gas turbine. Their critical property is mechanical strength for long time at high temperature. Since large CCPP gas turbines - in contrast to airplane/vehicle propulsion units - can be operated at a comparatively low level of external shock and vibration, and at a fairly constant power level, high creep strength and a slow rate of creep damage accumulation are decisive. The higher the temperature of operation, the more difficult it is to fulfill these requirements.

One solution is the use of advanced Si_3N_4/SiC ceramics. While most design engineers are still reluctant to envisage a "ceramic engine," the CCPP gas turbine does present a nearly ideal case for these materials, since the low temperature brittle fracture is much less important than in vehicle propulsion engines. Fabrication of sufficiently large parts will be possible in the near future, and the problems still existing with respect to grain boundary creep strength should not be over estimated. Low creep ductility is not a decisive problem since the turbine blades are not allowed to elongate by more than 0.5%, anyway.

An alternative is cooling of superalloy components by air or by water. There are limitations due to fabrication of parts with very sophisticated cooling systems, and the necessity to keep the fine cooling channels free from deposits of particulate matter and corrosion products. Moreover: more cooling = more loss in thermal efficiency.

Presumably, air cooling systems have now reached a design limit. Both theory and experiment show, on the other hand that only the low temperature core of a cooled turbine blade has a load-bearing function, while the (hot) outer sections essentially act as heat barriers and corrosion sinks. The obvious consequence is a turbine blade constructed from 1. a load bearing supperalloy core with a simplified cooling system and 2. a ceramic heat/corrosion barrier overlay or shield of greatly improved efficiency.

2.2 Corrosive attack within the turbine.

Every gas turbine will have to face corrosion attack by carbon monoxide, by residual hydrocarbons, and by a small oxygen partial pressure. It is highly desirable, though, to avoid at least the additional attack by sulphur and particulate matter. Sulphur is known to increase solid state reaction rates, in particular with superalloys. Fine particle impingement erodes protective layers and forms a hazard of congestion for air cooling systems designed to work over 100,000 hrs. and more. Thus, CCPP gas turbines should be driven by combustion of clean fuel. While pressurized fluidized bed combustion has certainly a high economic appeal, it is doubtful whether really successful hot gas scrubbing systems can be developed without an essential loss in thermal efficiency.

Thus, the expensive way via coal gasification/liquefaction is possibly the safe solution. It meets both environmental protection and corrosion protection requirements. Though quite satisfactory protective coatings for superalloys have been developed, the corrosion issue would be less dramatic if the gas stream meets a nonmetallic blade surface.

3. Discussion of the Long-Lifetime Approach

As stated before, the demand for high strength and corrosion resistance and, at the same time, high thermal efficiency via high gas temperature plus what might be called the 200,000-hour-philosophy, account for the majority of materials problems for CCPP. Roughly, the useful lifetime is reduced by an (exponential), Arrhenius function, if the temperature is increased by a certain amount. In combined cycles, the steam turbine will dictate the total lifetime, which makes the job so difficult for the designer of the gas turbine stage. This holds even with advanced cooling and protective systems and fancy materials.

The question is to be raised whether the demand for gas turbine lifetimes of 100,000 hrs. and more in a combined cycle fossil (non-nuclear) powerplant is reasonable at all. One reason is that these long lifetimes are contradictory to the accelerating pace of technological development enlarged. The same holds for the economical and geopolitical scenario of the year 2010 and (which would be about the 200,000-h-lifetime of equipment conceived today). The strange situation that engineers might create truly "fossil" power stations just by application of the most advanced technologies is not so unrealistic: already today the average fuel efficiency of all power stations falls considerably below the values for new equipment, due to the "overaging" of "overdesigned" plants built in 1950 through 1965.

Therefore, it is proposed to investigate alternative lines of development, e.g., the following two parallel gas turbines are combined with one large steam turbine. The gas turbines may have a design life of, say 60,000 hrs. (= 7 years) and a correspondingly higher temperature, so that the fuel efficiency of the whole plant is raised accordingly. The steam turbine could be designed for 120,000 hrs. At mid-life of the steam turbine, the twin gas turbines are successively overhauled (new sets of blades) or even replaced by newly developed ones. The cost for this is paid off by increased fuel efficiency during the whole lifetime (technological progress interest rate), and by the advantage to adjust at mid-life to a changing market. For high availability of the combined cycle, the twin gas turbines might be optimized for two load levels, e.g. 100 and 150%, and the steam turbine for 200 and 150%. Thus, during inspection or overhauling or replacement of one of the gas turbines, the combined cycle may still operate at a load level which is satisfactory from both an engineering and an economical point of view. A design pattern like this would also allow for repair work. It is claimed that repair of components by expert firms with specialized equipment including HIP amounts to only 40% of the cost of replacement by new parts, without loss in design life.

Material Aspects of a Shell-Koppers-based Combined-Cycle Power Plant

K.J. YAP

(Shell Internationale Petroleum Maatschappij B.V.)

Introduction

The Shell-Koppers process for the gasification of coal under pressure is characterized by:

- practically complete gasification of virtually all solid fuels;
- production of a clean gas without byproducts;
- high throughput;
- efficient heat recovery.
- environmental acceptability.

There are numerous possible future applications for this process. The gas produced (93-98% vol.hydrogen and carbon monoxide) is suitable for the manufacture of hydrogen or reducing gas and, with further processing, substitute natural gas (SNG). Moreover, the gas can be used for the synthesis of ammonia, methanol and liquid hydrocarbons.

Another possible application of this process is as an integral part of a combined-cycle power station featuring both gas and steam turbines.

The integration of a Shell-Koppers coal gasifier with a combined-cycle power station will allow for electricity generation at 42-45% efficiency for a wide range of feed coals. The required technology and equipment are expected to be commercially viable by 1985.

The capital investment for a Shell-Koppers/combined-cycle station is slightly higher than for a conventional coal-fired power station with stack gas cleaning, viz. US$370 million as compared to US$340 million for a 500 MW station (basis mid-1978, location Netherlands).

The higher capital requirement is more than compensated, however, by a better station efficiency, viz. 43.9% compared to 35.9% for a conventional scheme in base load.

Initial economic studies justify the expectation that, for large electricity generating plants equipped with sulphur emission control facilities and operating in base load service, Shell-Koppers gasification with combined cycle offers an economically attractive alternative for virtually any coal. In addition the process offers important technical and environmental advantages like versatility to feed coal, clean ash disposal and low cooling water requirements.

Material Requirements

The high efficiency of a Shell-Koppers-based combined cycle power station is based on the capability to fully exploit the possibilities of high gas turbine inlet temperatures (above 2100°F) and the ability to generate high-quality steam (2400 psi/1000°F) in the waste heat boiler of the gasifier.

1. Gas turbine inlet temperatures much higher than the currently achieved 1750-1900°F could be realized by the application of porous,sintered blade materials enabling transpiration cooling with cooling air penetrating through the entire blade.

   With the film cooling techniques, applied at present, improved blade materials (e.g. coatings) could also contribute to increased gas turbine temperatures, certainly with the option of water/ steam cooling.

2. To sustain an efficient steam cycle, full use is to be made of the high-level heat in the waste heat boiler of the gasifier. In view of the hydrogen and hydrogen sulphide content of the gas produced in the pressurized gasifier and the presence of particulate matter, the high wall temperatures in the superheating and evaporating sections would require the installation of high-alloy steels.

   While such materials are available, (e.g. Incaloy 800) they are very expensive, and the development of less expensive materials capable of withstanding the conditions in the gasifier waste heat boiler would improve the economics of a Shell-Koppers-based combined cycle power station.

   The waste heat boiler inlet conditions on the process side for the most demanding case, viz. oxygen gasification, are given below:

Temperature	1650-1800°F	Raw gas	composition
Pressure	225-300 psi	H_2	25-30% v
		CO	60-65%
		H_2O	3-5%
		CO_2	1-4%
		H_2S	up to 2%
		Traces	0.2%
		N_2	3-7%

The gas contains solidified flyash as well. The amount depends mainly on the ash content of the coal, but a typical figure would be 0.025 kg/Nm^3.

GEOTHERMAL ENERGY DEVELOPMENT-- MATERIALS PROBLEMS AND PROSPECTS FOR RESOLUTION

D. W. Shannon
Battelle Memorial Institute
Pacific Northwest Laboratory
Richland, Washington 99352

Any long range view of the future of mankind must recognize that energy is essential and supplies of oil and natural gas are finite. It really doesn't matter if there is an 'oil glut' today, as some suggest, or even if another Prudhue Bay or Mexican Bonanza are discovered tomorrow. The exponential increases in the consumption of petroleum, year after year, inevitably must stop as the earth's finite limits are reached. The recent price increases by OPEC clearly indicate the trend; prices will rise to keep supply and demand in balance. Who will curtail his use of petroleum as the price rises? It will be the economically disadvantaged that will do without. It will be Third World countries that will see their hopes for a better life dashed as they pay more and more. At least that is the probable outcome if they try to copy the pattern of today's oil fueled economies of the world.

Geothermal energy may only fill a few percent of the energy needs of the United States, but for over 50 countries of the world, significant amounts of geothermal energy lie waiting to be used. A look at a plate techtonics map reveals how extensive geothermal resources are, since most geothermal energy occurs along the plate boundaries.

A recent report by the Electric Power Research Institute stated that if only 2% of the geothermal resources are high enough temperature for electric production, the electric energy potential is about 1.2×10^3 giga watt--centuries, electric. This is equivalent to running today's worldwide installed electric power system for 10,000 years! The lower temperature resource base which could be used as heat is even larger! While a 50 MWe generator is a "pilot plant" in the U.S., there are many places in the world where that electrical power output would improve the standard of living dramatically.

So what is preventing us from utilizing this vast heat resource of the earth? I would answer, "nothing very important!" For those who have traveled from afar to hear a list of materials problems now, I apologize. I believe there are no really serious materials problems which are preventing us from developing at least a fourth of the world's geothermal resources. What problems there are concern defining specific locations for plants, economics, legal issues, environmental concerns, and institutional practices. There are technical problems like mineral scale deposits fouling equipment. Some hardware needs to be developed and manufactured in economical quantities. We need pioneer demonstrations of how to use geothermal energy and to develop the more difficult geothermal resources like hot dry rock and geopressured resources. Above all we need vigorous leaders to lead the way. But right now you can buy most of the hardware needed for a lot of useful geothermal projects.

Having urged that we get on with the development job, I would now like to address some of the technical materials problems that do exist. Solutions to these problems would lower costs, reduce risks, improve confidence and increase further the geothermal resources that we could develop soon. Technical innovation will clearly speed up the process of geothermal utilization.

Cements

Based on oil field practice, the well casing (usually double) is sealed into the ground with cement. As hot fluids are produced tremendous thermal expansion stresses must be accommodated, as well as high pressure, and often exposure to acidic brines. Today's cements have serious deficiencies. Cements used in above ground canals are corroded rapidly by geothermal fluids.

Well Casing Steels

The geothermal well casing must last a long time and a failure can produce a serious well blowout. The common carbon steel well casings can fail by oxygen corrosion from the outside and occasionally by sulfide cracking. As the salinity and temperature of the geothermal fluids increase, corrosion of carbon steel increases. Since high saline brines are typically acidic (due to brine--mineral chemical equilibria) we need materials that will withstand 10- to 20-year exposure to dilute hydrochloric acid brines (pH 3 to 5) at temperatures up to 370°C. At present no easy economical solution exists. The common nickel alloys are attacked by H_2S which usually is present, and titanium can undergo catastrophic crevice attack above 250°C in salt brine. Fortunately few wells have brines this agressive and carbon steels usually serve in the more common low salinity, neutral pH geothermal fluids.

Corrosion Fatigue in Turbine Blades

Geothermal steam typically has high concentrations of CO_2, H_2S, and NH_3. Experience at the Geyser's geothermal plant has indicated the typical 12% Cr turbine blade material has significant susceptibility to corrosion fatigue. While at present, conservative turbine design controls the problem, better fatigue resistance clearly is desirable.

Bearing Materials

Geothermal fluids usually have a very high particulate content. The hot abrasive brines destroy bearings of pumps. Current pump designs keep bearings flushed with clear water, but better wear properties would be useful.

Mineral Scale Control

The mineral deposits that form when energy is extracted from the water, range from a minor maintenance problem to causing a total failure. The problem is often severe enough that chemical or mechanical controls are needed, such as acidification or blasting with water jets to remove scale. Scale control methods can create more agressive conditions for the materials of construction than the geothermal brines themselves.

Work is needed in the whole area of scale control all the way from basic research on brine thermodynamics, to high temperature chemical instrumentation to be used with the scale control methods.

Elastomers

Present elastomers fail in high temperature brines. Elastomers, with useful life times at 250°C or above in high pressure brines would find wide usage.

Drill Bit Wear

The whole field of drill bits needs further improvement since geothermal well cost has a big impact on power costs.

These materials topics are not all that could be listed, but will suffice for the limited time available at this workshop.

Materials And Geothermal Energy Development

V. T. NGUYEN And H. S. DHILLON
(The MITRE Corporation, McLean, Virginia)

The geothermal fluid, by nature, contains chemicals which, when coupled with the high temperatures of the fluid, cause considerable operating problems in fluid contacting systems. These problems are basically materials failures due to corrosion, erosion and fatigue, and are encountered in such systems as wells, fluid gathering and transport lines, pressure vessels, heat exchangers and prime movers. In addition to operating problems, the drilling and completion costs of geothermal wells are currently high because of the lack of suitable seal, drill pipe , and drill bit materials. The resulting effects are high well cost, high equipment capital costs (due to necessary over-design), and high operating and maintenance costs (due to short component lives).

The high costs of equipment, wells, and plant operations lead to high costs of geothermal energy and, in many cases, can limit the development of this type of resource. Thus the availability of low cost materials, which are suitable for use in the aggressive environments of geothermal resources, has a significant bearing on the geothermal resource development. However, there are problems in developing such materials because of the site-specific nature of geothermal resources, and the lack of incentives for materials developers and manufacturers to enter the geothermal market.

This paper examines the materials related issues associated with the development of geothermal energy. The most crucial materials are identified and the near-term and long-term options for satisfying the materials needs of geothermal energy are discussed.

Materials Problems in Fluidized-Bed Technology

JOHN STRINGER

(Electric Power Research Institute, Palo Alto, CA)

The fluidized bed combustion of coal offers some significant advantages over conventional systems. Because of the low combustion temperature, the emission of NO_x is reduced; and by incorporating an acceptor such as CaO in the bed SO_x control can be achieved. Furthermore, the lower combustion temperature should limit slagging in any heat exchangers above the bed, and reduce the release of alkali salts. There are several different concepts currently being considered: three of particular interest are: (1) an atmospheric pressure bed with heat exchange tubing in and above the bed, producing steam; (2) a pressurized bed with no heat exchange surface acting essentially as an external combustion chamber for a gas turbine; and (3) a pressurized bed with in-bed and above-bed heat exchangers, producing steam; the combustion gases being expanded through a gas turbine.

Because of the low temperature of the combustion gases leaving the bed (typically 900C, 1650F), it is most economical to superheat the steam in the in-bed exchanger, where the excellent heat-exchange characteristics of the fluidized bed more than compensate for the low temperature. For steam at 538C (1000 F), the external metal temperature might be as high as 650C (1200 F). Originally, it was believed that the absence of molten phases in the ash and the lower anticipated alkali release would result in there being no serious corrosion problems for the in-bed tubes. However, it has now been demonstrated that there is a risk of a form of attack in which the sulfidation of the metal inhibits the development of a protective oxide scale, allowing rapid oxidation to take place. This appears to occur because local low oxygen activity regions are formed: the presence of CaO and $CaSO_4$ in the bed results in the development of high sulfur activities in these regions. Values of oxygen activity as low as 10^{-12} atm have been reported; the corresponding sulfur activity would be 10^{-6} atm or so.

There are several possible reasons for the development of the low oxygen regions. Within a fluidized bed operating at low fluidizing velocities, bubbles move upward; the solid material is in a comparatively dense mass, the particles moving relative to each other. This is sometimes called the "emulsion" phase. The air in the bubble phase exchanges with the gas in the emulsion phase, but it would seem likely that the oxygen activity in the emulsion would be relatively low. Local inhomogeneities in flow which would reduce the rate of mixing would result in more stable regions of even lower oxygen acitivity: such regions develop immediately above horizontal tubes. In the vicinity of the coal feed ports, which are usually at the bottom of the bed, it is expected that local substoichiometric conditions would be present, and indeed severe sulfidation/oxidation corrosion has been observed in these locations.

Changes in the geometry of the bed, the fluidizing velocity, and the design of the coal feed ports all may have an effect on the incidence of this form in corrosion.

It appears that high nickel alloys are particularly prone to sulfidation/oxidation attack, perhaps because of the formation of low melting point nickel sulfide eutectic. The simpler austenitic steels such as Type 347 behave much better. Uncooled support members may present a special problem.

In a very few cases, erosion of in-bed components has been reported. The nominal velocities (3-8 fps; 0.9-2.5 m/s) seem very low; in conventional pulverized coal-fired furnaces ash erosion is not observed if the furnace is designed to have a nominal gas velocity below about 65 fps (20 m/s); the local particle velocity could be perhaps as high as 100 fps (30m/s). However, within the bed, a small but finite fraction of particles could have velocities as high as this, and in view of the very high particle density in the bed the possibility of erosion cannot be wholly ruled out. Where it has appeared, it may have been due to flow inhomogeneities producing jets.

If the pressurized combustion gases are to be expanded through a gas turbine, this may be exposed to erosive and corrosive conditions. The particle loading of the gas leaving the combustor is high, typically in the range 10-25 gr/scf (20000-50000 ppm); ordinarily, gas turbines will not accept more than 0.02 gr/scf (35 ppm) although catalytic regenerator expander turbines are designed for 0.1 gr/scf (180 ppm). Accordingly, very effective cleaning of the hot gas is required. Initially, two stages of cyclones will be employed, but it it likely that a further stage of cleaning will be required: this could be a further high efficiency cyclone, a granular bed filter, or a high-temperature bag house. The degree of cleaning and the capacity of the turbine to accept particulates will clearly be a trade-off.

It appears that the combustion gases may contain as much as 1-2 ppm alkali salts, and previous experience would suggest that this would be sufficient to induce hot corrosion of the first rwo nozzles and blades. The experimental evidence to date is less than clear: some specimens have suffered hot corrosion in pfbc exhausts, but equally other specimens in other tests have shown no damage, suggesting that the detailed chemistry of the deposits may inhibit corrosion. Further studies of this aspect of the problem are currently in progress.

It is possible that coating or cladding techniques could be developed which would optimize resistance to both erosion and corrosion in the pfbc exhaust gases: projects with this aim have recently been initiated.

Materials Problems in Fluid-Bed Combustion

DR. J. A. CLUM
Department of Metallurgical & Mineral Engineering/Extension
University of Wisconsin-Madison

DR. C. R. LOPER, JR.
Department of Metallurgical & Mineral Engineering
University of Wisconsin-Madison

An important problem deals with the bed itself. In the bed, lime (hi-calcium or dolomitic) is used to absorb the SO_x produced. The sulfation of lime tends to occur by formation of a solid sulfate reaction product.

Frequently the sulfate exists as a layer on lime particles with the interior of such particles remaining unreacted. This problem seems more serious with hi-calcium lime than it is with dolomitic lime.

In order to effectively reduce the SO_x emission from the combustor, a large excess of lime (over the stoichiometric requirement) is used. Such a large inventory of lime in the combustor can cause lower process efficiency and can increase operating and capital costs.

Methods of increasing the degree of sulfation have been tried. For example, the addition of chlorides to the combustor results in reduced SO_x in the effluent at a constant lime inventory. However, chlorides may have a serious corrosive effect on the combustor itself. The reactivity of the lime may also be increased by physical means, i.e., by charging with smaller lime particles. The use of smaller particles, however, adversely affects fluidization characteristics. Consequently, there needs to be some consideration given to the following questions:

1. What degree of sorbent utilization can be achieved with changes in sorbent characteristics and with the use of special additives?

2. How do the changes in sorbent characteristics and/or the use of additives affect overall combustor operation, i.e., can long-term costs be reduced?

Materials Problems in Fluidized-Bed Coal-Combustion Systems*

J. H. DEVAN AND T. G. GODFREY
(Oak Ridge National Laboratory)
Metals and Ceramics Division
Oak Ridge, Tennessee 37830

Fluidized bed combustors (FBCs) incorporate several components that are unique in terms of their materials requirements. The areas of principal concern are the in-bed heat-exchanger tubes, air distributor plate or grid, side walls, coal-feed lines and nozzles, spent-bed removal hardware, and possibly the cyclones that return elutriated material to the FBC carbon-burnup cell.

Corrosion and erosion of in-bed heat exchanger tubes will depend strongly upon particular design features of the fluidized bed. Cr-Mo steels, Incoloy 800, and 300-series stainless steels are likely candidates for evaporator tubing, but their tolerance of off-design local environments is not established. Reducing or cyclic redox conditions must be avoided for the tubes to have reasonable lifetimes. Erosion of tubes should not be a significant problem if local particle velocities are reasonable. Acceptable velocities, however, are not well defined; furthermore, superficial velocities are normally specified and do not necessarily quantify the local conditions. Also, jet-impingement from coal-feed nozzles must be avoided. Erosion must be controlled by design and verified by tests to ensure that the oxide scale is protective of the tube wall.

The air distributor plate is critical to the operation of the FBC since its performance and integrity in large measure dictate local bed characteristics. Materials are not necessarily limiting in this application, since a variety of alloys and/or ceramics appear to meet the intended temperature and environmental conditions. Rather, engineering design and the operation of the FBC will determine performance.

Side walls should present no significant problem if proper regard is given to local conditions. A variety of alloys and/or refractories are applicable, but each material must be qualified for the particular

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design. A potential problem exists in the vicinity of any penetrations in the side walls where the atmosphere could be stagnant and reducing. Catastrophic hot corrosion of alloy tubes has been observed in a FBC where the tubes passed through the refractory wall and experienced a locally reducing condition.

Of the two possible ways of introducing coal to the FBC (spreader stokers and in-bed feeders), the in-bed type is the one with potential materials problems. The atmosphere surrounding the nozzle or injection tube is potentially reducing and sulfidizing and might, therefore, require use of ceramic components. Considering the large number of such coal feed points, this area must be carefully evaluated through experiments and long-time testing. A failure in a feed nozzle could accentuate bed inhomogeneity with dire consequences for other components.

Problems with spent-bed removal hardware are very design-dependent. With the possible exception of valves that might be required to handle the hot, abrasive bed material, suitable materials are available for this application. As in the other areas cited above, locally reducing or cyclic atmospheres could be catastrophic. The problems of valves for hot and abrasive solids is not unique to FBCs and is a severe materials problem. No totally acceptable solution is at hand.

The problem with regard to cyclones is one of erosion and corrosion of the internals and is well documented. The FBC application is more severe than usual, however, because of the elevated temperatures and will require special attention.

Materials Technology for Silicon Solar Cells

S. KAR and E.C. SUBBARAO
Indian Institute of Technology, Kanpur-208016, India.

Renewable, dispersed energy sources are particularly attractive to India, in view of its large population, much of it thinly distributed over 550,000 villages, with a very low per capita energy consumption. In this situation, solar energy can play a significant role. All solar energy devices-solar thermal, photovoltaic, photosynthesis, and photoelectrochemical-are well suited to the Indian conditions and needs. Insolation is high all over India. Unlike all other energy conversion devices, the cost of energy from solar cells is invariant of the size of the generator. This is specially suitable for India since 60 percent of the total energy is consumed in the village and this sector will grow.

Although photochemical energy conversion appears to be very attractive for India, no concrete ideas have yet taken shape. So at the moment solid state solar cells appear to be the most feasible alternative. Solar cell research and development are now vigorously pursued in India and actively encouraged by the Indian government. Very active in this area are educational institutions (Indian Institutes of Technology, Indian Institute of Science, Jadavpur University), research laboratories (National Physical Laboratory, Solid State Physics Laboratory, Central Electronics Engineering Research Institute), and industry (Central Electronics Limited, Continental Devices (India) Limited). The research areas include investigation of pn junction, SB, MOS, and ITO solar cells on single crystal, polycrystalline, and amorphous silicon, and $CdS-Cu_2S$ solar cells.

All research and development work in the solar cell area is directed towards reducing its cost for terrestrial application. The present cost is about $10.00 per peak watt, about half of which is material cost, and the other half processing cost. In a large number of areas in India no distribution system exists unlike in the developed countries. It is therefore believed that solar cells will be attractive in India at a cost of $1.00 to $1.50 per peak watt. Several possible ways being investigated like remodelling the conventional processes for mass production or making use of simpler devices like SB and MOS solar cells which require simpler and fewer processing steps are expected to reduce the processing cost in the near future. For reducing the material cost also, several alternatives are being looked into. These basically are the development of solar grade semiconductor and use of thin semiconducting films on inexpensive substrates. Theoretically a direct bandgap semiconductor with a bandgap of 1.4-1.5 eV such as GaAs, $Ga_xAl_{1-x}As$, and CdTe is most suitable for solar cell. However these semiconductors are more expensive and the raw materials limited. Silicon seems to be the most suitable semiconductor based on its abundance, established technology and easy passivation of silicon devices.

Device grade silicon is produced by very expensive and energy-intensive processes, which produce material of high purity and crystalline perfection, characteristics that are critical for the usual silicon devices or even space solar cells. However for terrestrial solar cells the most critical criteria are cost, energy consumption, and the availability of abundant raw material. The solar grade silicon is still to be defined, i.e. what impurities and crystal imperfections can be tolerated to what extent. Metallurgical silicon which is the starting material contains mainly : Al, Fe, Ti, V, Mn, Ni, B, P, Cr, in the order of concentration. Some impurities which were thought to be harmless previously have found to cause serious problems in solar cells, and vice versa. Impurities which are presently considered harmful are in the order of importance [Hill et al, 1976]: Ti, Zr, V, Na, Cu, Fe, and Mg. Thus, the whole materials technology for producing silicon has to be looked anew from the point of view of solar cells, i.e. a technology, economic in terms of cost and energy, but suitable for producing tonnage quantities. This process has begun already, and only a revolution in silicon technology can bring about large scale solar cell application.

The most promising alternatives seem at the moment to be : (a) casting of metallurgical grade silicon and purification by unidirectional solidification [Schmid, 1978]; (b) EFG (edge fed growth) silicon ribbon [Ravi et al, 1976]; (c) and thin layers of amorphous silicon on metallic substrates [Carlson et al, 1976]. Already 10 and 6 percent efficient cells have been realized in case of (b) and (c) respectively. A 10 percent efficient cell is considered good enough on really inexpensive material, an efficiency of 15 percent would certainly be excellent. Grains in cast silicon must be at least of 1.0 mm size and cells fabricated on such material but of device grade chemical purity have shown better than 10 percent efficiency. EFG ribbon avoids material waste involved in cutting and lapping silicon ingots, however it is not clear whether this alternative will ultimately meet the materials goal. Amorphous silicon has very interesting properties such as an order of magnitude higher absorption coefficient, higher bandgap, and smaller electron affinity than single crystal silicon, however it remains to be seen whether higher efficiencies on larger areas can be obtained. In conclusion, one may remark that we are confronted with a materials technology problem of the first order, and the success of the solar cell program lies in its solution.

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Automated Admittance Characterization of Fossil-Fuel Material and Solar-Cell Devices

JOEL DUBOW
Electrical Engineering Department
Colorado State University
Ft. Collins, Colorado

Evaluating novel processing and prospecting techniques for fossil fuel extraction technologies and characterizing advanced photovoltaic cells requires both a data base and an understanding of the behavior of these materials and devices. The electrical transport properties (conductivity and dielectric constants) are sensitive indicators of the state of a material. Moreover, when combined with a thermodynamic measurement such as differential thermal analysis, these techniques form a particularly valuable tool for elucidating the nature of state changes and phase changes in a material. For energy conversion devices such as solar cells, the electrical admittance is a sensitive indicator of the properties of critical interfacial aspects of the device. For example, the frequency and temperature dependence of the admittance can be used to obtain doping densities, interface state densities, interfacial layer thicknesses, and energy levels of the interface states. Conventional techniques for determining these parameters typically use impedance bridges which are extremely time consuming and cumbersome. This precludes using these sensitive tools for obtaining timely information for the evolution of device process variations to speed the development of solar cell devices. This paper describes the technique and critical results obtained from an automated admittance measurement.

The technique consists of combining a frequency synthesizer and gain phase meter network analyzer combination through a programmable computer calculator. A block diagram is shown in Figure 1. An interface circuit allows this technique to be used on a wide variety of loads by eliminating the impedance mismatch problem which previously ruined the sensitivity of the technique for all but a limited range of samples. The samples are placed in an insulated and controlled atmosphere oven which may be cycled from close to liquid nitrogen temperatures up to 100° C. In another oven, the temperatures may be cycled from room temperature to 1000^{o} C. In this manner the DTA curve and the conductivity and dielectric constant may be obtained simultaneously at many frequencies over the frequency range 50 hertz to 10 megahertz. The voltage bias across the device and or material may be varied to give field dependent behavior. These data may be obtained at different temperatures specified in the temperature programming cycle. This allows data to be obtained rapidly during the course of phase changes and or reactions and less rapidly during more thermally stable regions of temperature.

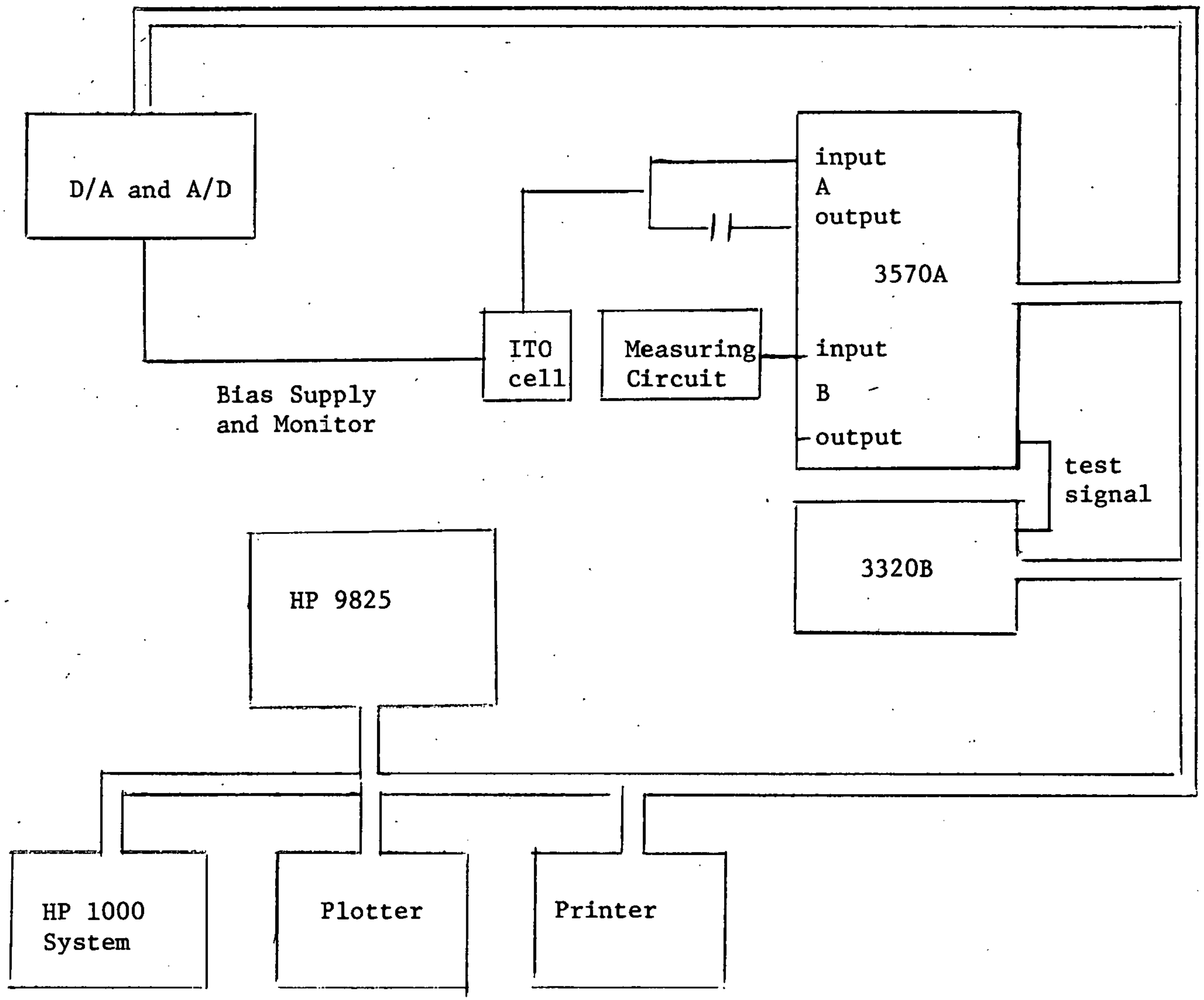
This technique has been applied to a number of materials. Three illustrations are: the phase transition of potassium perchlorate; admittance change through the transition temperature of oil shale which occurs prior to the onset of rapid Kerugen decomposition; and the admittance characterization of ITO SIS solar cells in which the role of interface states is elucidated.

Previously thermal analysis studies have shown that potassium perchlorate exhibits a phase transition that is reversible at approximately 170^{o} C. Concurrent measurement of DA and DTA show that the phase transition in this material corresponds to that observed in the literature. However, the DA technique shows that the forward and reverse phase transitions occur at slightly different temperatures and that the magnitude of the dielectric constant change is different at different frequencies. Thus the dielectric analysis provided a better measure of the transition temperature as well as the nature of the polarization change and dipole moment relaxation time during that transition.

It would be most useful for in-situ oil shale retorting to have a diagnostic which would yield the boundry of the retorting zone. Temperature dependent admittance characterization has been used to elucidate the temperature range over which the change of phase occurs. The admittance data has been correlated with mechanical, thermal, and accoustical properties data which also exhibits this phase transition. However, admittance data gives a major qualitative change which could be used as the basis of a field sensor. The data also has implications for mine design, in that they predict the onset of the rapid loss of strength of oil shale as this transition is approached. After the phase transition oil shale begins to regain its strength once again, probably due to carbonate recementation. When combined with differential thermal analysis, it can be shown that this phase transition is physical rather than chemical in nature.

In the course of development of a new type of solar cell, information concerning the barrier heights, interface state densities, and interfacial layer thicknesses are critical to adjusting the process parameters. Detailed admittance characterization yields useful data but is often extremely time consuming. Using the temperature dependent automated techniques, many more devices can be processed through admittance measurements and more comprehensive information obtained about the effect of a process variation upon device performance. Specifically, the unsuspected role of interface recombination states was pointed out through the characterization of the capacitance-voltage and conductance-voltage curve at different frequencies on representative solar cells made from indium tin oxide on silicon. When coupled to a computer graphics system, multi-dimensional plots showing capacitance versus voltage and conductance versus voltage as functions of frequency show relaxation time and surface state contours which are useful for indicating the origin of these loss mechanisms.

Descriptive details of the technique and representative data from materials and device measurements will be given to support the above conclusions.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WORKSHOP 4

THE ECONOMICS OF MATERIALS USE UNDER CONDITIONS OF RISING ENERGY COSTS

CHAIRMAN: MANFRED LIEBRUCKS (GERMANY)

ORGANIZER: ANNE CARTER (U.S.)

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Materials Economics & Technological Adaptation

PROF. BARUCH RAZ
Interdisciplinary Center for Technological Analysis
& Forecasting, Tel Aviv University, Tel Aviv, Israel

The abrupt changes in energy prices have affected the costs of production of materials dramatically, Moreover the effects have been quite unevenly distributed depending, of course, on the energy contents of each material. The sudden changes in input costs have added a new dimension of uncertainty to the materials' market. Everything has been affected: relative demand, relative production costs, the urge to innovate technologically. The purpose of this discussion is to try to identify the effects of changes in energy costs on materials economics and technological adaptation.

The following is intended to be a presentation of a series of assertions,some more provocative than others, some quite firmly adopted by the author, some much less so. The purpose of this way of presentation is to focus the discussion along lines that seem relevant to the problem and stand for issues that are still debatable.

1. It is quite obvious that we are living in a period of change regarding the production and consumption of materials. The length of this transition period is characterized by a mismatch between the time constant of technological changes and that of market changes. This mismatch implies a perpetual deviation from a state of equilibrium. It is important to identify the components of the long technological time constant, and enquire into the costs of their curtailment. It might be argued that research and development is a very time consuming and relatively inexpensive stage in the process of technological change. Investments in R&D could lead to an accumulation of relevant knowhow preceding serious changes in the market. Thus, shorter transition periods could be achieved.

A problem to be discussed is whose responsibility it is to invest in processes such as R&D that is to a considerable extent a nonproprietory good ? A related problem is how should the different time horizons of government and private firms manifest themselves in the relative burdens they undertake in order to "smoothen" changes.

2. An attempt to forecast the transitory behaviour of the materials market in response to changes in input costs, is fraught with difficulties. The main reason for this is the non-linearity of the problem. In other words, there are many interlinkages between different materials. Some interrelations are easily discernable as is the case with materials that replace each other (PVC & aluminum in certain water pipes). In some other cases the effects are less obvious. This intransparency of the problem has caused some people to suggest procedures such as energy accounting. (Slesser,1973); (Chapman,1974); Raz & Treitel,1975) in order to add more physical insight into the problem. The debate whether physical quantity acoounting is worth the effort has no general concensus and should be retaken.

3. Input- output analysis has been one of the major tools for the understanding of interrelations between various sectors in the economy. The extension of I/O to non-equilibrium situations which involve technological changes has been attempted with the use of using time dependent technological coefficients. In particular logistic curves have been applied to describe the time dependence. (Ayres et al.) . It is important to try to evaluate the success of this approach and its potential for the future.

4. Energy saving has been the most direct response to the energy crisis of 1973. Without addressing the problem of whether this is the most efficient response, it seems important to formulate goals to the saving of energy in material production. Is there any economic sense in using thermodynamic efficiencies as goals of guidelines? (Berry and Fels, 1973). Is there any sense in attempting to create a policy of coherent saving based on thermodynamic free energy considerations?

5. The reduction of perceived risk with regard to future prices can be achieved through physical means (stockpiling), and through creating better information banks and the use of forecasting techniques. The two avenues are of course interdependent, yet the costs of each option are quite different. It might be interesting to formulate criteria for the optimal investment in forecasting market changes and the hedging against the consequences of changes through stockpiling.

The above discussion is relevant to a case where all the above mentioned options : changes in production technologies, substitution, stockpiling etc., are indeed open. In some countries economies of scale considerations preclude some options. In some other countries the nonavailability of primary materials limits the choices of options. The optimal choices in limited-option situations will also be discussed along with the reasons for the existence of limitations.

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The Political Economy of Materials Policy

WILLIAM A. VOGELY
(Department of Mineral Economics,
The Pennsylvania State University)

Since World War II, materials policy has been a major preoccupation of the Federal Government. At least five major Presidential Commissions or Presidential level task forces have addressed the issue starting with the so-called Paley Commission which reported in 1952. In spite of this high level attention to the materials policy issue, the result in explicit materials policy statements or actions has been virtually nil. With the exception of the 1970 Minerals and Materials Policy Act, there has been no coherent addressing of the issues of materials policy by either the Congress or the Executive.

How can one explain the immense amount of interest and the lack of any action? It is argued here that the reasons for this, while manyfold, come down to two general and broad factors. First, it is not within the framework or mores of the Congress and Executive Branch of the United States to address themselves to an industrial sector in terms of explicit policies. With the exception of the agricultural sector, there is no example in history to serve as a role for such sector policies. In energy, for example, in spite of a generally perceived problem that is accepted by all sides of the debate, the path towards a sector policy for energy has proved extremely long and difficult; and, in fact, is not yet achieved. Unlike European countries and Japan (where sector policies are, in fact, the standard way of operating), in the United States, because of the plurality of the political process within the Congress, they are not an accepted way of doing business.

Second, given the aversion to sector policies, the case for such a policy must be overwhelmingly obvious - both from rational and political criteria - as in the case of agriculture. In fact, the material sectors have not made such a case. In reviewing all of the calls for materials policy since World War II, one finds recurrent themes relating to increased import dependence, criticality of materials in the production function (without them, you can't produce anything), and help for the domestic producers. It is argued here that a case based upon these factors is simply not persuasive or correct. Import dependence is not, per se, bad; in fact, in an interdependent world, it is clearly the efficient solution in many cases. Since the production function for any good is multiplicative in nature, the lack of <u>any</u>

factor of production will result in zero output. So, materials are not unique in that they are needed for production. Finally, while the producing industry is important locally (and, therefore, has local political support in terms of its "help"), from the point of view of the total economy the sector is simply too small to generate broad-based political support.

Thus, if materials policy is to be explicitly stated, the case must be made on different and better grounds than those used historically. It is argued that such grounds, if they exist, must flow from the nature of the physical constraints surrounding the production function for minerals, and the characteristics of these demand functions.

The production function is multistaged; it involves a very high risk operation of exploration; directed, specific research for the mining and beneficiation of an ore body; immense capital investments for a long period of time before production; and an expensive, often dedicated transportation system. Mineral demand is doubly derived from final demand, and is thus very volatile. Short-run price elasticities are very low. Long-run price elasticities are very high. The result of these supply and demand conditions is highly unstable markets that may result in non-optimum flow of new capacity over time.

A contributory factor to the justification of the need for a materials policy can also be found in the changing international institutional structure of the industries. Specifically, the emergence of the national firm, the growth of the multiproduct, multinational private firm, and the establishment of international political institutions (such as UNCTAD) might lead to the need for U.S. policy actions.

The Arguments For and Against Free Mineral Markets, Mineral Policies and International Agencies

ROBERT PRYOR
Royal School of Mines, Imperial College,
University of London

Starting with first principles, mineral raw materials must be recognized as different from other commodities. They are non-renewable and can only be produced from those locations where geological events have placed them. Some are widely distributed, some are unevenly distributed, and some are very rare and unusual occurrences.

Mineral production is constrained by these geological factors, over which man has no control. With a large yet expanding population, and little unallocated land, the pressures on the mineral supply industries are increasing. Yet in spite of prophecies of early exhaustion, there is an air of optimism amongst geologists and mining engineers that, given freedom of access, the challenge of supply can be met. However, political and economic pressures may exert over-riding influences, giving rise to irregularities of supply and demand.

The consequences of imbalance in supply and demand could provoke profound crisis. National economies are increasingly dominated by urban communities. Whereas predominantly agricultural communities have some flexibility to resist partial, or short term, deprivation of mineral raw material supplies, urban communities have much less resilience. They would quickly collapse under severe shortages if the industries, upon which they depend for their livelihoods, had to curtail their production. In cases of over supply, the effects would be felt at the mineral producing end. Consequently the results might be less widespread, but might be even more severe and rapid.

From the point of view, therefore, of both producers and consumers, there is a mutual objective in maintaining an equilibrium between supply and demand.

However, there are many other objectives of a political and economic nature that bear upon the mineral supply/demand equation. For the producer and consumers these pressures can distort prices and upset any free market.

Political and economic objectives may include:

- o maximising return on investment
- o maximising wages
- o full employment

- protection of the environment
- conservation of resources
- monopoly pricing
- leverage in political or other negotiations
- issues of human rights
- maximising the taxable return by direct or indirect means
- national development
- balancing of national payments
- survival

Furthermore, many of these objectives may vary, and even conflict, at regional, national and international levels.

It is against this scenario that we have to set the arguments For and Against Free Mineral Markets, Minerals Policies and International Agencies.

In three recent minerals congresses, the arguments for and against intervention in the free market have tended to polarise into emotional issues of government interference with industry on the one hand and industrial dictatorship on the other. Little can be resolved by such polarisation.

From reports of the UNCTAD it would seem that the tendency to polarisation there is between the Developed and Less Developed countries, with the former tending to prefer freedom of access and free markets and the latter seeking protection from outside coupled with total control of their own resources from within.

This polarisation into the most emotive political aims tends to obscure the other perfectly admissible political objectives, some of which have been enumerated.

For individual nations, or groups of nations such as the EEC, with some common objective in the supply/demand for minerals, there may be chances of achieving the objective by some form of intervention or bilateral agreement. Each nation or group has its own particular problems to solve and aims to pursue, so there can be no panacea for all of them.

There may be however some ethical guidelines or criteria which many professionals, working within the industry, would probably support. For example:

1. Man must take from the earth those materials he knows how to use.
2. Man must take minerals in the quantities that he needs and rely upon his inventiveness if and when they are no longer available.
3. Conservation of mineral supplies should be ethical if:
   (a) the material is consumed, e.g. the fuels and alternative sources are not available.
   (b) potentially valuable material may be sterilised in the ground by exploitation techniques.
   (c) a mineral is required as a reserve for bargaining power or national security.

4. Changes in the utilisation of minerals are inevitable and should be encouraged if they are conducive to greater efficiency in the utilisation of human and material resources. However, it should be recognised as appropriate to plan the rate of change in such a way as to smooth out the impact of change that is too rapid. Industries, or individuals in those industries, need time to adapt.
5. If there are no such specific constraints, man should use the cheapest available material that meets his specifications.
6. Since energy and labour are two of the principal components of cost, the cheapest available material should reflect low energy and low labour inputs.
7. The objective of working minerals is to produce a saleable product - or in a closed economy to meet a demand. That need not exclude the creation of demand, provided that the demand is itself wholesome.
8. Creation of employment is not a valid objective for working minerals and the artificial use of a large input of cheap labour is undesirable. However, creation or maintenance of employment may well be an expedient that must be taken into account on a temporary basis.

Acceptance of this basic reasoning points clearly in favour of interference in the free market, the adoption of minerals policies and, for implementing these policies, the creation of international agencies.

The arguments against interference and against international agencies depend in the main upon three reasons:

1. that because of conflicting objectives they will be unsuccessful;
2. that the inability to forecast with adequate precision will mean that the policies are frequently likely to be mistaken, because they are designed to counter events that do not materialise.
3. ideological concepts of freedom, including freedom of ownership of portions of the earth's crust.

A comprehensive study entitled Long Term Forecasts for Metals - The Track Record 1910 - 1960's was published by W. Page and M. Rush of the Science Policy Research Unit, University of Sussex (England) last year. That study set out on a statistical basis the successes and failures of the Paley Report (1952), Resources for the Future Study (1964) and the Report on World Tin Position prepared for the International Tin Council, as well as many forecasts in journals. The conclusions were many and varied. Qualitative forecasts are more likely to be near the truth than quantitative ones. Individual professional forecasters appear to score higher than committees and teams, possibly because they are restricting the scope. Explicit models and simple methods were the most accurate. However, many forecasts failed to recognise important relevant future developments outside the metal industries. On the value of the forecasts the authors stressed that accuracy is not the only parameter of interest. Indeed some of the least accurate forecasts may have been some of the most useful. The fact that they were used could, in some cases, have been responsible for their negation.

Perhaps the lessons that may be learned are:

1. Policies based on forecasts should be both flexible and able to tolerate substantial margins of error.
2. Forecasts should be carried out by professionals at regular updating intervals so that accuracy can be improved by experience. A once-off exercise or one carried out only once in 10 - 20 years is unlikely to be accurate.
3. Inherent weaknesses of any model used should also be examined before using the forecasts.
4. Discussion data banks prepared by different organisations should assist in improving the quality of input data. Organisations should be encouraged to model their banks on compatible lines.

Assuming that it is possible to develop and use some form of acceptable forecasting - after all, this conference is founded on acceptance of the forecast that energy minerals will be in short supply - the main problems lie in the arena of conflicting political objectives.

It must be widely recognised that it is not possible to develop new resources other than with a long lead time - usually of several years. Nor is it possible to close down producing units at times of over supply without causing severe consequences, even catastrophic consequences, to whole communities dependent on production for their employment and livelihood. Stability is an objective in its own right.

It is against this background that the efficacy has to be judged of UNCTAD IV, the Commodity Agreements, the Common Fund proposals, GATT, Compensatory Financing, the EEC Stabex and Lome conventions. Normally mineral commodities are lumped into the same agreements as agricultural commodities. They deserve separate consideration. Political and economic objectives are bound to play dominating roles. But minerals are not like canned beans, cosmetics, cigarettes and sweets, that is consumer goods to be turned on and off at the tap. Minerals, like the land on which we live and the seas in which we fish, require both national and international stewardship if they are to be used to permanent advantage.

That stewardship can only be achieved if, in addition to the pursuit of national interest policies, we inject further measures of professionalism into the organisations concerned, laced with international interests for the survival of all nations.

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WORKSHOP 5

MATERIALS EDUCATION FOR THE INTERRELATED ENERGY AND MATERIALS WORLD

CHAIRMAN: ANTHONY KELLY (U.K.)

ORGANIZER: DANIEL DRUCKER (U.S.)

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MATERIALS-ENERGY EDUCATION

H. KENT BOWEN
Department of Materials Science and Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts, U.S.A.

The interconnection between energy and materials has often been pointed out (Department of Energy, 1977), and the recent political and economic events have moved energy science, engineering, management, and policy to the limelight. The temptation is to respond immediately to the societal need and to create a new academic department for this emerging discipline-a Department of Energy Engineering. My personal opinion, and I believe that of most of the MIT faculty, is that to form such a department is not only premature, but also illadvised. The approach to teaching energy engineering should be evolutionary. We must teach students to be fully qualified in the accepted engineering disciplines, e.g., materials, electrical, or mechanical. The major reasons for this are that energy engineering is multidisciplinary or, at best, in specific energy technologies interdisciplinary. Thus, there is not enough time to teach a student all of the principles that would make him an expert in each discipline.

The rational approach at the current time is to introduce the engineering student to concepts about energy as an add-on program. I would like to describe some successes that we have had at MIT in this type of teaching, and in graduate student research in which the theme of energy and materials are intertwined.

EDUCATION: CLASSROOM

The classroom subjects which are an integral part of both undergraduate and graduate programs provide an easy path to introducing the energy-related problems quickly as a need is perceived. There are currently over 40 subjects taught (outside the Nuclear Engineering Department) which are direct-d toward energy problems and two of these are energy-materials subjects. For example, the course on Materials for Advanced Energy Systems relates the specific energy system needs to the available materials and to those properties and processes which need further development.

RESEARCH ON A COMPLEX ENERGY-MATERIALS SYSTEM

The most easily recognized program in which the complex materials-energy interrelationships are demonstrated is laboratory research which involves undergraduates, graduate students, and research staff. An example of this is research on materials for coal-fired, magnetohydrodynamic (MHD) power generators, which involved three faculty members, six research staff people, and over 20 students, and which led to one B.S. thesis, four M.S. theses, and eight Ph.D. theses. Students participated not only in their own laboratory studies, but also in tests in an MHD Simulation Facility, consisting of a 7-megawatt burner, electrode walls, coal slag, etc.

The in-coming graduate student was assigned a literature review problem in order to bec ome familiar with the principles and background of the system, and to provide a back-up data base. Then the particular research topic was chosen as a part of the overall problem. For example, there was a proposal to use electrodes and insulators which might attain chemical equilibrium with the coal slag which costs an MHD channel. The chemical system was simplified to Fe-Al-Si-O, and the critical problems were defined such that individual studies were possible:

Slag:
- Interrelationship between Composition and Electrical Properties;
- Effects of Microstructure on Corrosion of Refractory Materials;
- Chemical Activities of Liquid Sulfates;
- Thermal Segregation of Fe and K due to Large Thermal Gradients.

Electrodes:
- Electronic Properties and Point Defects in Fe-Al-Spinels;
- Atomic Transport Properties in Fe-Al Spinels;
- Thermosegregation and Interdiffusion in Fe-Al Spinels;
- Electron Emission from Ceramic Electrodes.

Insulators:
- Effects of Fe-contamination of the Resistivity of Al_2O_3;
- High Temperature Dielectric Breakdown of Al_2O_3;
- Effects of Microstructure on the Thermal Shock Resistance of Al_2O_3.

The important educational feature of an integrated program was that students took their results into the test rig to determine what contributions the idealizee laboratory studies made to solving the multiphenomena, complex problem. It was clear from this research-education program that students gained a broader, more realistic understanding of the interrelationship between energy and materials.

RESEARCH ON MATERIALS PROCESSING FOR ENERGY SYSTEMS

A new program at MIT is directed to the problem of materials fabrication peculiar to ceramic materials in severe environments. In this case, there are several critical elements: ceramic materials for high-temperature turbines, heat exchangers, or adiabatic diesel engines fail because of processing compromises or processing accidents (flaws); and there is a complete lack of basic data, understanding of principles, and models for developing the new and sophisticated technology for manufacturing parts. "The major and over-riding problem of high performance ceramics is that components with desired properties and microstructure cannot be reliably and reproducibly manufactured" (Department of Energy, 1978).

Our approach here was again related to classroom subjects, and to laboratory research, but most importantly, to solicit the help of the industrial community: to provide advice through a seven-member advisory committee; and to solicit financial support for equipment, fellowships, and research programs not fundable from the usual agencies. Within two years, we have come from some empty rooms and no students, to a modern processing laboratory with over a dozen student and staff researchers. The key to the intense interest of students is that it is very clear to them what impact their research can have on the energy problem--more efficient heat engines, and understanding the principles of process control.

The camaraderie and espirit de corps of the students in these energy-materials research programs are only part of the benefits. It is clear that the end product, the educated materials engineer, is better prepared to meet the challenges of limited energy and materials resources. The future educational programs in energy and materials are even more exciting as other research centers are established at MIT. Faculty and staff are working on a Coal Research Institute, and recently an Institute for Mining and Minerals Resources Research wqs established. Thus the importance of materials beneficiation becomes a part of the total educational experience.

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MATERIALS EDUCATION IN EMERGENT NATIONS

DR. ADENIYI A. AFONJA
Dept. of Metallurgical & Materials Eng.
University of Ife, Nigeria

In the past few decades, the rate of growth of material consumption has become an important indicator of the economic and industrial development of a society. The volume and variety of materials used in a modern technological society have increased at a phenomenal rate and new technological advances call for the development of new materials with unusual properties. The phenomenal increase in the demand for materials has resulted in two major problems: the imminent depletion of the raw material base, and the degradation of the environment. The current challenge to many developed societies is how to maintain the supply of materials and avoid the undesirable consequences. The role of the materials engineer in the developed world therefore is not only diverse but changing rapidly in scope and complexity and the educational institutions are, to some extent responding by constantly reviewing and modifying curricula to reflect the national needs and objectives. The role of his counterpart in an emergent nation is equally complex but of a different nature. He probably grew up in a non-technical environment and trained in a foreign institution which runs courses that are often of little relevance to the needs of his own country. It is not surprising therefore that his chances of fulfilling the role expected of him are very limited.

Very few educational institutions in emergent nations have training programs in materials engineering and when they do, such programs are usually a synthesis of the curricula of a number of top foreign institutions. The first materials engineering training program in Nigeria was introduced at the University of Ife four years ago and the first set is expected to graduate next year. In designing the curriculum, an attempt was made to reconcile the personal needs of the student, considering his background, with national needs and objectives. The extent to which this has been achieved will not be known for many years but the excercise has prompted a detailed study of the needs of a materials engineer in an emergent society and some of the findings are summarised below:

(i) His non-technical background is a major handicap which has to be compensated for at an early stage of his training if it is to be effective.

(ii) He is one of very few in his profession and has to learn therefore to function virtually independently.

(iii) He is expected to be an expert in every area of materials engineering and allied fields. His training therefore must give him a fairly wide scope with relatively low emphasis on specialisation.

(iv) He expects to function in a nation which invariably has no clearly defined technological objectives, hence he must be trained to use his initiative in helping to orient the nation towards identifying and defining her needs.

(v) He often has to assume top-level managerial responsibilities much earlier in his professional life than his counterpart in a developed nation. His training therefore must include material which adequately prepares him for such a role.

(vi) He will often interact internationally with other professionals and he should at least be familiar with the latest developments in materials science and engineering.

TECHNOLOGICAL EDUCATION IN THE ENERGY AND MATERIALS SCIENCE LABORATORY, UNIVERSITY OF NIGERIA, NSUKKA

A. O. E. ANIMALU
Professor of Physics
University of Nigeria, Nsukka

INTRODUCTION

Nigeria has been undergoing a rapid economic and industrial expansion since 1970 as a result of her newly found oil--petrodollars. Nigeria is a member of OPEC, that 20 year-old organization, that made its international presence felt after the October 1973 Middle East War by hiking oil prices. The proven Nigerian crude oil reserve at the time (January 1974) was about 20 billion barrels. The high quality of Nigerian crude oil (sulfur content averages 0.2 percent), the country's geographical location west of the Suez Cannal, and Nigeria's non-involvement in the Middle East dispute favored the oil rush by the industrial nations of the West, notably the United Kingdom and the United States. At the current high rate of output, Nigerian oil would be exhausted by 1995. It is in light of this that one should assess Nigeria's energy requirements in the 1980s and 1990s, and set up an educational framework to create the necessary national awareness of the energy crisis.

ENERGY-MATERIALS LINKAGE

In the meantime, as a backlash from the industrial nations for hiking oil prices, Nigeria and other OPEC members are undergoing economic and political difficulties, primarily as a result of the retailiatory increases in the prices of manufactured goods from the industrial nations. No doubt, this has sparked off a new round of crises in the raw materials coming from the developing countries to the industrial nations. And in the case of the African nations, the South African conflict is a potential anchor for the materials crisis, just as the Middle East conflict was the anchor for the energy crisis. The argument is over the fact that Africa is a vast storehouse of a number of vital mineral resources --almost all of the world's reserve of diamonds and chromium, 90 percent of the cobalt, 40 percent of the platinum, 33 percent of the uranium, 50 percent of the gold, and so forth. It is in light of this energy-materials linkage that one must assess the attitude of the developing countries toward the problems of the transfer of key technologies, such as those connected with the iron and steel industry, the oil and petrochemical industry, and communication systems, from the industrial nations to the developing countries. The prevailing attitude of the industrial nations (through their multinational corporations) is that such a technology transfer may occur (at a rate dictated by their control of world's technological know-how) only by exchange of technology for some vital raw material, such as oil or minerals. These polarized attitudes are responsible for the major problems of underdevelopment--low industrial productivity, lack of import substitution, meager per capita income, inefficient communication systems, etc.--which may be termed the technological crisis.

TECHNOLOGY TRANSFER BY REPLICATION

Being aware of the above energy-materials linkage from the political point of view on the one hand, and the linkage between energy and materials in a thermodynamic sense on the other hand, technological education at the Energy and Materials Science Laboratory, University of Nigeria, Nsukka, has been designed to achieve technology transfer by replication through indigenous effort. To illustrate, suppose that Nigeria wishes to buy a state-of-the-art steel plant from an industrial nation when there does not exist any significant pool of manpower to operate, manage, and maintain a steel plant. And suppose further that the Energy and Materials Science Laboratory is selected to implement the project. The approach of the Laboratory is to mount a large-scale, ambitious, interdisciplinary program to replicate that steel plant on a small scale, starting with the indigenous process (available from local talents, blacksmiths, etc.) in order to define the materials problem. Then a team of professors, staff, students, and technicians and possibly foreign consultants would be assembled to implement the program.

Systems engineers form the nucleus of the replication program. It is their responsibility (with their students) to acquire a thorough understanding of the structure and operating principles of the state-of-the-art steel plant; to design a prototype for the replica; and to supervise the assembly of the replica. The other engineers (mechanical, electrical, and chemical) in the program will be responsible for supervising their students and technicians, as well as for designing, fabricating, and assembling the various specialized components of each subsystem in the prototype in accordance with the specifications given by the systems engineers. The scientists (chemists, materials scientists, physicists, and mathematicians) and their students, in addition to acting as resource persons shall be involved in research, for example, the area of materials specification and substitution. Initially, it may be necessary to import foreign personnel to fill some of these positions; and it is to these posts that Nigerians trained in the industrial nations should be placed when they return to the country. To make the program succeed, enthusiasm and dedication are demanded.

The strength of this program lies with the student. The good student through interaction with the technicians learns their language and picks up most of their skills. At the same time the student interacts with his or her immediate supervisor as well as with the supervisors and students in related fields to gain a broad practical experience in engineering principles, design, and research. Some students may drop out of the program; others find that science and engineering is not their vocation and switch to other disciplines; and yet others find the program too challenging and decide to become technicians. Generally, those who make it through the mill become engineers, scientists, and management personnel. Some of them will work for existing manufacturing companies, while others will pursue careers in academia. It is the latter group who close the loop in this technology-transfer-by-replication process by supervizing a new generation of students in other replication projects. A third group that makes it through the system will become entrepreneurs and form spin-off companies in diverse and specialized areas of technology. This is the group that will ultimately have the potential to convert the country from importer to exporter of technology.

Egyptian Metallurgical Engineers: Is Education Meeting The Changing Situation in Energy and Materials?

T. M. EL-MEHAIRY
(Social Research Center, American University in Cairo)
S. M. EL-RAGHY
(Faculty of Engineering, Cairo University, Giza, Egypt)
A. E. EL-MEHAIRY
(Faculty of Engineering, Cairo University, Giza, Egypt)

The five year curriculum leading to a degree in metallurgical engineering is briefly described, and examples are given to demonstrate to what extent could the contents respond to the changing situation in energy technology and materials supply. Options open to the graduates for higher studies and continuing education are also enumerated and discussed.

The philosophy behind sending students for advanced degrees at universities in countries known for advanced technology is elaborated with special reference to the requirements of a developing country.

It is felt that the crucial question of whether metallurgical education has responded to the changing situation in energy technology and materials supply could not simply be answered by a few persons' opinion. Therefore, a study has been designed to answer this question. The sample will be collected from senior students of metallurgical engineering, university graduates (with at least 2 years of industrial experience) currently enrolled in a continuing education program leading to a diploma, scientists and engineers who received their post-graduate education in developed countries abroad, and senior professionals.

The findings from the questionaires and interviews will be analyzed and presented.

Educational Considerations on Energy-Materials Problems in Developing Countries

FRITZ HINZNER
(University of Chile - Santiago)

The increasing price of oil since 1973 has changed the energy policies of many countries. This situation has had important effects in materials. Many of them also went up in price, but others, due to a recession effect, went down in price. The recent energy crisis has been a hard reminder that natural resources are not unlimited. One could easily extrapolate the past into the future and predict how long our resources will last. Also some fairly elaborate models have been developed which don't necessarily come to such a drastic conclusion, but predict various future energy and materials supply crises (Mesarovic, 1974). This whole situation of material resources, must urgently be reviewed, and new policies which must include educational and information aspects must be elaborated.

Our industry and in general all the consumers, have been used to relatively cheap energy and abundant materials. This situation will not change in the short range, because industries can not be transformed immediately to save energy and materials. Such changes will take place within the next ten or more years. Most probably education and information have less inertia and it should be possible in a much shorter period of time to teach, do research and inform the public in general of the scarcity of resources and how to save them. This has the advantage that, on one side the better informed public on energy matters will be able to pressure industry, and on the other side when industry is ready to make the changes, there should be enough learned scholars in these matters to undertake such improvements.

Since very few countries belong to the OPEC, most of the developing countries were very severely affected by the energy crisis. The high oil prices shifted the balance of payment to the negative side, and since developing countries do not have great reserves, this caused inflationary problems. If one adds the world recession of 1975-76 that reduced the demand causing the price of materials to drop (i.e. copper in 1974 was between \$ 0.80 to \$ 1.00/lb and dropped to \$ 0.55/lb in 1976 - 77), the crisis had a double negative effect. For this reason it is even more important in developing countries to thoroughly inform the people of the energy and materials situation.

This information should start even at the early stages of education, in primary schools, teaching about the resources of energy and materials, the effort involved in making them available to society, how valuable they are and how to save them. During high school some more ambitious tasks can be carried out, making small surveys or research projects where students should investigate and go to the original information on the world resources problems, and become aware of reality in this matter. At the university level the energy and materials education can be better directed toward precise objectives. Obviously Materials Science students will be the most indicated ones for such programs, but also double major programs of Materials Science and other branches of engineering such as civil, mechanical, electrical, chemical and nuclear should be favored. Such experience has been made in many universities such as the University of California, Berkeley with great success (Parker, 1975). Since developing countries are mainly producers of primary or raw materials, the courses on mineral engineering, extractive metallurgy and petroleum engineering should be improved, and the programs modernized. Also there should be courses that describe in great detail the resources of the country in relation to its own present and future needs and evaluate the most efficient way of exploiting those resources for the export market. Research should be directed towards improving the energy intensive processes, and basically develop those materials that save energy. Some typical topics in this aspect are raising the critical temperature of superconductive alloys, developing magnetic materials to make feasible magnetic levitation, etc. (Pick, 1976). All these up-to-date and sophisticated topics, even though very important for more developed countries, would have doubtful success when done in developing countries, since the contribution will not be proportional to the effort of the university and the investigators. Research within the energy-materials field is also important in developing countries but the topics should be directly related to the production of the country. In this aspect an analysis should be made to assess which materials or products give the country a comparative advantage over the rest, and concentrate the efforts in these topics. It is absurd that many developing countries try to produce highly sophisticated products such as cars, specialized electronics and even aircraft at a very high cost, for a reduced market and diverting capital, materials and manpower into such products that in the end do not meet adequate standards and are very expensive. Research and thesis projects should be directed in developing countries, for example to those products that require much manpower which is abundant and less expensive in those areas. Research in food production from fish industry should be very attractive in countries with an extensive coast line. It is necessary to implement and improve the methods for exploring vast areas that are almost undiscovered in developing countries, and above all, improve the methods of the extractive industry which usually are very outdated, very energy consuming and have a low material recovery.

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CONCRETE ENERGY EDUCATION

G.M. Idorn, D.Sc., Consultant

The education in science and technology in the Western world does offer basic knowledge and methodology, which make the students capable to take up work during careers in conservation or development oriented environments. Professors and researchers at universities do themselves work with the creation of new knowledge, besides doing the teaching; but they rarely deal with application of new knowledge in technology - and there are but few courses in the university world today which teach how new knowledge can be used systematically for technology development.

It is an inheritance from the history of science, which has made it a cultural value in the society to operate the dualistic approach of science and technology converging somehow, but not managed as a streamlined move into progress.

In the post-war period this established pattern of a continuity of accumulation of basic knowledge advancing in its own right was set aside by the high-technology industry development; first in the U.S.A., then also in Europe and Japan, and elsewhere.

As long as the new high-technology industries operated with materials and energy from apparently inexhaustible resources the new association of basic science with brilliant technology creativity was accepted by everyone as a singular spearhead of human progress for more consumption and better defense. - What really was conceived was sophisticated management of science, research and innovation.

Naturally, the students of nuclear physics and of electronics and mathematics suddenly became conscious of the tremendous power for development in their basic sciences, which hitherto had remained undiscovered by their academic environment.

But in general, this discovery was not acknowledged by the science and research world, and even less reflected in the academic education. Though maybe indirectly, by seeding the fear for the unknown future which was a feature in the students uprise in 67-68. (Rahm and Segner, 1976, Fakstorp and Idorn, 1978).

The year of 1973 brought an abrupt end to the continuity of high-technology development and unlimited use of the natural resources, and induced new driving forces: depletion of materials, energy and capital. And this while masses of people living in misery in the LDC's commenced to taste consumerism and to see their inherited continuity of "recycling" in rural life ruined at the same time.

The university world in general did not refine its 1967-68 turbulence into a broad campaign for consciousness concerning the rising ghosts of depletion. Thus, until this day one may say that the alerted parties are to be found mostly in the intellectual elite, and in the R & D-intensive industries who have learned to manage development. Within these groups it is envisaged, that further expansion of urbanisation in the world depends upon extraordinary efforts for making technology advances: Energy transfer from natural resources into industry usages must be operated with much less non-recoverable consumption of energy than so far and energy-effectiveness must be singularly improved in the heavy industry sectors, those about primary materials, building and construction, food and agriculture etc.

The broad acceptance of this concept is essential, above all because a penetrating reformulation of science and technology education in universities is indispensable if the next decade shall see the needed changes appear and be accepted in the social life. One might say that while in the past, science most often dissociated itself from the actual demands of industry and society, and at present is exposed to political pressure for letting itself absorb in actual requests on serviceability, the fundamental issue now is that science and technology has not advanced enough to slow down the depletion of the resources sufficiently fast.

The possibility to accomplish this dual requirement is great. Although the high-technology sectors have for many years now enjoyed the glamour of consumers and investors and thereby indirectly contributed to establish the present comparative obsolescence of the heavy industries, the accomplishments of the high-technology industries are now available for modernisation in the sectors that are lagging.

What primarily is required is transfer of the R and D system approach from the developed industries to the heavy sectors so that sufficient innovation can be created. A period of intensive R and D management training should be implemented in universities to accomplish this in broadness, associated with a renovation of research for science application in heavy industries. A deliberate, initial movement to this effect would most likely be enough stimulation to open for a spontaneity which may prove more effective than legislative regulations of the education.

No single theme of science shall be particularly emphasized - except that if the aim is energy efficiency then a broad adaption of thermodynamics in materials technology is indispensable. Not least because so very few students today leave university with the comprehension that thermodynamics is something of relevance to their work in industry.

If at all professionals in the engineering-materials areas are concerned about thermodynamics, they preferably deal with the first law. But to conduct energy conservation on a simple input/output concept does not lead to deceleration of the entropy in any industrial process. And in the heavy industries there are so much Kjoule to count with, that neglectance means invalidation of energy and materials conservation.

Thus, concrete, for instance, with 7000 mill. tons a year is the most produced solid material in the world. And although concrete manufacture in itself is a relatively low-energy process, the proportion of energy consumed during the manufacture itself is appaling, compared with the energy transferred into structural capability and durability during the hydration of the cement paste. Science today possess the basic knowledge to improve this situation radically, but its true thermodynamic character and its implications have not been assessed and made public property, and the vehicle for transfer of science into the potential, refined technology is only incipiently created here and there, not a mainstream of the development as it ought to be and can be made by education.

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Obtention of the Latin American Capacity in Materials Knowledge. Analysis of the Atomic Energy Commission Action

SARA VOLMAN DE TANIS and HERALDO BILONI (CNEA, Argentina)

The Development Branch (DB) of the Argentine Atomic Energy Commission (CNEA) began in 1955 with a dozen of professionals graduated in engineering, chemistry and physics. In a few years they acquired knowledge covering metals physics and technology. In 1958 they fabricated the fuel elements of the first Latin American reactor growing up to more than 50 in 1960. In 1962, with OAS and IAEA support, the First Pan American Course was organized. At the same time technical assistance to the industry began. When the CNEA acquired a nuclear power station the DB took responsibilities in the inspection of nuclear fuels, pressure vessels and other components. At the end of the 60's actions covering fuel elements fabrication, materials science,processes and technical assistance to industry integrated the DB. The further expansion of the nuclear plan and the new technologies incorporated expanded the DB that now is formed by 600 people among scientists, engineers, technicians and logistical support.

The development of the capabilities, as well as their extension to Latin America involved the following actions:

I) Human Resources

i) To overcome university background deficiencies the CNEA organized post graduate courses and sent their professionals to the best international laboratories, at the same time invited professors to teach for short periods. ii) In 1960 a group of fellows started their PhD work and took a full year in Metallurgy. iii) This experience was a basis for the First Pan American Course repeated in 1965 and given yearly since 1967. A new generation of metallurgists appeared and spread out to all Latin American where the graduates started the metallurgical activities. iv) The research fellows of the DB started teaching at CNEA and later on in Latin America. Simultaneously, recycling of professionals from the Industry and the Latin American universities began. v) In 1976 Seminars in specific areas for post doctors began at regional scale. During 11 weeks the best specialists of the world interact with those of the subcontinent in special technological topics. Table I resumes all the training activities.

II) Research and Development

Simultaneously laboratories, pilot plants, workshops, libraries, documentation services, technical assistance to the industry, etc.were organized. In order to obtain capabilities in the nuclear field the CNEA forced the DB to develop and erect research reactors and to interact with the local industry. In the national field DB supported the erection of R&D centers and the engineering postgrade. At international level, special programs with OAS, United Nations and IAEA were impulsed.

Within the OAS frame in 1969 the Multinational Program of Metallurgy started. This program took over most of the training activities previously described as well as activities in R&D. More than 30 PhD theses were made by Latin American students. Associated Latin American research fellows interacted during periods from some months to two years. These actions allowed that Latin American fellows developed metallurgical research in their own countries and that more than 20 laboratories of the region reinforced their capabilities in teaching and in R&D. The research programs gave way to multidisciplinary projects integrated at national and multinational level.

Starting 1979 a new project among seven Latin American countries will be developed in Aluminum and Copper within the OAS that covers not only research but also development of technologies of regional interest. Through UNPD in 1973 a Non Destructive Testing Institute was created, equipped with up to date facilities that helps the industry all over the country (Table I resumes the courses given in this frame) and extends to Latin America through the OAS Project.

Conclusions

1. In the metallurgical area many research groups with international level were developed.
2. New R&D institutions were created and others backed up.
3. The output in training and R&D was more than 60 PhD theses and international journals, 600 internal reports, notes for all the above mentioned courses and seminars, more than 60 PhD theses and 50 for masters degree.
4. Hundreds of scientists of international level visited the laboratories in coordinated research plans.
5. The OAS and UN support permitted to extend the activities to Latin America. A firm support from the country and these international organisms allows the application of a pragmatic methodology to overcome regional differences.

Recommendations

In the materials field this methodology could be applicable to Latin America and other developing regions as follows:

1. Preparing the curricula vitae of the future engineers and MSc.
2. Up-dating the knowledge of the professionals working in the field with intensive trainings in the new technologies and materials.
3. Organizing 8-10 weeks' seminars for senior level professionals. In these seminars would be discussed:i) necessity of R&D in new materials; ii) high level courses for participants having good experience in fields as metals, ceramics, plastics, etc.; iii) discussion of the planification for medium and long terms at regional and national level; iv) convenience of erection of new R&D institutions.
4. Establish a network between the existing laboratories and institutes to start the R&D activities in new materials on the basis of the human resources now working in the region.
5. The international organisms as the OAS and the UN should play an active role for these actions.

Courses	N° Courses	N°Participants
Cursos Panamericanos de Metalurgia 1960-1974	10	200
Curso de Entrenamiento Avanzado en Metalurgia 1976-1978	3	20
Recycling courses for professionals of the industry* 1960-1978	107	1.595
Recycling courses for scientists 1969-1978	66	1.171
Post-doctoral level Seminars 1975-1978	4	89
PhD Thesis		62
Master degree thesis		55
Courses and Seminars in Latin America 1969-1978	73	2.500
Associate fellows from Latin America		26

TABLE I

* Includes the short courses given in the Pan American Course, by the Institute of Non Destructive Testing, in industry, etc.

Materials Education : Options and Goals

Israel, 1984 - 1999

D.G. BRANDON

Dept. of Materials Engineering

Technion, Israel Institute of Technology

Materials education in Israel is available at three levels: Technicians are trained in technical high schools, where the options available to them include courses on Metallurgy, Polymer Technology and Strength of Materials. Engineers also are required to take general courses in Materials Engineering and in consequence acquire varying degrees of familiarity with the terminology and concepts of the subject. Finally, specialist education in Materials Engineering is available, at either the B.Sc. or the M.Sc. level or both, in four of Israel's five universities.

At each educational level there is strong pressure to make materials courses more practical and technologically "relevant" (to today's technology, that is). As a result there is a well-recognized danger of turning graduates into "monkeys minding machines." Although no generally agreed strategy exists for combatting this tendency, much lip-service is given to two unconnected lines of defence. The first of these is the development of a sound basic technical education, independent of technological expertise. The second would require student exposure to problems of professional ethics and an improved student awareness of the social context of technology.

In Israeli engineering education, core subjects, such as Thermodynamics, Strength of Materials and Applied Mathematics, are seen to embody concepts which have very general application. In this respect such courses are different in kind from courses on Engineering Metallurgy or Materials Science. Nevertheless the depth of understanding required of the student in his core subjects must be supplemented by an adequate familiarity in breadth with modern technology, for example with methods of power generation, transportation and communication, and, of course, production and processing of materials.

The second line of defence, exposure to ethical problems, has so far received little encouragement and less support. Although many Israelis are basically sympathetic to the twin problems of conservation and pollution, there is a general feeling that Israeli society is threatened by more immediate dangers which require more urgent attention. Even so, there remains some awareness in Israel that technological solutions to the problems of our society are at best partial solutions and are prone, at worst, to spawn even worse problems than the ones they solve.

A good zero-order approximation to our future needs is to assume that tomorrow's need will remain identical with today's requirements, only more so. Seen in the light of this approximation, Israel has two dominant characteristics which are relevant to any discussion of our educational infrastructure and its future development. The first is the small scale of Israeli society (the population of the country is about three million). The second is the very wide spectrum of technological activities being undertaken in Israel, both in terms of levels of achievement and in terms of varieties of expertise. This second characteristic generates an overwhelming imperative for flexibility* in technological education. It is fortunate that the first characteristic helps to assure us that such flexibility is in fact an achievable goal.

One approach to an educational programme which would be both self-consistent and would have the necessary flexibility for the future could consist of three ingredients. The first, which could loosely be called "Engineering Science" would include the best possible teaching of core subjects leading to an in-depth understanding of concepts such as 'stress', 'entropy' and a wave equation. The second of the ingredients would be a broad state-of-the-art survey of both established and newly-developed technology in the student's chosen field. For the materials specialist, such a survey could range all the way from shipbuilding to microelectronics and should certainly include a programme of factory visits and work in industry. The third and final ingredient would consist of projects and seminars on the interaction between technology and society. This last ingredient should provide much more than ethical background to professional engineering practice. It could include, for example, strictly practical insights into the economics of production, the marketing of products and legal aspects of professional responsibility.

In a Utopian engineering faculty these three ingredients would not be served up as separate course items, but would be blended into

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* The rather vague term "flexibility" can be brought into better focus if we think in terms of two additional parameters. The first of these is needed to gauge the type and level of the technological skills we require, and to distinguish established technologies from newly developed industrial fields. The second can serve as a yardstick for the relative economic and social value of labour, materials and capital in any given production process and for any specified social context.

one another to provide a variety and continuity in the student's educational experience which would mirror the kaleidoscopic variety of both today's and tomorrow's technology. The lead-time for implementing major changes in university education is about five years. If we plan today it could help to prepare us for the pressures of 1984, but who will teach the teachers?

MATERIALS EDUCATION IN A DEVELOPING COUNTRY

E. C. SUBBARAO
Indian Institute of Technology, Kanpur 208016, India.

INTRODUCTION

India is a typical developing country, characterized by a large population (550 million in 1971) with a predominantly rural bias (440 million dispersed in 570,000 villages), low percapita income ($86 compared to $4274 for U.S.), low percapita commercial energy consumption (189 versus 11,128 kg of coal equivalent per year for U.S.). Non-commercial sources provide most of the energy for rural India. Materials education in a developing country for the interrelated energy/materials field is discussed here against this unique background.

ENERGY CONSUMPTION

The percapita total energy consumption in India is 565 kg coal equivalent, with 264 for rural and 1773 for urban population. The non-commercial sources (including human and animal) provide 89 percent of the energy consumed in the villages. Firewood, dung, and agricultural wastes contribute 86, 40 and 60 percent of the total energy in rural, urban and whole of India respectively. In a village, energy consumed in domestic work, agriculture, small industries and transportation are 64, 22, 7 and 3 percent of the total respectively (Ravelle, 1976). Eighty-eight percent of the commercial energy is consumed by 20 percent of the population living in urban areas (Parikh, 1976).

By 2001, the rural population is expected to reach 660 to 800 million out of a total of 870 to 1110 million. This calls for a ten-fold increase in coal and electricity as energy sources continue to play a significant role.

RELEVANT TECHNOLOGIES

The fast growth rate of the commercial forms of energy in India is expected to follow essentially the same path as in developed countries: larger sized thermal plants at coal pit heads, hydro plants, breeder reactors and possibly magnetohydrodynamics. Work is in progress on all of these. Those technologies are emphasized here which generate small packets of energy from local, preferably renewable, sources and supplied to dispersed populations with low levels of energy consumption. This becomes imperative for social, economic and ecological reasons, besides the prohibitive transportation costs (National Academy of Sciences, 1976; Häfele and Sassin, 1977).

The two important relevant energy sources are biogas and solar. It may be recalled that India has a large cattle population (235 million out of world's 1275 million) and that bullocks are used for farming and transport. In the biogas plants, the animal dung and agricultural wastes are fermented anaerobically in a tank. The biogas (CH_4 60-65, CO_2 30-35 percent) provides a clean, convenient and efficient fuel for cooking and lighting, while the residue from the plant which contains 2 percent nitrogen is a good fertilizer (Parikh and Parikh, 1977). It would be advantageous if the biogas can be converted into electricity via a fuel cell. Steel and cement constitute 40 percent of the cost of the plant ($250 for a 2 m^3 or 64 ft^3 unit). Though some 20,000 biogas plants have already been installed, engineering analysis and application of materials technology can optimize the design, cut costs and maximise fermentation.

The renewable, non-polluting, dispersed solar energy is ideal for rural applications, since the insolation values are high (7-8 $kwh/m^2/day$) and costs are independent of size. Both the thermal and the photovoltaic routes have their unique uses. Solar water pumps could decrease the load on rural electrification. If photovoltaic solar cells come down in cost to about $1 per peak watt, they will have a dramatic effect on rural India.

Storage devices, particularly rechargeable batteries, are important in villages either to store energy from intermittent sources such as solar or to supply small packets of power.

MATERIALS EDUCATION

Following a conference of materials science education in 1966 in India, materials science found a firm place in the engineering curriculum. Over 150 college teachers were trained in short, intensive courses which included a laboratory. In 1971, an interdisciplinary graduate programme in materials science has been initiated at the Indian Institute of Technology Kanpur, where an Advanced Center for Materials Science has recently been established to provide a focus for research on materials of national importance and to train manpower in this field. More institutions have since started materials science programmes.

INTERRELATED MATERIALS/ENERGY WORLD

Special courses developed in this area are typified by one on Materials for Energy Conversion and Storage which emphasizes the unconventional energy conversion methods much as solar, biogas, fuel cells and storage devices including rechargeable batteries, besides courses on photovoltaic devices, solar thermal processes and bioengineering, etc. Some of these programmes are particularly relevant to developing countries and are best developed and offered in them. International cooperation along the following lines could be most valuable: (a) visiting faculty; (b) sister institution relationship between selected institutions with strong programmes in the Materials/Energy field in developed and developing countries; (c) cooperation in diffusion of relevant or adapted technologies; and (d) joint specific materials research and development (e.g. Si from rice husk and ferrosilicon, polycrystalline Si solar cells, selective coatings and collectors, methane-based fuel cells without using Pt, storage devices including rechargeable batteries, etc.).

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Materials Education for the Interrelated Energy/Materials World

DR. J. A. CLUM
Department of Metallurgical & Mineral Engineering/Extension
University of Wisconsin-Madison

DR. C. R. LOPER, JR.
Department of Metallurgical & Mineral Engineering
University of Wisconsin-Madison

A few years ago we presented our view of how materials education may be adapted to the problems of scarce energy and raw materials. (1) In that presentation at the 1975 Annual Meeting of ASEE we described the type of curriculum adjustments which can train materials engineers for an economy which is based on recycling. It was clear to us at that time that the traditional metallurgical or ceramic engineering curriculum which included extractive courses was well suited to a materials recycling professional's training. That is, the basic physical chemistry and unit operations courses which are central to extraction from virgin raw materials can be readily adapted to extraction from wastes and discarded materials.

The major link between historical extractive operations and recycling operations was shown to be based on a special topics course in which students were exposed to actual cases. In such a course the use of principles in recycling operations was shown to be analogous to historical methods.

By necessity such a course must also examine the effects of dealing with unusual contaminants in the recycling 'ore.' Those effects are considered not only as they affect processing but also for their effect on properties of the products.

The use of such a course continues to be effective in our curriculum where it is available to both graduates and undergraduates and to non-metallurgists, as well.

We would offer this scheme as a rather easy means of adapting current materials curricula to the future materials/energy problems.

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Educational Modulus for Renewable Resources

R. L. YOUNGS
(U.S.Department of Agriculture, Forest Service,
Forest Products Laboratory,
Madison, Wisconsin)

Engineering educators are increasingly aware of the importance of providing students with a background in materials science and of the energy and resource implications of materials use. Such educators tend to concentrate on metals and nonrenewable resources--this despite the fact that the worldwide consumption of wood, exclusive of that used as fuel, approaches a billion tons per year, twice that of steel. Rough timber used by farmers and primitive people might double what is accounted for by regular commerce. On a weight basis, wood and steel are comparable in strength. The total burdens carried by wood must be comparable to those carried by steel. Wood fibers form the basis for the massive paper industry and for essential fiber products. Resource and energy considerations lead us to believe that renewable resources will have more importance in the future. These facts are not reflected in present engineering curricula.

In the week of August 14-17, 1979, the Forest Products Laboratory, in cooperation with the University of Wisconsin, the National Science Foundation, and the American Society for Engineering Education will conduct a Workshop on Wood as an Engineering Material. The workshop will bring together 30 selected materials science educators and 9 specialists who will serve as session instructors. Discussion will center around nine topics important in understanding wood as a material. The primary output of the workshop will be a set of written "modules" for engineering instruction. Each module will be equivalent to a class period and will be available nationally and internationally through the National Science Foundation project on Educational Modules for Materials Science and Engineering. While the first workshop will concentrate on materials at the undergraduate level, workshops in subsequent years will give emphasis to civil engineering, architecture, and fiber products.

WORKSHOP 6

MATERIALS SCIENCE FOR MORE ENERGY
EFFICIENT MANUFACTURING

CHAIRMAN: JAMES MATTICE (U.S.)

ORGANIZER: CHARLES BERG (U.S.)

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Manufacturing Techniques and Materials for Heavy Construction

Thomas E. O'Hare
Brookhaven Laboratories
Huntington Station, New York

My experience is with process plants, primarily, oil refining, fertilizer, and petrochemical units, and to a lesser extent, pulp and paper and iron and steel plants. These plants use high technology, and large equipment and are highly capital intensive. Indirect charges associated with capital (interest, taxes, insurance, depreciation, constant dollar indexing, etc.) are usually greater than 60 percent of unit operating costs, the remainder being raw material and energy.

The engineering, purchasing, and construction of process plants is of fundamental importance. There are many instances where competitive units as designed contain 30 percent less material and 20-35 percent lower operating costs.

The replacement cost of mature technology cannot be achieved from present depreciation reserves and retained earnings because of inflation factors. We cannot afford to duplicate what we have and even if we could, it may be uncompetitive in the world's market place.

Clearly, something must be done. Many have said that we must invent new processes. However, in so doing, more recognition must be given to less energy-intensive materials; the energy quantity embodied in different materials; and the lifetime energy cycle of materials.

A yield improvement in a chemical process that involves a reaction at high temperature and pressure may not be economical in today's accounting because the high-strength alloy for the vessel and associated piping may contain too much energy that is already capitalized. This in turn, will lead to inflated labor costs in purchasing and erection because of budgetary and schedule difficulties, not to mention, the costs associated with one-of-a-kind activities.

In other words, we must recognize the interdependence within our industrial economy. Giant strides in manipulating process reaction kinetics and catalysis in chemical plants must be accompanied by equally giant strides in the materials of construction or the potential economics and technology advantages will not be achieved.

In our energy accounting procedures, we should add in all of the energy expenses associated with a given material and its fabrication, from its inception to its contemplated use and subsequent obsolescence. In so doing, our choice of materials may change; the materials of construction, rather than the process conditions, may dictate the plant design philosophy, or we may invent new materials.

Future Directions For Metal Treating

BERESFORD N. CLARKE

The blacksmith's temple still stands at the foot of the Accropolis in Athens. The Bible tells us that ancient Israel was lost for want of a smith. For an industry that has been around for a few thousand years it seems reasonable to hope for recognition in the near future of the metal treating industry's unique ability to conserve more energy and material than it uses as well as to recognize its vital place in our lives.

The metal treating industry has the capability of producing very significant energy and material savings in return for relatively modest commitments in the energy required for it to function. This ability to conserve more than it consumes has not been fully recognized or provided for in the National Energy Plan of the United States which currently relegates metal treating to priority level 5 or 6.

The near future should bring about an increased educational effort to acquaint engineers and designers with the characteristics of metals and their alloys, and with the enhancement of these characteristics produced by heat treating. Our machines should be designed to do their intended jobs without being either over or under designed. Achievement of the full potential of available new materials and processes depends upon improved communications among the involved disciplines and basic engineering and scientific education.

The metal treating industry is beginning to look with suspicion at pleas for conservation of the fuel it uses. In response to pleas for conservation it has achieved substantial reductions in the use of natural gas but these reductions have not resulted in increasing our national energy bank account. It can be demonstrated that conservation by the metal treating industry results in the transfer of the saved energy to domestic and commercial uses. The future direction for this industry must involve a clarification of the goals and results of conservation if the basic philosophy of conservation is to remain believable.

Following World War 11 there was a period of approximately twenty years during which very few fundamental developments in heat treating equipment and processes were made. The first major new technique to become available was the use of varying degrees of vacuum to replace protective atmospheres in the heat treatment of metal. Today this process is mature and equipment and information is readily available. The future will bring further development of partial pressure carburizing which uses basic vacuum equipment.

Fundamental developments in metal treating have historically resulted from the need to solve a specific problem which concerned an individual company. Often such developments are proprietary and are not available for general use. The common need to reduce our consumption of energy and materials as well as the dedication of the scientific press and professional societies has done much to reduce this secrecy. Recently, details of the ion nitriding process as well as equipment for its accomplishment have become available. As larger numbers of users supplement the fifteen years of in-house experience of a few original developers, the future developments in this general field should be significant and useful.

Methods for the surface hardening of large numbers of parts using laser and electron beam processes are available for use in production situations. Future development to increase the flexibility of these processes to permit more general application is needed.

With the realization that the period of cheap natural gas has ended, increasing attention is being paid to substituting mixtures of industrial gases for generated atmospheres. Initial results are encouraging. Substantial reductions in natural gas consumption are achieved and the overall system energy balance is favorable. A DOE sponsored research program in this area is well underway and full disclosure of results is accordingly guaranteed.

Paralleling the development of substitute atmosphere systems is a revival of interest in using hydrocarbon fluids to provide feedstock for atmosphere generators and directly in furnace chambers to generate neutral and carburizing atmospheres. The use of a combination of hydrocarbon fluids and industrial gases may provide the flexibility which will permit heat treating processes to be carried out where natural gas and propane are not available. Current investigations will continue well into the future.

There appears to exist substantial future opportunity for the application of the efficiencies of induction heating methods to heat individual workpieces while they are enclosed in small individual work chambers. Into these small work chambers could be injected precise small quantities of carburizing atmosphere at ultra high pressures. Activation of this atmosphere might be achieved by ionization to achieve deep case depths in short periods of time with precisely controlled characteristics.

The metal treating industry is often and easily overlooked. It continuously contributes in ways which affect almost every aspect of our daily lives. It possesses an arsenal of processes and technology which have not been completely recognized nor fully exploited. The metal treating industry is ready to help solve many of our most distressing industrial, scientific, and economic problems. The effective employment of this available weapon is the responsibility of groups such as this one.

Laser Processing of Materials

BERNARD H. KEAR
(United Technologies Research Center)

The adaptation of lasers to materials processing tasks got its start in the mid-1960's. At that time, only pulsed lasers were available commercially, so that applications were limited to simple operations, such as hole drilling, trimming and spot welding. Later, with the advent of continuous wave lasers, the range of applications expanded to include cutting, welding and heat treating operations. There are now a number of successful industrial cutting and heat treating operations using high power lasers, as well as a few significant welding applications. Within the past few years, successful demonstrations have been made of the usefulness of lasers in other areas of materials processing. Illustrative of these new processes are laserglazing, laser shock hardening and laser machining.

'Laserglazing' is a new method for the surface treatment of materials involving surface localized melting followed by rapid solidification and subsequent solid state cooling. In practice, the desired surface treatment is obtained by rapidly scanning a sharply focussed, high power density laser beam over the workpiece surface, or by indexing the workpiece with respect to the fixed beam. Optimum surface properties, e.g., enhanced corrosion, erosion and wear properties, are usually achieved by melting in pre-alloyed material. Using available high power cw lasers, very high melt-quenching, or cooling rates (up to 10^{8}°C/sec) can be realized in appropriately thin sections. Even higher cooling rates (>10^{10}°C/sec) are attainable in very thin sections (<1μ) using high power density pulsed lasers. This feature has recently been exploited to obtain complete recovery of the surface structure of ion-implanted semiconductor crystals. A variety of metallurgical microstructures have been produced by laserglazing, including amorphous metallic solids, extended (supersaturated) solid solution phases, metastable phases, ultrafine eutectics and refined dendritic structures.

'Layerglazing' is a related development, in which a bulk rapidly solidified structure is formed by the sequential build-up of one laserglazed layer upon another, using a continuous supply of pre-alloyed feed material. Provided that the feed material is delivered to the interaction zone at a precisely controlled rate, bulk structures of remarkable structural integrity can be fabricated. Apart from the structure/property advantages inherent to rapid solidification processing, the layerglaze process also permits structure and properties in bulk parts to be graded as desired, since it is a simple matter to substitute one feed material for another as the structure is built-up. Incremental solidification processing by layerglazing can also be combined with incremental thermo-mechanical treatments (deformation and annealing), so as to further modify the structure and properties of the bulk part. So far the layerglaze process has been applied to the fabrication of simple axisymmetric shapes. It is anticipated that, following the introduction of sophisticated numerically controlled work stations, it will be possible to fabricate parts of arbitrary shape.

'Laser shock hardening' is a process that utilizes very high power density pulsed lasers to effect surface hardening. The energy density in the beam must be sufficient to cause nearly instantaneous surface vaporization, so that the rapid expansion of the vaporized material produces an effect similar to a blast wave. As a consequence, a shock wave propagates and reflects within the material and causes extensive work hardening. Although some surface melting normally occurs under such intense laser irradiation, this can be avoided by employing a sacrificial coating, such as black paint. The shock hardening effect has been demonstrated for a variety of materials, and has been exploited to re-harden fusion and heat-affected zones in welded material. Since the peak pressures generated by the process are very high, interest in this area of laser processing is now centered on effective control of laser-induced pressure and thermal transients to produce high pressure metastable phases.

'Laser machining' refers to the process of material removal by means of a high power density laser beam, without the use of a cutting tool. The process has been applied successfully to the shaping of difficult-to-machine ceramic materials. Laser machining of ceramics occurs either by an ablative, or spallation mechanism, depending on the material properties. Ablative machining is characteristic of materials that sublime rather than melt, e.g., silicon nitride, whereas spallation machining is characteristic of thermal shock prone ceramics, such as alumina. Surface contouring is achieved by moving the workpiece in a controlled manner through the interaction zone of peak power density in the focussed beam. In practice, a short focal length laser is preferred so that material removal occurs only at the exact focal spot of the beam. Laser machining of ceramics into arbitrary shapes seems to be a realistic prospect for the near future.

So far, commercial applications for these new processes have not been realized. However, since the potential is clearly there, it seems only a matter of time before they will become commonplace in industry. In addition, laser processing research continues unabated in many laboratories throughout the world, and new concepts and opportunities are constantly being recognized. For example, interest is now developing in laser spraying, laser atomization and laser controlled gas phase reactions, such as chemical vapor deposition. It seems reasonable, therefore, to conclude that the future holds great promise for a rising tide of successful applications for lasers in materials processing tasks.

To summarize, lasers are becoming important tools for materials processing tasks. Lasers have already made an impact in traditional areas of materials processing, such as heat treating, welding and cutting. Furthermore, new opportunities for laser processing have been identified in a number of different areas, including machining, rapid solidification processing, spraying and gas phase reactions. The incentive for applying lasers to materials processing tasks derives from the unique capabilities of lasers as means for energy delivery. These capabilities include precise control of energy delivery at high power densities, precise control and limitation of process interaction times, accurate control of the location of energy deposition because of the ability to focus finely, the ability to operate out-of-vacuum in a variety of gaseous atmospheres and at various pressures, the cleanliness and remote nature of the laser as a heat source, and the adaptability of lasers to computer control and automation.

Manufacturing with Polymers

NAM P. SUH
Massachusetts Institute of Technology

Many metallic parts can be replaced with polymeric parts in a cost effective and energy efficient manner. These are typically parts used at low temperatures. The total energy required to manufacture plastic parts is much less than that required for metal parts. This is because the conversion of monomers into polymers consumes less energy than the refining of ores into metals, and because some polymer processing techniques require less energy and are simpler than metal fabrication processes. Therefore, it is expected that many metallic parts used at low temperatures will be replaced by polymeric parts, especially by composites with fiber reinforcements.

The energy consumption in the polymer industry can further be reduced if some of the present irrational processes are replaced by more rational ones. Many thermoplastics undergo several cycles of heating and cooling before they are made into final products; the energy consumed in most mixing processes is a few orders of magnitude larger than the minimum energy required for mixing, due to redundant work; and the phase separation of polymers from solvents and water require as much as 5000 BTU of energy per pound of rubber produced. In many elastomeric products the energy cost can be in the neighborhood of 15% of the overall manufacturing cost. There should be great incentives provided to improve the manufacturing processes for the purpose of reducing the manufacturing cost and the energy consumed.

A few examples of less energy intensive processes developed at MIT will be given to illustrate the future potential energy savings in the manufacturing field through a rational development of materials and processes. Among the processes to be discussed are the direct forming of thermoplastics, electromechanical mixing of viscous liquids, mixing of elastomers, and the MIT reaction injection molding system for polyurethane.

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WORKSHOP 7

SCIENCE AND TECHNOLOGY FOR ENERGY EFFICIENT MATERIALS FROM RENEWABLE RESOURCES

CHAIRMAN: SANGA SABHASRI (THAILAND)

ORGANIZER: JAMES BETHEL (U.S.)

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Energy From Biomass

KYOSTI SARKANEN
University of Washington

Until the middle of last century, mankind depended on biomass to fulfill most of its needs for energy and chemicals. Later, in developed countries, coal assumed the role of dominant fuel, to be replaced, in time, by petroleum. Now, when the depletion of global petroleum reserves is in sight, the question arises as to what extent the recent historical development may become reversed. In particular, we are interested in the future potential of biomass resources as a source of energy, in competition with such alternative sources as coal, hydroelectric power and nuclear fuels.

It should be noted first that the use of biomass for energy is not limited as much by its overall availability as it is limited by problems associated with collection, transportation and storage. Far too little attention has been paid to the logistics of these operations in the past. In contrast to fossil fuels, biomass concentration in any given area is generally small and its fuel value is lower - 9000 Btu/lb as compared to 12,000 Btu for coal and 18,000 for fuel oil. In addition, the natural moisture content of biomass materials limits its useful fuel value even further.

Under these constraints, biomass fuels are not really transportable fuels today. Their use for energy is limited to the utilization of accumulated biomass waste, such as spent liquors of the pulping industry wood waste from lumber and plywood mills ("hogged fuel") and municipal waste. Even so, biomass is supplying 1.8 quadrillion Btus (quads) to the U.S. economy, mainly in the form of energy recovered from pulping liquors and waste wood in the forest products industries.

Several ways may be considered for the improvement of the transportability of biomass fuels. These include:

- drying and compaction
- conversion to charcoal
- conversion to liquid fuels

So far, trials to upgrade biomass fuels have met with limited success only. Examples of currently practiced methods are the pelletization of sawdust and agricultural residues and the conversion of low-grade wood to charcoal. It should be noted, however, that the combination of efficient collection and fuel upgrading methods could bring relatively large quantities of unutilized biomass to the category of transportable fuels. Examples of this sort include logging and agricultural residues and whole-tree chips from low-grade hardwood forests. The annual U.S. production of straw and similar agricultural residues has been estimated to be approximately 400 MM tons. In the West Coast area alone, the residues and waste wood left to the forests to rot amount to about 800 MM tons.

Conversion of Biomass to Energy. Extraction of energy from biomass can be performed in two different ways: either by direct combustion or by first converting biomass to more versatile gaseous liquid fuels. Direct combustion is widely practiced in pulp mills. The energy-generating facility consists of storage area, conveyer system and boiler. For the same energy output, the investment cost is 3.5 times higher than that of an oil-fired facility, and the operational cost is likewise higher.

Tillman has pointed out that a more advantageous comparison with oil-fired furnaces is obtained if the steam produced is utilized for the cogeneration of electric power and process steam, or alternatively steam for district heating. In this case, the wood-based facility requires only 2.1 times higher investment cost than an oil-based facility.

Improvements in direct combustion methods are possible. Reducing the moisture content of the wood fuel by drying would improve the energy recovery in combustion. Replacement of conventional spreader-stoker furnaces by fluidized sand bed burners may result in more economic boiler designs. Gains in the efficiency of the operation resulting from such improvements will, however, not be very substantial.

Conversion of wood or charcoal to producer gas containing CO, H_2 and methane is an old and well-known technology. Recent war-time experience has demonstrated that such gas is a useable although inferior fuel for automobile and diesel engines. Under normal conditions, gasifiers operating on waste wood may be used to product auxiliary fuel for oil- and gas-fired furnaces and operational units for this purpose are commercially available. Gasification of biomass fuels could undoubtedly gain major importance, if it were possible to use producer gas turbine-boiler combinations.

The fermentation of such biomass materials as sewage, manure or kelps to methane gas also represents old and well-known technology, potentially applicable in locations where such materials are available in sufficient quantities.

Liquid fuels may be produced from biomass materials in a number of ways. Alcohols, particularly methanol and ethanol, have been extensively discussed recently. Ethanol can be produced from such varied biomass materials as sucrose, surplus grain, corn starch and softwood glucomannans using well-known hydrolysis and fermentation methods. Its production from sugar cane is planned on a major scale in Brazil for use as automobile fuel supplement. In the United States, a large number of people believe that the cellulose component of biomass materials could become a large-scale feedstock for fuel-ethanol production. It should be noted, however, that the amount of cellulose is less than one-half in lignocellulosic materials and severe losses occur in the hydrolysis to glucose. Furthermore, the separation of ethanol by distillation from dilute fermentation solutions is an energy-intensive step. It would seem, therefore, that the conversion of lignocellulosics to methanol via producer gas would be a more advantageous way of obtaining liquid fuel from this source. For methanol, on the other hand, coal is a better feedstock material, as shown by the careful process analysis carried out recently by Dr. Raphael Katzen.

Another approach to biomass liquefaction consists of conversion to fuel oils either by pyrolysis or by reductive cracking. Both methods are currently being investigated. Pyrolysis produces, in addition to fuel oil, pyrolysis gas and char and requires relatively simple engineering design. Higher yields of fuel oil are obtained in reductive cracking, performed with pressurized carbon monoxide with sodium carbonate as catalyst. This method, developed by the U.S. Bureau of Mines, requires an elaborate engineering design. The overall impression obtained from experimental data on both methods is that they may lend themselves better for the production of such chemical feedstocks as phenols, carbon black and levoglucosan than liquid fuels.

Professor Calvin has proposed that polyisoprenoid extractives present in certain plants to the amount of 10 to 20 percent of the biomass weight be used as source for liquid fuels, gasoline in particular. This approach requires the establishment of large-scale plantations and the engineering feasibility of Dr. Calvin's proposal has not, as yet, been demonstrated.

Conclusions. Summarizing the available information, it appears that direct combustion of biomass materials will remain the dominating method of energy generation from this source for decades to come. The competitive position of biomass fuels may be improved by cogeneration methods and by the development of more effective methods of collection, transportation and drying. It is to be expected that such large-scale sources of biomaterials as agricultural and logging residues will soon enter the category of practical fuels. Waste wood gasification will probably become a useful method for producing limited amounts of supplementary fuels and similar minor contributions are to be expected from methane generated by fermentation methods. The conversion of biomass to liquid fuels appears to be of doubtful practicality, with the exception of the generation of ethanol from surplus grain or sulfite pulping liquors.

Even with this conservative estimate the total annual contribution of biomass to the energy needs of the United States could grow to the level of 6 to 8 quads by the year 2000 - an estimate given recently by Tillman. This amount corresponds to nearly 10 percent of the total energy needs and is of the same order of magnitude as the energy contribution anticipated from such alternative sources as hydroelectric power or nuclear energy. It is also obvious that conditions outside of the United States, particularly in many developing countries, are often more favorable towards development of biomass energy sources than those in our country.

Five New Machines and Five Structural Products Can Triple Commodity Recovery from Southern Forests--And The Manufacturing Operation Can be Energy Self-Sufficient

PETER KOCH
Chief Wood Scientist
Southern Forest Experiment Station
Forest Service, USDA, Pineville, Louisiana

While national demands for structural wood products are rising, annual timber harvests in the West are leveling off; increasing the product yield from southern and eastern forests appears to be one tactic for avoiding projected shortages. Mixed southern pine-hardwood stands now yield 20 to 22 percent of their tree biomass in wood products.

A new energy self-sufficient system (fig. 1) using tree pullers, wet-fuel burners, mobile chippers, shaping-lathe headrigs, and continuous kilns can convert 67 percent of the biomass (above- and below-ground parts of trees of all species) into products worth about $150 per dry ton. Products of the system are pallets, dowel-laminated crossties (no adhesive), structural exterior flakeboard, structural lumber glue-laminated from veneer, studs, and hogged fuel for plant energy. Composite structural panels or fiberboards could be made also. Application of the system could provide high returns to private landholders while halting incursion of low-grade hardwoods into the southern pinery.

The concept, called Biomass Retrieval and Utilization with Shaping-lathe Headrigs (BRUSH) has been more fully described by Koch (1978)[1/].

[1/] Koch, P. Five New Machines and Six Products Can Triple Commodity Recovery from Southern Forests. Journal of Forestry 76:767-772. 1978.

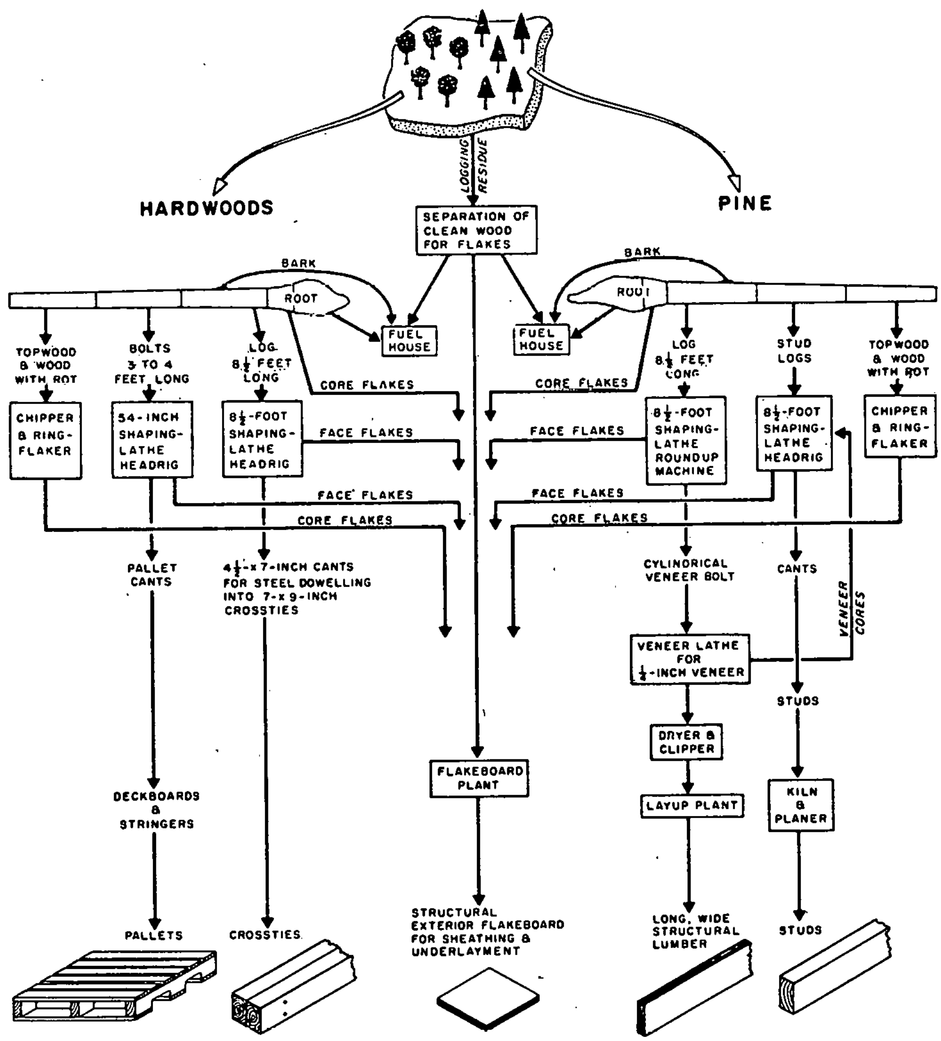

Figure 1.--BRUSH system flow plan, whereby 67 percent of above- and below-ground biomass of trees in mixed-species southern forests ends as pallets, crossties, structural exterior flakeboard, long wide structural lumber, or as studs. The system is self-sufficient in energy. (Drawing from Koch 1978[1/].)

Energy From Grape Marc

DR., GERNOT GRAEFE
Submitted by Prof. Dr. Erich Schmid

Grape marc treated according to a proper method is a considerable energy carrier. Applied adroitly, it influences other organic substances and holds a key position in effective recycling in agriculture, forestry and horticulture. Thorough investigations on an optimum application of grape marc were carried out by the Institute of Comparative Behavioristics of the Austrian Academy of Sciences in the years from 1973 up to the present. In 1978 as a result of this research, a large-scale bioenergy converter for utilization of 1,200 t marc was built and put into operation in Austria.

The method comprises eight sequential phases of which phases 2 and 8 are suited for long-time release of heat. In phase 2, primarily all esters produced during the first process step are decomposed by microorganisms. In phase 8, oils and nutritive reserve substances exposed after grinding the seeds are processed microbially while simultaneously releasing heat, carbon dioxide and moisture.

Amongst all the various biomasses, grape marc is particularly suited for utilization. It is available in accumulations and incurs no transport cost if processed near wineries. Heat release occurs preferably during winter seasons. Assumedly, no other organic material exists in such large quantities which is able to develop in so very small quantities this kind of rapid hot rot and which can be handled as easily.

After esterification is completed during the first process step, the marc material is stabilized to a certain extent and can be handled in such a way as to effect an aerobic hot rot only in the intended place and at the intended time. Separated and unground grape seeds are storable. They may be transported to their place of application and ground there if required. Subsequently, temperatures up to 64^{o} C develop within a few hours. Heat and carbon dioxide production of hot seed groats may be applied to plant cultures under glass or plastic sheeting inducing increased growth and an earlier harvest.

Wherever energy yielded by hot marc rot is used, whether in horticulture, for hotwater supply or for space heating, the final product when cooled down will always be an organic fertilizer much more valuable than its unrotted basic material. By applying all process steps, three different kinds of fertilizer with different qualities are obtained and, whether from seeds, skins or stems, have one common characteristic, i.e. that in addition to a certain humidity they do not contain anything but organic substances, trace elements in equilibrium and vegetable nutritive substances, the latter surprisingly concentrated.

Supply of Renewable Resources

ROBERT N. STONE
(USDA-Forest Service Forest Products Laboratory)

Man has learned to make things from an astonishingly large number of materials. Some are renewable, they tend toward being restored. The major renewable sources of stuff are the living things--both plants and animals--that can grow and multiply. It may be useful to also define plants and animals as expandable resources since mankind has learned to manipulate and increase their production. They can be cropped, or exploited to extinction.

This workshop is concerned with renewable materials with energy implications, excluding food. Consequently, we can focus on forest products from timber lands and largely ignore the seas, range and agricultural lands as presently having much more to do with food production than as suppliers of renewable materials.

The fact that timber is biologically renewable appeals to those concerned with long term supplies of materials. By enlarging the use of timber, a renewable resource, non-renewable resources such as fossil fuels ought to be conserved, thereby delaying their ultimate physical scarcity. However, such reasoning should be conditioned by careful evaluation of economic reality (Manthy, 1977).

Clearly the distinction between economic and physical supply must be made. At a single point in time the physical stock of a resource can be visualized as a constant. Its economic supply depends on the price, hence is a variable. But passing time can bring new supply discoveries, new technology, and new products that lead to redefining the useable stock of a resource so that in effect physical supply over periods of time may appear to also be a variable. We should spend some time discussing the distinctions between physical and economic supply.

Nor does biological renewability forestall economic depletion. Replacing the magnificent old-growth Douglas Fir that are gradually being cut out along the West Coast is as unlikely as is restocking the gas fields of Michigan by chemical conversion of aspen leaves, because of economic impracticality not lack of technology. We might discuss in this workshop what renewability means in the resource supply connotation.

Present knowledge about the forest resources is incomplete for many countries of the world. Inventories of the world's forest resource are inadequate to define patterns of change in timber supply. Available forest-area and growing-stock-volume estimates for 1973 are shown in Table 1. (Persson, 1974).

Table 1. FOREST-AREA AND GROWING-STOCK VOLUME ESTIMATES FOR 1973.

	Closed forest (million ha.)	Growing stock volume (100 million m^3)	Forest area per capita (ha.)
North America	630	585	2.8
Central America	60	55	0.7
South America	530	915	2.8
Africa	190	250	0.5
Europe	140	120	0.3
U.S.S.R.	765	735	3.2
Asia	400	380	0.2
Pacific Area	80	60	0.2
World	2,800	3,100	0.8

Source: Persson, 1974.

These estimates are supported by field inventory data of only some 40 percent of the world's forested areas. The productive forest area of 2,800 million ha is a more reliable estimate than is the 310,000 million m^3 estimate of growing stock volume. This is partly the case because defining forest is less difficult than is defining usable timber volumes. The FAO estimate of annual timber growth for 1973 on these forests is 3,000 million m^3 (Persson, 1974). This indicates a rate of timber growth below 1 percent but 20 percent greater than the volume of timber harvested.

Forest area per capita is unevenly distributed as shown in Table 1. The area of forest land in developing countries was less than one-third that of industrialized countries.

In his summary of world forest resources, Persson estimates the manmade forest area at 100 million ha (247 million acres) or 4 percent of the world's productive forest area (Persson, 1974). Although a significant achievement, these plantations will not change a world timber situation that still depends almost totally on natural forest areas.

This brief overview of the forest resources of earth is superficial beyond pointing out the vastness of the forest areas and timber inventories in existence and the ratio of the timber "reserves" to current extraction levels.

There is a growing need to know precisely how fast forest area is being reduced, how much wood of the many kinds and tree sizes there is, and where it is; how fast it is growing and can grow; and how much is being removed. We face the future with inadequate timber resource information. Another important question for discussion in this workshop is "Is there a need for resource inventory by means of modern technology, e.g., satellites?"

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Resource Renewability

BRUCE ZOBEL
North Carolina State University

Resources are for the use of Mankind, but prudence necessitates that they be used wisely. For many materials, resource use must be equated with reduction in supply, i. e., they are not renewable. A notable exception is the general area of forest products, which are a renewable resource. With reasonable management, currently available forest products can be used indefinitely but they can be improved and the supply increased. The potential productive capacity for the wood resource is several times greater than the current inventory and, in fact, where good forest management is being practiced, the inventory of cellulose is increasing at a rapid rate. The too often-expressed hysteria of "Save that tree," "Don't harvest the forests" is a most puzzling reaction, fostered by persons who really know nothing about forest production. Trees are not destroyed; the mature ones are harvested and replaced by young, vigorous, healthy forests.

There are numerous reasons why wood is so valuable as a renewable resource; I have space to list only a few reasons, so have chosen examples only for purposes of illustration:

1. Wood requires less energy to convert into useful products for construction than do most other major resources. The trees are planted, then grow with very minimal energy input until harvest age. Conversion to lumber or plywood requires a low energy input and most mills have enough residue and waste to supply more than the energy needs to convert the tree into the final product.

2. There are many kinds of trees with variability in wood qualities that is almost unbelievable. This enables utilization of wood for many diverse products and it makes possible an efficient usage of the total land resource available.

3. Wood qualities can be changed or varied by the forest manager with no extra energy need. Of course, different species produce different kinds of wood, but major differences in wood are also possible within a species. Changing the harvest age of the trees will drastically affect the quality and utility of wood, and special wood qualities are easily obtained by breeding for the

desired characteristics. We now have strains of loblolly pine that have been developed with wood qualities ideal for newsprint, others for tissues, others for bags and boxes, and others for high-grade writing paper. No other raw material has the potential and flexibility to be developed into a more suitable final product without the need for large amounts of energy.

4. The renewable forest resource serves many purposes in addition to supplying the desired raw material. There are aesthetic benefits from the forests as well as benefits from more and better water, clean air, land stability and wildlife. All of these additional uses can be maintained at high levels while the forests are still producing the wood needed, despite some loud vocal comments from the uninformed who would like to restrict forest usage for their single pet purpose. But forests are a renewable resource for all the goods and services listed when proper multiple-use management is employed.

Additional use of our forests is the potential to supply energy and base chemicals for plastics and other industrial products. There is no doubt that the energy needs of the forest industries, including the high energy-using paper industry, will soon be totally supplied by trees, mostly from utilization of what were formerly considered to be waste products. There is much interest and research about growing trees specifically for energy through the use of so-called "energy plantations." The method is quite feasible botanically but the economics of alternate usage of wood for fibers or for energy is not yet clear. Continuous and renewable production of energy from forest lands poses no problems that can't be easily handled. In my opinion, the use of the renewable forest resource as a base chemical for industrial products is more feasible than the use of wood as a primary energy source. The organic chemicals available are similar to those from petroleum and coal and can be used for the same purposes. The matter is also one of economics. Plants for chemical conversion are planned and methods are known for operational production of chemicals from wood. The main restraint is the uncertainties of the petroleum market.

Many things can be produced from the renewable forest resource. Solid-wood products, such as boards or plywood, consume very little energy so have a very low-energy input to end product ratio. Many wood chemicals, extruded cellulose and other, can be converted to multiple products, some such as hardboard, some fire-resistant board, and some with excellent accoustical properties. The disadvantage of the latter type of product or those from extrusion is that they require a rather high energy input.

Forests can produce many products with low energy input. We now have the knowledge to have the forest resource as renewable indefinitely; even better, we can increase the inventory of cellulose severalfold if present knowledge about forest management is utilized.

Importance of Improved Forest Utilization and Engineering Design to World Energy Problems

JOHN G. HAYGREEN
(University of Minnesota)

By the year 2000 about 25% of the world's energy consumption is likely to be consumed in developing countries as compared to only 15% today. In the developing nations the overall demand for energy will increase 4 or 5 fold over the next 25 years. A large portion of this increase, about 40% of it, will be used by industry to produce the materials needed to improve peoples' lives.

The increased demand for industrial energy to produce products needed for housing materials and paper are going to be competing in many countries with the growing populations' need for cooking and heating fuel. In 1975, the non-OPEC developing countries of the world had a population of about 1.6 billion people. By the year 2000 this population is expected to exceed 3 billion. The increased demand for fuelwood will have a major impact on the wood supply available for industrial use. In India, as an example, noncommercial energy was estimated at 59% of total energy consumption in 1960 and 48% in 1970.

The forest products industries have the potential for producing as much energy from residues as is consumed in the manufacturing process. Consider a situation, typical in countries with tropical forests, which demonstrates what is technically feasible at this time. A large integrated forest products complex consists of a sawmill, plywood plant and a pulp mill. The annual wood consumption in the plywood plant and sawmill is 1 million cubic meters per year and an additional 500,000 cubic meters per year are used as pulpwood. Of the 1 million cubic meters for the sawmill and veneer mill approximately 60% become chips and residue. By using chips and residues plus harvesting an additional 700,000 cubic meters per year to generate energy, the entire integrated complex could be made energy self-sufficient. In other words, if the annual harvest were increased from 1.5 million cubic meters per year to 2.2 million cubic meters per year the wood, bark and residues available could generate as much process steam and electricity as is consumed. Fuel for harvesting and other vehicles would be the only energy to be purchased.

The energy/materials balance may not be as favorable for non-integrated forest products industries although even here the potential is promising. The major use of energy in lumber manufacturing is for drying, which consumes about 65% of the total energy used. Energy for drying in the form of process steam is easily obtained from bark and wood residue. A typical sawmill in the United States develops enough slabs, edgings and sawdust that if this waste is converted to energy there would be 30 to 50% more energy produced than is used in the manufacture of the lumber. For independent pulp and paper firms the situation is more difficult as this is an energy intensive process. Much of the energy used for pulping, particularly if it is a mechanical or partially mechanical process, is in the form of electricity. While electricity can be generated from wood residue the capital costs are high as compared to systems for generating process steam.

The forest industries in developed countries are rapidly switching to the use of wood residues, bark and even roundwood as a major source of process steam and electrical power. Countries poor in fossil fuels should do all possible to encourage the development of forest industries which can avoid the economic burden of imported oil. However, at present there appears to be a lack of technology and technology transfer which is slowing the move to energy self-sufficient forest industries in the developing countries.

In developing countries, as illustrated by the example given above, there is tremendous opportunity for energy saving through more complete utilization of the resource. The same opportunity exists in North America and Europe, but to a lesser extent. Wood shortages in these areas have led to more complete utilization and much of the easily obtained residues are already utilized. In the developed nations a major opportunity for energy conservation in materials use is through improved engineering and design of buildings. Two aspects of design are involved. Engineering the structure to provide satisfactory service with a minimum quantity of materials and to require the minimum amount of energy for heating and cooling. Unfortunately, means of meeting one of these objectives often has a negative effect on the other. The amount of research and development directed toward these areas of opportunity has been minimal. Potential savings in heating and cooling energy through improved design has been shown to exceed 50%, in extreme climates. Unresolved problems, however, include adequate ventilation or infiltration and moisture condensation in wall and ceiling cavities.

The impact of energy cost and availability upon nations and peoples is obvious as are the implications for employment and income. The formulation of national materials policies intended to insure long range availability of necessary materials must consider the energy implications. The effects of energy on national materials policies has yet to be crystalized and in fact may never become a major concern.

of governments pulled in many directions by economic and social "crisis". There is therefore a major need to develop authoritative information on the impact which greater use of renewable wood products could have on national energy and material resource needs. A systems approach must be developed and used to evaluate the interaction of population, energy, environmental concerns, and the greater utilization of energy-self-sufficient renewable materials.

Government officials, politicians and the general public are realizing the problems related to energy costs and supply, however they do not generally recognize how forest based industries can play a positive role in helping a nation meet its industrial material and energy needs. In fact they often do not even realize that there is any connection at all between future energy needs of a country and forest products development. To awaken decision makers to this relationship is difficult. In order to develop a systematic approach to these materials/energy relationships, as a means of providing the information base which is needed, there is need for new means of cooperation between educators, scientists and engineers in all fields of materials science. The term material science is used here in a broad sense, not the very limited sense which in the past often excluded materials from renewable resources.

Recycling Primary and Secondary

J. Rodney Edwards
American Paper Institute

As materials and energy conservation gain focus in the industrial sector of the economy the paper industry has a number of accomplishments, in both, worthy of recognition. The paper industry is somewhat unique compared to many other basic manufacturing industries - its raw material, wood fibers, can be used to make paper or burned as fuel.

In the paper industry for the year 1978:

- Almost 60% of its fiber requirements are recovered waste materials. 24% is waste paper, 35% is waste wood from lumber and plywood manufacturing and the use of both waste materials is increasing.

- Over 47% of the industry's fuel requirements are internally generated when spent pulping liquors, bark and waste wood are burned in the mill's power plant.

Looking more closely at waste paper recycling in 1978, a record 16.7 million tons of waste paper were collected in the U.S. which represented 24% of the 69.5 million tons of paper and paperboard consumed. This was a record high demand for waste paper and reflects increased use of this raw material by the paper industry itself and a record high demand for exports.

Of the 16.7 million tons recovered, 14.8 million tons of waste paper were consumed in the manufacture of paper and paperboard products, 3.8% above the corresponding 1977 total. Waste paper exports increased 5.8% from the previous year to 1.6 million tons, while imports declined by more than 20% to 70,000 tons. The consumption of wastepaper for other uses, such as packaging materials and insulated bags, remained at 140,000 tons. Usage in the manufacture of cellulose insulation dropped an estiated 70% in 1978 to 150,000 tons.

The growth in the recovery of waste paper should be looked at by analyzing the grades collected. Over 35% of the corrugated board consumed in the U.S. was collected last year accounting for the largest portion of paper recycled. Recovery of these grades amounted to

5.3 million tons of used corrugated boxes and 2 million tons of clippings from box plant converters. This reflects the expanding usage of old corrugated at mills making linerboard and corrugating medium.

The recovery of old newspapers dropped in 1978 to 25% compared to a 30% recovery rate in 1977. There was a peak demand for old newspapers to manufacture cellulose insulation during 1977, but when many recycling mills found old newspapers in short supply, they shifted to using more old corrugated containers. In 1978, the sharp decline in cellulose insulation manufacture contributed to the drop in the recovery rate for old newspapers to 25%.

High grades, which include pulp substitutes and deinking grades of waste paper, showed minor changes last year. 1977 consumption levels were maintained throughout 1978, with a slight increase experienced towards the end of the year. Over 3.1 million tons of all high grade waste papers were recovered. The increased demand for paper-making fibers to manufacture printing, writing and tissue grades caused the year-end pick up in demand for deinking and pulp substitute grades. New capacity to make tissue products came on stream last year creating additional pressures for high grade waste paper.

The paper industry is expected to utilize increasing quantities of all waste paper grades during 1979. The API Capacity Survey shows that the paper industry alone has the capacity to consume 17 million tons this year and 17.5 million tons in 1980, if it operates at capacity levels. The planned increase for waste paper usage is distributed among all paper and paperboard end products. The largest utilization however, will be used corrugated boxes at mills producing paperboard for packaging such as boxboard for folding cartons and containerboard for corrugated boxes.

In the U.S. waste paper recycling depends upon a number of factors:

First, Americans must make an extra effort to recycle waste paper. It must be source separated and kept clean from other contaminating materials. In homes, old newspaper can not be comingled with moist and putrid wastes. It must be string tied in bundles for collection by charitable groups, municipal trucks or individuals who deliver old newspapers to recycling centers, waste paper dealers or consuming mills. The same is true for old corrugated boxes which are generated in retail stores or factories.

Second, there are 200 paper mills that depend almost exclusively on waste paper for their raw material. Another 300 mills use a portion of waste paper in their furnish.

Third, there are over 1,500 waste paper dealers throughout the U. S. that buy waste paper from collectors and sort and bale it for shipment to recycling mills.

Fourth, over 60 million Americans are active in waste paper recycling. This is an estimate; the actual number is probably much higher. Many recyclers are volunteers and the income earned goes to their club or organization for special projects. In 1978, dealers and mills paid $60 million for old newspapers alone, and, 3 to 4 times that amount was paid to those who source separated the other grades that are recycled.

Fifth, a new grade of waste paper is starting to be generated in office buildings where workers sort their clean white waste paper from all other wastes and the company organizing such a program sells this higher grade waste paper to dealers.

Sixth, increasing export demand will put pressure on the U.S. collection system. The U.S. is the largest exporting nation. Many countries who buy waste paper from the U.S. have already maximized their domestic collection and to expand their paper industry will depend on shipments from the U.S.

The future of waste paper recycling is not without problems. The Solid Waste Act of 1965, The Resource Recovery Act of 1970, and The Resource Conservation and Recovery Act of 1976 put the Federal Government in position to help municipalities solve the mounting garbage problem in the U.S. In 1978, cities will collect about 140 million tons of garbage at a cost of about $4 billion. According to EPA about 29% of the total is waste paper. Of course, if the 16.7 million tons of recyclable waste paper were not separately collected the burden on the municipal collection and disposal system would be much greater.

As landfills are running out and as new ones are difficult to locate, solid waste officials seek new disposal systems. Because of the energy situation, attention is being focused on burning solid waste to generate steam and electricity. When an incincerator is built to burn garbage it is almost always "over sized" and authorities must take steps to maximize the "put through." In some cases this has meant precluding the collection of waste paper for recycling and directing it to the incinerator where it can be burned to recover its fuel value. Frequently, this is called "recycling" and residents are told that it is preferable to put their newspapers in the garbage can so that they can be recycled into energy. This has the result of convincing Americans that they no longer need to make that extra effort to recycle waste paper to recover its fiber value.

The paper industry believes that waste paper should be recovered to be used at its highest economic value - today that is recycling. Recyclable waste paper must be source separated so that it is not contaminated with food wastes, tramp materials and moisture. It is not economical to recycle all waste paper, therefore, that which cannot be recycled can be burned to recover its energy value. However, in the future, as the demand for waste paper for recycling increases, there must be provision for it to be diverted from incinerators to the recycling mill.

The paper industry refers to this as "the burning issue" and is now organized to monitor the development of resource recovery programs in the 170 largest SMSA's in the U.S. In each city we intend to point out the importance of the waste paper recycling industry. We will identify the number of recyling mills, waste paper dealers and the tons recycled, to set a priority of source separation programs for recyclable waste paper over programs to burn it as fuel.

In the Energy Conservation Act of 1978, the Congress made the assumption that recycling waste paper saves energy and charged the DOE with setting targets for increased use of waste paper through 1987. Although recycling waste materials can save energy in industries such as aluminum, it is not necessarily true of the paper industry. There are many complexities that must be taken into account. Probably most important is mill location. Every paper mill requires steam to generate power and to dry paper. The amount of energy required depends upon the temperature of the incoming water. Therefore, northern mills will require more energy per ton of output than southern mills irrespective of the mill's raw material. The amount of internally generated fuel is also an important factor, some mills are almost 100% independent from fossil fuels. Another factor is that a number of paper mills are burning coal.

The interrelationship of fiber and fuel requirements is taking a new perspective. Several companies are investigating the economics and feasibility of burning municipal solid waste in their power plants. These mills will, of course, require source separation of recyclable waste paper, and will probably remove glass and metals for resale and burn the remainder to generate steam and electricity.

Conclusion

The paper industry is working to increase its utilization of waste materials, both waste paper and waste wood. It will reduce its dependence on gas and oil as boiler fuels and may even be burning municipal solid waste in the future.

More waste paper must be collected to meet domestic and export demands. Separate collection of source separated waste paper reduces the burden on municipal solid waste collection systems.

All programs will be undertaken when they prove to be economically attractive in that they reduce fiber costs and/or fuel costs at the same time making a product that is competitive in the market place.

Energy Conservation Through Improved Conversion

R. L. JAMISON, DIRECTOR OF ENERGY MANAGEMENT
(Weyerhaeuser Company, Tacoma, Washington)

Wood biomass is an ideal example for this years International Materials Congress focus on interrelationships between energy and raw material uses of renewable material. The forest products industry currently harvests about 200 million dry tons per year of timber and uses the residuals to supply 45% of the energy needed for product manufacturing. The industry is progressively becoming more energy self-sufficient by seeking ways to more fully utilize not only each tree harvested, but also more of the biomass grown on each acre.

Today, more than ever, it is important to make effective use of limited resources. This implies putting each unit of raw material to its highest use in addition to maximizing yields and utilization. Improved conversion efficiency is the key to conservation of materials and energy.

In this session we will discuss some of the barriers impeding progress and try to identify some opportunities. Four subject areas will be covered: 1) supply of wood residuals, 2) environmental constraints on use of wood energy, 3) technology options, and 4) efficiency considerations.

Wood wastes from manufacturing operations are the most readily available source. And in areas where a surplus still exists, these manufacturing residuals can be cheap. However, the supply is rapidly depleting, as higher value components are selectively channeled into raw material uses. Sawdust, for example, replaces pulp chips; planer shavings are going into particleboard; and bark is becoming garden mulch. Nationwide, only 20-25% of the manufacturing residuals generated each year are still not used, and in Oregon State less than 5% are unused. As long as the value of wood for raw material remains roughly double the value for energy, raw material uses will preempt the supply. However, when these manufacturing residuals are gone, the next increment of wood energy will be forest residuals; i.e., currently unmerchantable biomass now being left on the acres harvested. The cost of bringing in forest residuals is substantially higher compared to manufacturing residuals. And, contrary to expectation, this cost will increase as larger quantities are delivered to a single point. There are two reasons for this: first, transportation costs increase as the area of wood harvest becomes larger, and second, more and smaller pieces must be gathered from increasingly difficult terrain, because the easy to get material was recovered first. Where terrain is level and the stand is close to point of use, forest residuals can be delivered for less than $20 a dry ton. Where terrain is steep, or distances longer and pieces larger, as in the Western United States, costs may run up to $40-$60 a dry ton delivered. The message seems clear: We must find cheaper ways to collect and deliver forest residuals.

Environmental constraints are in effect impeding greater use of wood for energy. In the past, wood emission standards have been based more on aesthetics than health or nuisance hazards. An extensive literature search has failed to turn up any health hazards from wood burning. Assuming this initial conclusion is sustained, a revised emission standard specifically for wood fueled combustors would seem justified. Wood is a relatively clean fuel. It has very low sulfur content, compared to most oils and coals, and the ash in wood is of lesser quantity and less objectionable than coal ash. Yet air emission standards are identical for existing large coal and wood waste fueled combustors (if capable of combination firing with oil or natural gas). In order to meet particulate standards, costly control equipment must be installed, typically adding millions of dollars of capital in order to reduce particulate emissions a few percent more. Using effective combustion controls and two stage cyclone collectors, particulate emissions can be controlled to .7 lb. per million Btu of fuel at a capital cost only 25-30% of best available control technology (BACT). In a typical case, BACT removes less than 1% more particulates per million dollars of capital, or 38 pounds per hour compared to 6000 pounds per hour for a million dollars invested in cyclone collectors. BACT also increases electrical energy consumption significantly. In a typical case the power requirement went from 400 kw for 2 stage cyclones to 2000 kw for a wet scrubber. Two stage cyclone collectors appear to be a reasonable compromise between health, nuisance, economics and our national goal of reduced oil imports. If a mechanism could be found, leading to a resolution of this highly complex tradeoff, it would be a very significant contribution.

As higher-value, clean, dry fractions are removed from the flow of manufacturing residuals, the remaining material becomes wetter and dirtier; i.e., its fuel quality deteriorates. To burn it efficiently and cleanly requires better technology than is conventionally in place. Three solution approaches are possible: 1) develop new improved performance combustors, 2) convert the fuel into other forms or purify it, 3) put environmental controls on existing combustors. Adding environmental controls is the least desirable, because energy use is thereby increased. Furthermore, this usually creates both water and solid waste effluent problems, it is costly and inflationary. The second approach would make it possible to extend the lives of existing oil and gas fired equipment by converting solid wood into gaseous or liquid forms. Otherwise, existing equipment must be replaced with conventional wood burning equipment, having capital costs three or four times as much as gas/oil equipment. A number of new technologies for pyrolyzing or gasifying wood into cleaner, more convenient fuels, that can be burned in existing burners with only minor modifications, are in various stages of development. The first approach is also being pursued, with fluid bed burners being one promising example. The fluid bed acts as a thermal flywheel, absorbing slugs of moisture and dirt in the fuel that typically cause boiler stacks to turn black due to incomplete combustion. The merits of all three approaches will be discussed in relation to opportunities and needs of industry.

The moisture content of wood waste fuel normally varies from 35-65%. Higher moisture content results in significantly lower thermal efficiencies. Boilers fueled on wet wood typically operate at 63-67% efficiency compared to industrial fossil fueled boilers at 75-85% efficiency. The efficiency of wood fueled burners can be increased in several ways: 1) by drying the wood, 2) by making the fuel stream more uniform, so less excess air is required, or 3) by converting wood to other fuel forms such as oil, gas or char. We must be aware, however, that there is no free lunch. It takes energy to do all of the above; the bottom line is <u>overall</u> efficiency. If excess air can be reduced, or the stack temperature lowered without increasing the volume of flue gas, we have indeed increased efficiency. Another efficiency opportunity is to expand cogeneration. Several industries, including pulp and paper, already cogenerate a major part of the electricity used. Large users of process steam have an option to generate steam at high pressure, pass it through a steam turbine to generate electric power, and then use the exhaust steam for process. Electricity is thereby generated far more efficiently than even a large utility, which has to reject two-thirds of its fuel energy to cooling water or the atmosphere. A further improvement in power generation efficiency would result from use of gas turbines in a combined cycle with steam turbines. But the technology for firing gas turbines with non-premium fuels is not quite ready. In the interest of improving our national energy efficiency, cogeneration and combined cycle are being touted; we will discuss potential barriers and incentives for overcoming.

Development of Harvesting Systems that Reliably Deliver Wood to the Fuel Pile at Low Cost is the Key to Economic Success in Use of Wood for Fuel

PETER KOCH
Chief Wood Scientist
Southern Forest Experiment Station
Forest Service, USDA, Pineville, Louisiana

Direct combustion is the most promising process for converting wood to energy. The forest products industry is the industry which can profit most from use of this process. Many major forest products plants in the southern pine region can approach, or achieve, energy self-sufficiency by combusting unused hardwoods and logging residues.

The logistics of supplying such plants with wood are impressive. For example, a 50-megawatt electrical generating plant requires three 25-ton trailerloads of green pine-site hardwood hourly, 24 hours per day--every day.

Handling of such tonnages at the plant site is a solvable problem. Throughout the South pulp mills are routinely transporting comparable quantities of roundwood and chips to receiving facilities, preparing the wood, delivering it to storage piles, and retrieving it for use.

The great unsolved problem is harvesting pine-site hardwoods and other logging residues at a cost that will permit economic conversion to energy. Today, at least half the biomass in pine-hardwood forests customarily remains there after harvesting. These residues are wasted, and destroying them during site preparation for the ensuing tree crop may cost $85 per acre.

Significant work recently has been done toward developing equipment and techniques to harvest certain classes of residual woods such as cull hardwoods 3 inches and larger in dbh standing on gently sloping terrain (Harris, 1977; Bryan, 1978), southern pines and hardwoods with taproots in sandy or clay soils (Koch, 1976, 1977), and woody residues on rolling rock-free terrain (Koch and Nicholson, 1978). However, before the South can utilize a great part of its residual wood, the more difficult classes of residues must be extracted at low cost; for example, economic methods are needed to harvest short, crooked, limby, hard oak and hickory from the steep rocky hills of north Arkansas.

Before useful solutions to the harvesting problems can be achieved, detailed data characterizing the above- and below-ground biomass on each important site are needed, together with a description of soil characteristics such as tolerable bearing pressure, rock content, and slope. These studies can be made by presently available experienced people--all that is needed is money. The next step is far more difficult; only a high degree of engineering imagination coupled with ample budgets in numerous centers of innovation will bring useful solutions to these difficult harvesting problems. In such an effort there will be many more failures than successes.

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The Energy Intensity of Forest Products--
An Observation and a Suggestion

JEROME F. SAEMAN
(U.S.Department of Agriculture, Forest Service,
Forest Products Laboratory,
Madison, Wisconsin)

The demand and price situation for petroleum in the years ahead poses an unprecedented threat to all people. The optimistic view is that new fossil fuel resources will relieve the problem for the next decades, and advanced technology will eliminate the problem in the next century. Even a small risk of failure, however, is unacceptable; so the search for lower energy-intensive systems is mandatory. This requires us to pursue diverse approaches rather than search for one universal solution.

In the view of many of us, increased relative dependence on timber as an industrial material is one of the more effective ways of reducing the energy intensity of our existing system.

This hypothesis has led to elaborate efforts to estimate the precise energy intensity of the wood-based segment of our economy as compared with other segments based on nonrenewable mineral and petroleum resources. For the most part, the cost and complexity of such efforts has been high, and the impact of the studies on national policies has been low. There is little chance that such a study would ever be financed and directed in adequate fashion.

It is not always necessary to base decisions on massive, meticulous studies. I submit that some decisions can be made with moderate chance of error on the basis of very general considerations, and in some cases "error" does little harm.

Our timber supply can be more than doubled with much less significant environmental impact than that characteristic of modern agriculture. As things are going, damage to soil by annual crop production will interfere with the production of food long before our production of timber will be diminished. It is difficult to imagine people faulting us 50 years hence for providing them with more timber than they want.

Our existing forestry practices and our existing siting and use of the timber resource were established in a period of abundant, low-cost energy. Even so, forest products have low relative energy intensity. With new siting and new forestry practices, our entire forest products industry can be made energy self-sufficient, requiring in net balance no fossil fuel for the production of forest products.

Forest products evolved in their present form on the assumption of very low raw material and energy costs. All existing structural products, panel products, and fiber products can be produced in higher yield and with higher performance.

Pound for pound, wood products can provide structural members competitive with steel for many applications. On the newly important basis of energy input, we can use as a working hypothesis the assertion that wood products, for very many applications, outclass the alternatives, and we can advantageously increase our relative dependence on wood as an industrial material.

This already familiar statement is offered not as a basis for hard-lined policy, but rather as a basis for support of research and activities which help maintain or increase the relative place of wood in our economy. Funds in sufficient amount to prove or disprove this hypothesis with a small margin of error may not become available. We can, however, act confidently on the hypothesis with little adverse consequence if we are in error. This is a case which calls more for objective decisions by competent specialists than for intensive formal study.

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WORKSHOP 8

MATERIALS SCIENCE AND TECHNOLOGY FOR MORE ENERGY EFFICIENT TRANSPORTATION

CHAIRMAN: I. G. C. OGLE (CANADA)

ORGANIZER: MORRIS A. STEINBERG (U.S.)

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Materials Science and Technology For More-Energy-Efficient Transportation

NILS CHR. TØMMERAAS
(R&D Corporation, Automotive Parts)

The key issue in transportation is to bring the payload from place A to B. There are however many restrictions which limit us from selecting the most energy efficient methods; comfort, speed, safety, noise and pollution are important, so are also prejudices and investments made in infrastructure and manufacturing. This discussion is therefore limited to suboptimalisation of transport by road, in particular concerning the weight/energy problem. The present generation of road vehicles are designed through evolution and manufacturing cost optimalisation. The energy content of the materials and has been of no importance, the energy consumed by the vehicle has only been of importance as a factor in the total operating cost picture. Even though the energy price has risen sharply in the last years, the price for petrol and diesel fuel is still so low that it does not heavily influence the operating costs.

Instead of increasing the fuel price by heavier taxation, the US government has decided to reduce fuel consumption through legislation. These regulations are limited to passenger cars and to light trucks and are expected to influence the automotive design world wide.

The energy contents of the materials used and the energy consumed in the manufacturing of a road vehicle are negligible as compared with the energy consumption throughout the operating life of the vehicle, regardless of the construction materials selected. Energy optimalisation can therefore be focused on reduced energy consumption per unit of transporation.

For passenger cars the average number of passengers carried seems to be independent of the size and seating capacity of the vehicle. Travelling distance may therefore be selected as unit of transportation, and "energy-efficiency" can be measured in MPG or litres per 100 km. For buses and heavy trucks the appropriate measure is passenger kilometers and ton-kilometers per liter of fuel consumed. Fuel consumption is basicly determined by four factors:

Driveline efficiency
Rolling friction
Air drag
Acceleration resistance

All these factors can be influenced by materials science and technology. So far the emphasis has been put on the first two items. The modern petrol and diesel engines are highly more efficient than some years ago, both concerning the combustion efficiency and the weight to power ratio. This is particularily so for European and Japanese engines, and has to a large extent been brought about by the European taxation system. The development of the highspeed, high compression ratio engines has however been made possible only through a continuous development of materials and manufacturing technology. This is one of the best examples of applied materials science.

There has also been an important improvement in bearing technology, in lubricants and in tires. This has reduced the friction losses in the driveline and has reduced the rolling resistance.

The air drag is a function of velocity, front area and the aerodynamic shape of the vehicle. The only factor which can be significantly influenced by materials science is the availability of materials and manufacturing processes which give the necessary freedom of shape. The effect of air drag increases dramatically with road speed, and is almost without effect in city driving.

Energy consumed in acceleration is proportional to the total inertia of the loaded vehicle. The energy used for acceleration is of particular interest in city driving and for vehicles which have frequent stops, like buses and distribution trucks. Both for busses, distribution trucks and for passenger cars the vehicle curb weight is by far greater than the average pay-load. It has been shown that 40% of the total fuel consumption for passenger cars in the US CVS-tests is caused by acceleration, while only 25% is caused by air drag and 35% by rolling resistance. This means that 75% of the fuel consumption is proportional to weight, and explains why the automotive industry is focusing on weight reduction.

This defines the task. Given that we cannot change the driving habits, the choice of vehicle size and the mode of transportation, we still can make substantial reductions in the energy consumed by road transportation by reducing the curb weight. The curb weight can be reduced in two ways, using materials science and technology:

optimalisation of design
substitution of materials

European car and truck manufacturers have shown that it is possible to reduce the weight of body, driveline and suspension without sacrifice of size, safety and performance just through redesigning processes, without materials substitution. In addition a substitution of materials can give additional weight reduction. On many components it is possible to reduce the weight to 50% or less by a change from steel or cast iron to an aluminum or magnesium alloy. Weight reductions may also be obtained by changing to better quality steel, or to plastics. With the possible exception of composites for structural parts, the weight reductions obtained by switching to higher quality steels or to plastics are smaller than for substitutions by light alloys.

The best results from materials substitutions are obtained when the effects of reduced weight for each component can be taken into account in designing the rest of the vehicle. In this way it is possible to reduce the weight of the average US car from some 1750 kg in 1978 to about 1000 kg in 1985. Of these 1000 kg, 110 kg is expected to be aluminium, 75 kg plastics and 40 kg composites. This transition will put heavy demands on the availability of materials and on the development of cost-effective processes and methods for recirculating the scrapped vehicles.

Energy Conservation in the Transportation Industry

WALTER E. BECKER
(Mobay Chemical Corporation)

The automotive industry is faced with the challenge of significantly improving the mileage and engine emission performance. By 1980, U.S. automobiles must achieve EPA mileage ratings of 20 miles per gallon and by 1985 a further improvement to 27.5 miles per gallon. Most observers agree this will be done through both a reduction of car size and the substitution of lighter weight materials. In the period 1978-1980, the industry plans to reduce the curb weight of the average car by 500-800 pounds through "down-sizing" and the proliferation of proven plastic applications in a greater number of models. The automotive industry will spend nearly $15 billion for engineering and retooling for these smaller cars. In the period of 1980-1985, emphasis will be on materials substitution. Estimates of resin consumption in 1985 are in the range of 300-350 pounds per car, up from 160 pounds per car in 1976.

The opportunities for energy conservation by the transportation industry are numerous. It is possible to use various subgroup breakdowns to define the areas of potential energy savings. The following will be utilized in this presentation:

A. Initial energy savings in vehicle manufacture
B. Energy savings due to reduced weight and resultant reduced gasoline consumption
C. After-use-energy contribution via recycling

In this presentation, we hope to document the contribution that plastics can make to saving transportation energy. The experience of the author and Mobay Chemical Corporation is primarily in the fields of polyurethane and polycarbonate chemistry. Therefore, much of the data presented here will be given, and it should be noted that the general energy savings principles discussed here will apply to some extent to all plastic materials.

The calculation of total energy required to produce a vehicle is far from an exact one, although the increased attention to energy savings will undoubtedly lead to improved accuracy. If one were to make a survey of the literature, the following estimates would be found:

Total Materials Energy	MM BTU/CAR	30-70
Plastics Energy Input	BTU/LB	7,500-55,000
	MM BTU/CAR	2-6
Glass Energy Input	BTU/LB	13,000-28,000

The range of these values, typical of most data on energy, are too broad to permit detailed evaluation. The "errors" are functions of definition as much as they are functions of accuracy. With respect to overall vehicle requirements, "errors" will arise via inclusion of ancillary operations such as transportation to dealers, plant air-conditioning and lighting, etc. Some researchers have even chosen to include manpower (food energy).

Even individual material and component energy assessments are prone to such definition errors. For example, is the lubricant usage for metal rolling considered as an energy depletion, is the calculation on a plastic material carried "back to the wellhead"?

Recognizing the potential errors inherent in these assessments, we offer the following as an analysis of energy requirements for vehicle manufacture.

The energy comparison shown in Figure 1 has been widely published. Perhaps a bit of background would be enlightening here concerning the motivation for the preparation of such information.

In the first days of our energy-problem awareness, there was much confusion regarding the relative energy impact of natural and synthetic materials. Much of this confusion was natural; after all, plastics resin manufacture does require petroleum feedstock. It should be noted here that less than 2 percent of the total petroleum feedstock goes to plastics. In spite of the facts, many persons not aware of the facts tended to consider plastics as "energy eaters". The plastics industry needed a clear pictorial statement of our energy impact versus that of competitive materials, hence the development of the energy comparison chart.

To develop a meaningful comparison based on a surface area basis requires an assumption regarding thickness. Figures 2 and 3 were developed by Ford Motor Company. As can be seen, of the five leading candidate materials, RIM polyurethane represents the lowest energy consumption candidate.

Owens-Corning Fiberglas recently published comparative energy figures for the manufacture of automobile hoods. Four candidates were considered:

1. Steel - 75 lbs. part weight
2. Aluminum - 36.7 lbs. part weight
3. FRP Two-piece - 47 lbs. part weight
4. FRP One-piece - 34 lbs. part weight

As shown below, a reinforced plastic hood (depending on one-piece or two-piece construction) required 0.21-0.74 million BTU less than a comparable steel hood and 2.1 million BTU to 2.62 million BTU less than a comparable aluminum hood.

	MILLION BTU			
	Steel	Aluminum	Two-Piece FRP	One-Piece FRP
Energy Required	2.10	3.98	1.89	1.36
Energy Saved (Lost) Compared to Steel	0	(1.88)	0.21	0.74

In addition, they reported energy savings as a result of lower vehicle fuel consumption due to reduced weight of the aluminum and FRP hoods as compared to the normal steel hood. The calculation was based on a correlation published in a Society of Automotive Engineers Paper No. 700174 which stated that one pound of weight savings can be equated to 0.79 gallons of gasoline over a car lifetime of approximately 100,000 miles. The energy savings which result due to the reduced weight are shown below.

MILLION BTU			
Steel	Aluminum	Two-Piece FRP	One-Piece FRP
0	4.39	3.21	4.69

When the manufacturing energy requirements from Table 2 are combined with the operating energy savings, the total (manufacturing and operating) energy savings for the three candidates compared to steel are shown below.

MILLION BTU			
Steel	Aluminum	Two-Piece FRP	One-Piece FRP
0	2.51	3.42	5.34

General Motors Manufacturing Development made a similar calculation on a fender liner. As shown below, the conversion to a plastic fender liner can reduce the total energy required by 50 percent as compared to steel or 30 percent as compared to aluminum.

EQUIVALENT GALLONS OF GASOLINE

	Manufacturing Energy	5 Year Operating Energy	Total
Steel, 15 lbs	3	11	14
Aluminum, 5 lbs	6	4	10
Plastic, 6 lbs	2	5	7

While not in my specific area of responsibility within Mobay, urethane finishes, particularly in the form of low bake systems, provide further opportunities for energy reduction by the transportation industry.

Constraints On And Implications Of Replacing Steel With Aluminum Or Plastics In Automobiles, Buses And Trucks.

Joel S. Hirschhorn
(Office Of Technology Assessment, U. S. Congress)

Issues for Discussion:

(1) How does the energy required for raw materials, processing, fabrication and new capital equipment (for original manufacture and subsequent repair and maintenance) offset the energy savings associated with lower vehicle weight with aluminum and plastics?

(2) Since recycled scrap steel is extremely valuable and extensively used by the steel industry, would a major reduction in steel usage increase the energy needs of the steel industry due to increased use of iron ores? Or would the reduction of steel in land vehicles cause a decrease in domestic steelmaking? If the latter is true, what are the implications for labor and consumers?

(3) Would there be sufficient weight and cost savings with newer higher strength alloy steels to offset any market penetration by aluminum and plastics? Is the steel industry doing sufficient R & D to insure success in this area?

(4) How will future increases in the prices of electricity and petroleum affect the competitiveness of aluminum and plastics with present type steels? Are there likely new aluminum processing technologies offering substantial energy savings?

(5) How would life-cycle energy costs associated with shorter life plastics offset any energy savings resulting from reduced weight?

(6) What disposal and recycling problems or advantages could result from the use of aluminum and plastics?

(7) Are there new types of steelmaking technologies or steel products that could radically increase its competitiveness? For example, could sheet steels be developed that eliminated the need for painting, coating and finishing of vehicles?

(8) Is there any potential to replace the steel frames of land vehicles with aluminum alloys or plastic-based composites?

(9) Would there be major savings or improvements in dealing with environmental problems by going to the use of aluminum or plastics?

(10) Are there negative effects of using aluminum or plastics on the safety of vehicle passengers?

(11) Could the availability of low cost steel imports minimize the replacement of steel?

(12) How will future fuel costs and engine developments affect the need to reduce vehicle weight?

(13) How will the production of "world cars" which can be made at many locations throughout the world influence the substitution of steel by aluminum and plastics?

Constraints on the Use of Reinforced Plastics in Road Vehicles

P. McGEEHIN and D.H. BOWEN
(U.K. Atomic Energy Authority, Harwell)

Recognition that the world is approaching the point where demand for oil outstrips supplies has focussed attention on the need to improve significantly the fuel economy of road transport and hence on the use of lightweight materials in vehicle construction. Polymers and elastomers, which combine low densities with the facility to injection mould or extrude complex shapes at high production rates already make significant contributions to the reduction of vehicle weight. For example, the medium-sized European car with an overall weight of 1200 kg contains about 105 kg or 8.8% of plastics. (Jaeschke and Lammeck, 1978). Much of this usage, however, relates to non-structural components and there is considerable potential for further weight savings if plastics can be substituted for major steel components. For structural use, reinforced plastics will be necessary and it is proposed to consider the constraints on the use of reinforced plastics from the point of view of an informed observer of the automotive scene in both Europe and the USA.

Reinforced plastics are considered to include the following

- thermoplastics such as nylon, polypropylene, etc. generally reinforced with up to 30% of milled glass fibre in lengths not exceeding 1 mm.
- thermosetting sheet and bulk moulding compounds (SMC and BMC) made up of roughly equal proportions of chopped oriented glass strand ~25 mm long, polyester resin, and filler, the latter including agents to control the rheology of the mixture.
- thermoset resins containing up to 60% by volume of continuous, oriented glass, graphite or organic fibres for strength or stiffness application.

The choice of material will depend on the duty a component is designed to fulfil but alternatives to traditional materials will only be used if they are cost-effective in comparison with the materials for which they are substituted, or in terms of the energy saved over the vehicle's operating life as a result of weight reductions. There is little evidence, however, that the consumer is prepared to pay a premium in respect of fuel savings arising from lighter, but more expensive, materials and at least part of the driving force for the introduction of lightweight materials is likely to stem from legislation, as has already been introduced in the USA. Plastics components generally require less energy to produce than their metal counterparts and reinforced plastics less than unreinforced plastics (Johnson and Delville, 1978). However, unless the energy savings are reflected in reduced component cost it is unlikely that, in the absence of a legislative drive, energy conservation arguments will seriously influence the process of materials substitution.

Reinforced plastics are used more extensively in U.S. vehicles, typical figures for passenger cars being 12 kg compared to 3 kg in Europe (Allan, 1978). One reason for this, apart from the U.S. legislation, lies in the difference in methods of body construction. For example, front and rear ends in U.S. vehicles have been made traditionally from a number of steel pressings joined together, or by zinc die-casting. These components readily lend themselves to production of one-piece mouldings in SMC and over thirty U.S. models now feature such panels. In Europe, end panels tend to be simpler in style and to require fewer components so that the motivation towards parts integration has been less pronounced. In both continents, the use of glass reinforced plastics for body and cab panels of commercial vehicles is increasing rapidly: here lower volume of production makes the reduced tooling costs of these materials attractive.

Table 1 lists examples of automotive components and the materials commonly used. Thermoplastics predominate at present and for lightly stressed components, are likely to remain a preferred class of materials because the technology for low-cost volume production is well established.

The situation regarding thermosetting plastics reinforced with long fibres (e.g. SMC's, XMC's and graphite reinforced epoxides) is much less clear. Such materials, by virtue of their high specific strengths and stiffnesses can fulfil major structural roles and provide substantial weight savings over steel. For example, a weight saving of ~75% has been demonstrated by replacing a 60 kg truck spring with a hybrid glass and graphite fibre composite. These materials therefore offer the greatest potential for weight saving since their mechanical and physical properties make them suitable, in principle, for most elements of vehicle construction - chassis, wheels, springs and body shell. All of these elements have been demonstrated in experimental programmes in recent years but major advances in technology will be required before they become cost effective. Among those advances may be included:-

- the need for a wider appreciation by design engineers of the capabilities of the materials and of the very different design philosophies compared with metals

- much more performance data will be required under environmental and fatigue conditions to establish product durability
- improvements are required in the ability to absorb energy in collisions in the face of rising safety standards
- major developments in production technology are required to enable reinforced plastics components to be manufactured with the speed and facility of metal parts. An important goal is a reduction in resin cure times to shorten moulding cycles
- rapid, reliable methods of joining reinforced plastics components to themselves, and to metals, under plant conditions, need to be developed
- improved techniques for painting SMC surfaces are required or, alternatively, SMC's will need to be developed that are compatible with present, or projected, methods of painting
- improved heat and oil resistance will be required particularly to enable greater substitution for metals to take place under the hood
- new ways will need to be found to dispose of, recycle, or at least recover some of the energy content, of industrial waste and scrapped vehicles.

Most, if not all, of these topics are the subject of intensive R&D and the relatively small proportion of total vehicle weight currently accounted for by reinforced plastics is certain to increase in future designs. Competition from other materials, such as aluminium or high strength alloy steels, will be intense and the reinforced plastics industry faces both a major challenge and a major opportunity to expand its markets and to play a vital role in conservation of energy supplies in the future.

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Table 1

Examples of Plastic Automotive Components

Component	Material	Status
Front and rear end panels and accessories Truck cabs and side panels Air conditioner housings	SMC, BMC	In production over a wide range of models
Fenders Spoilers	SMC, BMC Glass reinforced urethanes Glass reinforced polyamides	In production over a wide range of models
Body shells	SMC	Limited production for special models
Hood and trunk lids	SMC	Limited production for special models
Springs Drive shafts Chassis members	Glass/graphite/epoxy	Experimental
Wheels	SMC, BMC	Experimental
Non-structural components, e.g. instrument panels crash padding seats upholstery heating, ventilating equipment trim	Most common thermoplastics with or without glass reinforcement	In production

Source: Jaeschka & Lammeck 1978
Owens-Corning Fibreglass Corp. 1978

Economy & Energy Efficiency: Can They Be Reconciled?

PETER J. DETMOLD
(Canadian Pacific Ltd.)

In a perfectly competitive market, the desirable degree of energy efficiency for each transport mode might be expected to be maintained at all times and to respond to changes in factor prices in an on-going self-adjusting process. Unfortunately, this does not appear to work out in practice. The purpose of this paper is to ask "why?".

Basic Relationships

Long ago it was demonstrated that the fundamental relationship between speed and resistance to motion is almost immutable for each mode at each stage of scientific knowledge and availability of materials. It is tempting, therefore, to compute the most energy-efficient mode as that which offers least resistance to motion, whether for passengers or freight. A great many of these "energy efficiency" studies have been made.

On the other side of the coin, the modal choice likely to result from the market process takes many other factors to account. There is no reason to suppose that the latter process would lead to the selection of the most energy efficient modes. It is instructive to consider the factors which lead to this divergence of choice.

Modifications of the Basic Relationships

There are two fundamental (amongst other lesser) reasons why a free market may choose other than the mode indicated by energy efficiency studies:-

1. The cost of other factor prices (e.g., labour) may make some other mode less costly to use;
2. The service offered by some other mode may be more "market attractive" than the energy-efficient mode.

It is highly important that this distinction should be made correctly, because the means taken to remedy a situation in which the energy efficient mode is rejected because it operates inefficiently are entirely different from policies developed in the realization that the mode cannot meet the demands of the market place. There is, however, a third situation to be considered -- that a new form of an energy efficient mode may be developed which fully meets the demands of some specific market that it does not satisfy at present.

Taking the example of 1. applied to rail freight transportation, the low potential cost of the unit train will generally confer on it a margin of cost advantage for the haulage of bulk commodities where year round water transport is not available, but operating economy may be hampered either for some institutional reason (e.g., the imposition of an uneconomical rate structure) or through lack of investment in suitable equipment. The remedies are obvious.

Where time sensitive freight is concerned, the subject is much more complex and every element of distribution cost must be analyzed in each specific case in order to determine whether it is in the second (hopeless) category, or the third category in which the market could be captured by developing some innovative kind of rail service. As an example of the latter, fast domestic container trains, though possibly slightly less energy efficient than the haulage of similar freight in specialized cars, may offer important economies by cutting out the use of classification yards and costly local rail movement; and the reduction in overall journey time may enable the railroad to penetrate markets long since conceded to the motor carrier.

Where intercity passengers are concerned, it may sometimes be possible for an efficient rail service to provide the least costly transportation, but this may only be expected to occur where the railroad has an energy price advantage (e.g., cheap electricity vs. very high cost motor fuel) combined with an exceedingly large volume of traffic. In other cases, the low frequency associated with the large energy efficient train may make it less acceptable to the market than higher frequency bus or air services or, of course, the ubiquitous private automobile.

Thus, analyses of energy efficiency are an inadequate arbiter of modal choice.

Some Policy Implications

The first task in formulating a policy towards energy efficient transportation must be to distinguish the traffic falling within each of the three categories.

Clearly, if institutional impediments are removed, then the market place will generally be the best means for determining the distribution of traffic between categories two and three. But the habit of innovation is not easily acquired in sectors of the transportation industry (e.g., bankrupt railroads) that have long ceased to have the means of implementing novel ideas.

For the railroad industry to play its full part in an energy efficient

North America, three events need to take place:

1. Industry as a whole must have the incentive to increase production and to reduce cost. That is to say, there must be the demand for more efficient transportation.
2. There must be a major increase in research effort. New technologies are available; the need is to *apply* them to the railroad industry.
3. Cash flows must be adequate to finance research and innovation. The preferred solution is for the cash to result from returns on investment comparable to those in other industries. But where this is not possible, the cash must be found by other means.

These are, however, also the principal ingredients for a renaissance in rail technology with the purpose of increasing the efficiency with which the inherent advantages of the rail mode are applied to both existing and new traffic.

Materials Science And Technology For More Energy Efficient Transportation — In The Case Of Transportation By Ship

KIYOHIDE TERAI
(Massachusetts Institute of Technology)

TATSUMI KURIOKA
(Kawasaki Heavy Industries)

There are mainly three kinds of energy to be considered as cargo transported by ships; these are crude oil, liquified propane gas (LPG) and liquified natural gas (LNG).

Oil has been used as a fuel to replace coal since the early 1930's. By around 1955 oil was transported by tankers up to 20,000 dead weight tons. In the late 1950's tankers of 100,000 DW tons were built, and at the beginning of the 1970's tankers as large as half million tons were built.

Both LPG and LNG carriers became available as a method of energy transportation in the 1950's. Independent tank structure with insulation for marine transportation at a low temperature (about -40°C) was available in the early 1950's and carriers with the tank capacity of 10,000 to 30,000 cubic meters were built by the mid 1960's. In these cases, however, tanks were mainly assembled in hulls being built on the berths. Accidents occurred during assembly of tanks and this difficulty made it impossible to build ships having tanks larger than about 30,000 cubic meters.

In building an LNG carrier, which carries LNG in temperatures below -160°C, the situation is more complicated than for an LPG carrier. In the case of an LNG carrier, tank structure is actually limited to the following two types; the independent tank type and the membrane tank type. In both tankage systems some technological problems, mainly associated with materials and fabrication, still remain unsolved when we try to make the tank capacity larger than the current level of 130,000 cubic meters.

Let us discuss the energy efficiency of a marine transportation system. Fundamentally speaking, there are four ways to improve the energy efficiency of a total system:

1. Increase loading capacity
2. Increase cruising speed while minimizing fuel consumption.
3. Reduce the number of crew
4. Reduce the ship price.

The authors have already discussed Item 1 to some extent. In the case of an oil tanker, the ratio of hull steel weight to dead weight has been reduced from 0.17 to 0.14 as the ship size increases from 40,000 DW tons to 80,000 DW tons. This trend diminishes, however, when the ship size increases beyond 80,000 DW tons.

Let us examine the energy efficiency of different kinds of carriers in terms of fabrication cost for transporting fuels with the same amount of calorie output. The building cost of an LNG carrier is about three times that of an oil tanker and twice that of an LPG carrier on the basis of carrying the same amount of calories.

Regarding Item 2, it is generally believed that ships having the ratio of ship length to breadth of around 6 are most economical as far as large ships are concerned.

Regarding Item 3, the automation of ship operation has resulted in considerable reduction in the number of crew. Many modern tankers, even very large tankers, have as few crew members as about two dozen men.

Regarding Item 4, the authors will emphasize effects of structural materials and fabrication technologies on the ship price which may be of interest to most people who will attend this conference. Discussions will be made of materials and technologies currently in use for carriers, recent trends, and future possibilities. Detailed discussions will be made of welding technology, which is the author's special field of interest.

SHIP MATERIALS AND DESIGN

DR. KIYOHIDE TERAI
Kawasaki Heavy Industries, Ltd.
Kobe, Japan

Marine transport of energy is mainly conducted by two groups of ships: crude-oil tankers; and liquefied natural gas carriers, including liquefied methane gas (LMG), liquefied ethylene gas (LEG) and liquefied propane gas (LPG) carriers.

Crude-oil tankers are the most efficient ships in energy transportation among those mentioned (Figures 1a and b).

As far as the production cost of LMG carriers is concerned, a ship of membrane type is more economical than that of a sphere type. However, technological reliability for protection against gas leakage in the sphere type is thought to be better than that in the membrane type.

A structure of semi-membrane type has been used in building a series of large LPG carriers and the results are very successful from both economical and technological aspects. As this type is also available in the construction of LMG or LEG carriers, development should be concentrated in this direction.

Among all ships in the figures, enlargement ship size is effective in reducing the ship production costs. The building of huge oil tankers should be continuously promoted from the viewpoint of more energy-efficient transportation. (It is difficult to compare the production costs of various ships of different cargo on the same basis; therefore, a unit of output energy obtained from cargo fuel "calorific power" is used as the abscissa in these figures.)

New joining technology, including laser and electron beam welding, should be developed. These will be available to join special materials used in liquefied natural gas carriers of larger sizes or in any other forthcoming special ships for further more energy efficient transportation.

RELATION BETWEEN CALORIFIC POWER TRANSPORTED BY SHIPS AND UNIT HULL STEEL WEIGHT AND UNIT SHIP PRODUCTION COST

Figure 1a

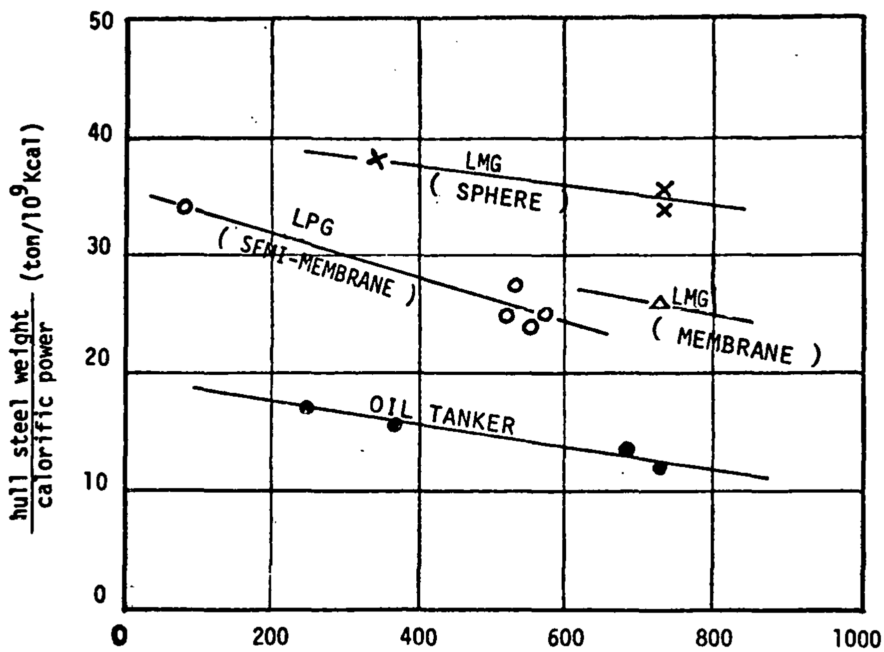
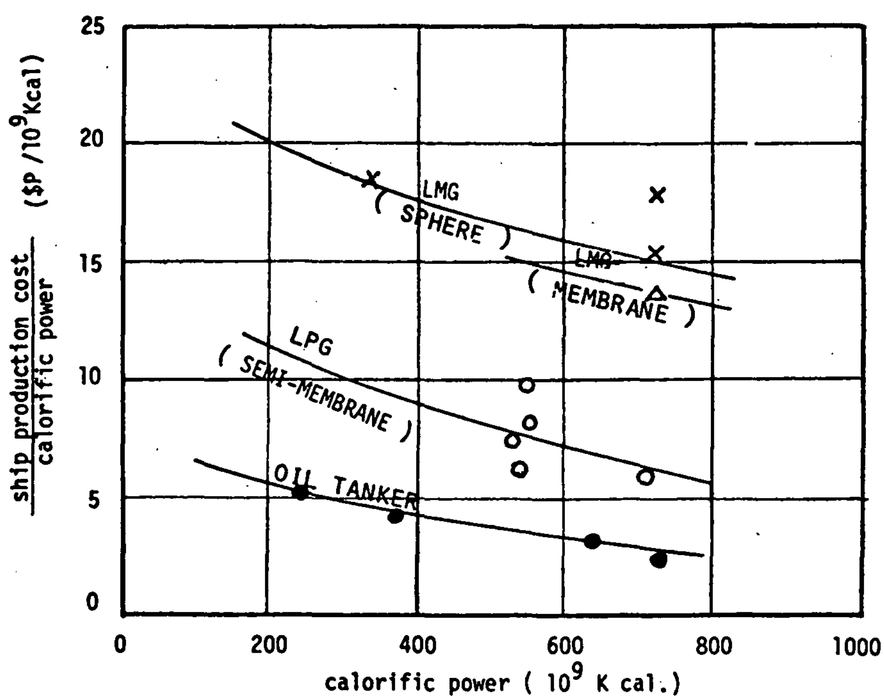


Figure 1b



More Energy Efficient Transportation Unconventional Systems

David L. Douglas
Electric Power Research Institute
Palo Alto, California

Given the present levels of affluence and life styles in the industrial world any viable system of personal transportation must provide the freedeom of movement inherent in the use of energy storage in highway vehicles. This essential is well satisfied by liquid hydrocarbons. Eventual exhaustion of the primary source of these high specific energy fuels, i.e., petroleum, has led to interest in unconventional automotive propulsion systems utilizing alternative methods of storing energy. The more promising of these alternatives include

(a) Electrochemical storage (batteries),
(b) Kinetic energy storage (flywheels) and
(c) Hydrogen (solid hydrides).

Of these, batteries are receiving the major share of research and development effort. It should be noted that batteries are proposed both as a storage means for the total propulsion energy requirements and as an ancillary power source for acceleration and hill climbing in certain hybrid configurations.

Battery powered street vehicles (EV's) are of an age within internal combustion engine (ICE) vehicles. The latter have captured almost all of the market for the simple reason that gasoline and diesel fuel are extremely convenient and low cost means for storing chemical energy. Thus, even with relatively inefficient engines and drive trains, ICE vehicles have substantially better performance (range, speed and acceleration) for lower cost then their conventional (lead-acid) battery powered counterparts.

The materials challenge of higher specific energy batteries presents many different, but not necessarily unrelated facets viz.,

(a) Use of higher specific energy active materials,

(b) Structures and/or formulations which increase substantially the utilization of existing battery active materials,

(c) Structural materials to reduce significantly the weight of existing batteries, i.e., lead-acid.

It is generally agreed that the greatest gains are to be made by way of use of more energetic electrochemical couples. Practicality requires that the materials used be widely available and low in cost. Most development programs directed toward sodium-sulfur, lithium-iron sulfide and zinc-chlorine batteries reflect these boundary conditions. Zinc-nickel oxide and zinc-bromine batteries rely on slightly less reactive species of somewhat greater cost. The materials problems associated with the several new battery systems are summarized in the table below.

Materials Issues in
Electrochemical Energy Storage

Battery System	Materials Issues
$Na/\beta\text{-}Na_2O\cdot Al_2O(s)/Na_xS_y$ (300-350°C)	• Conductivity, stability, strength of $\beta\text{-}NaO\cdot Al_2O_3$. • Corrosion of container by Na_xS_y.
$LiAl/LiCl\cdot KCl(\ell)/FeS_x$ (∿450°C)	• Separator (BN fabric?) stability • Oxidation resistant cathode current collectors.
$Zn/ZnCl_2(aq)/Cl_2(aq)$ (∿30°C)	• Polymers and metals resistant to Cl_2. • Graphite electrodes.
Zn/KOH(aq)/NiOOH (∿50°C)	• Oxidation and alkali resistant polymer separator.
$Zn/ZnBr_2(aq)/Br_2(aq)$ (∿50°C)	• Polymers and metals resistant to Br_2. • Electrocatalysts for $Br_2 \rightleftarrows 2Br^- + 2e^-$.

Use of active materials with a high specific energy almost inevitably means that corrosion of containers, current collectors and the like will be problems. Interestingly the existence of kinetic barriers to electrode reactions and/or ionic conductivity has caused investigators to resort to elevated temperatures in the sodium-sulfur and lithium iron sulfide systems. One hopes that research will lead to means of operating closer to room temperature.

One class of electrochemical energy storage system which is in exploratory stages, but which holds much promise for the future, is metal (aluminum, zinc and iron)-air. Here the materials challenge is to find an electrocatalyst <u>and</u> electrode structure permitting discharge of oxygen from air at good efficiency. Infrastructure barriers to exploitation of such systems must be overcome also.

Potential Impact of Materials Science and Technology Upon Energy Storage for Vehicular Applications

ROBERT A. HUGGINS
(Stanford University, Stanford, California 94305)

Various visions of the future include the development and utilization of electrically-powered vehicles. There are two interrelated areas of major potential improvement over today's technology that might result. One of these has to do with potential energy savings; the other with the possibility of a major reduction in air pollution in urban areas. Discussion should involve the basic assumptions involved in these two areas, and the reasons for their interrelation.

Major attention should be given to the role that materials science and future technology can influence the energy cost of transportation. This includes analysis of the central parameters involved in the conversion, storage, and utilization of energy for motive power.

Here, the focus will be upon land-based personal and small commercial vehicles. For such applications the storage of energy within the vehicle itself plays a central role, and electrochemical (battery) systems, flywheels, and hybrid systems appear to provide the most effective possibilities.

Progress related to new and improved materials and processes will play a critical role in the required improvement of such systems. Research and development is now underway related to revolutionary, rather than just evolutionary, changes in some areas. Some of these would necessitate substantial changes from present designs and approaches, and raise important questions concerning materials availability and cost, new manufacturing processes, safety during operation, and waste disposal or recycling at the end of useful life, in addition to the normal issues of properties and performance.

There are a number of possible directions in which these new technologies could evolve, and materials science and technology will play a most important role in their development. Some of the specific problems and opportunities within this realm will be discussed as time permits.

Materials Research for Electric Vehicle Batteries

R.M. DELL and P. McGEEHIN
(UK Atomic Energy Authority, Harwell)

Introduction

The era of the electric vehicle is dawning. In the United States, Japan, Britain, France, Germany and Italy major development programmes on EVs are being undertaken by industry with support from government. Among companies active in the field are automobile manufacturers, battery manufacturers and electrical component suppliers.

The electric vehicle has a number of social, political and environmental attractions. On the other hand it possesses certain operational disadvantages compared to conventional vehicles. These stem mostly from the low energy density of the lead-acid battery. Until an advanced battery is developed it seems likely that EVs will be confined to urban delivery vans, special purpose vehicles and, possibly, a few buses. An advanced battery is therefore crucial and this paper discusses some of the materials problems involved in its development.

Battery Specification

The specification for a traction battery is determined by the desired performance of the vehicle. Important factors are (1) daily range (stored energy), (2) acceleration and hill climbing ability (peak power output), (3) prevailing climate (operating temperature range of battery), (4) recharge time available and (5) life of battery when used regularly. Table 1 shows a typical specification for several vehicles, although it should be emphasised that this is only semi-quantitative and a lesser specification would be satisfactory for limited market penetration.

For many vehicles a battery energy density of 80-100 Wh/kg will suffice (compare lead/acid 20-40 Wh/kg), provided this is accompanied by a life of > 3 years, high charge/discharge efficiency and acceptable cost. These are the prime targets for research on traction batteries.

Advanced battery concepts under development are of four general types: aqueous electrolyte batteries, organic electrolyte batteries high temperature batteries and all-solid-state batteries. We review briefly the materials science problems associated with each.

Table 1. Vehicle Specification and Battery Performance Targets

		Urban Delivery Van	City Bus	Medium Car
Gross Vehicle Weight	tonnes	3.5	15	1.5
Unladen Wt	tonnes	2.0	10	1.3
Acceptable Battery Wt	tonnes	0.5	2.2	0.3
Range desired	km	140	240	160
Peak Power required	kW	50	150	27
Energy required	kWh	50	450	27
Energy/Peak Power ratio		1.0	3	1
Recharge time available	h	14	6	~16
Desired minimum cycle life	cycles	1000	>1000	500
Derived parameters				
Battery Energy Density	Wh/kg	100	204	90
Battery Peak Power Density	W/kg	100	68	90
Recharge rate	kW	3.5	75	1.7

Aqueous Batteries

These generally employ a nickel oxide positive electrode and a cadmium, iron or zinc negative with a KOH electrolyte. Cd/NiOOH and Fe/NiOOH batteries are commercially available, but their energy densities are too low. Zn/NiOOH is under intensive development around the world and shows promise of $\sim$ 80 Wh/kg at acceptable cost (Charkey, 1976). The latest NiOOH electrodes are much improved, but the principal problem lies in the brief cycle-life of the battery. This stems from the high solubility of zinc in KOH solution which causes (1) growth of metallic crystals (dendrites) on recharge; these penetrate the separator and short-circuit the cell (2) loss of capacity through change in shape of the electrode (slumping). Efforts are being directed at solving these problems, to give a battery life of > 500 charge/discharge cycles. This involves developing improved separators and zinc electrodes.

Other research is directed towards rechargeable aqueous batteries with halogens as oxidant. The Zn/Cl_2 concept (Amato, 1973) depends upon refrigeration to store chlorine as the crystalline compound $Cl_2.6H_2O$ (m pt 9^oC). This poses formidable engineering problems. With the Zn/Br_2 battery (Will, 1977), also under development, it is necessary to find a suitable complex of bromine of low solubility. Metal-air batteries (Zn/air, Fe/air) have been studied in depth, but the power density available from existing air electrodes is too low while, again, the engineering problems are severe and their solution imposes a cost and weight penalty. An improved air electrode is required. One interesting suggestion is a hybrid system with a metal/air battery to provide range and a lead/acid battery to provide peak power.

Organic Electrolyte Batteries

An aprotic electrolyte permits the use of electropositive metals (Li^+, Na^+) which yield high energy densities. A major difficulty is to find a solute/solvent combination of high enough ionic conductivity that excessive internal heating does not occur. Another problem is the sensitivity of alkali metals to traces of moisture, leading to electrode polarisation. The latest development with these batteries is the use of solid solution positive electrodes (Steele, 1976). These are generally layer-type compounds (e.g. TiS_2, $NiPS_3$) which intercalate alkali metals into their structure. Many new materials which have potential as positive electrodes are now being discovered.

High Temperature Batteries

The sodium/sulphur battery (operating temperature 300-400°C) is under intense development in several countries (Dell et al., 1976). This employs a solid, ionically conducting electrolyte, generally beta alumina, in the form of a ceramic tube. Liquid sodium, and liquid sulphur contained in graphite felt are the electrodes, one inside and one surrounding the tube. The materials science problems involved are formidable:

- the development of ceramic tubes to meet a stringent specification
- the development of hermetic seals
- selection of corrosion-resistant metallic cell cases and current collectors
- the development of cheaper carbon felts
- choice of materials for thermal insulation and safety engineering.

Considerable progress has been made with this battery during the past twelve years, but much remains to be done. Given a solution to the technical problems, a sodium/sulphur traction battery of 120-150 Wh/kg is in sight.

The other high temperature traction battery under serious development is the lithium-iron sulphide system (Walsh et al., 1977). This consists of a lithium negative electrode, generally in the form of a Li-Al or Li-Si alloy, a fused salt electrolyte and a FeS_2 or FeS positive electrode. At the battery operating temperature (450-500°C) a LiCl-KCl eutectic electrolyte (mpt 352°C) is generally employed. With FeS_2 as positive a cell voltage of 1.8V is obtained initially, but this soon falls as the cell is discharged. Moreover, the FeS_2 is corrosive towards most metal components. With FeS a smaller voltage (1.3V) is obtained, but this is fairly stable and the lower sulphur potential of FeS poses less of a corrosion problem. At present, these cells have an energy density of 70-80 Wh/kg. Materials science problems include

- the identification of a cheap, corrosion-resistant current collector which may be used with FeS_2, thereby yielding a higher energy density cell
- the development of a satisfactory, cheap separator material

(at present boron nitride cloth is employed, which is expensive). Significant progress has been made with this battery at laboratories in USA and Germany although, again, much remains to be done.

All-Solid-State Batteries

Small, solid-state primary batteries for low current-drain applications have been known for some time e.g. $Ag/RbAg_4I_5/RbI_3$. The idea that this concept may be extended to rechargeable traction batteries is novel and little research has yet been undertaken. It is necessary first to identify a suitable fast ion conductor which may serve as electrolyte and then to fabricate it into thin sheets. Next we must find an appropriate metal anode and a solid solution cathode which intercalates the diffusing cation into its structure. Finally, we must learn how to fabricate these electrodes with the electrolyte sandwiched between them. All this presents major challenges to materials science and technology, but the advent of an all-solid-state traction battery, although only a gleam in the eye at present, could revolutionise the prospects for electric vehicles. With the plethora of new compounds now being discovered by solid state electrochemists there may just be a chance of success.

Conclusions

As petroleum becomes scarce and prices rise, the prospects for EVs improve. The measure of success they will achieve hinges entirely upon the development of an advanced traction battery. The possibilities are varied, but the problems are legion. This is the challenge facing the applied electrochemist and materials scientist. Success, in both technical and economic terms, will go a long way towards determining the pattern of road transport and electricity storage in the 21st century.

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Materials Supplies in Relation to the Development of Electric Vehicles

A.F. ALDOUS
(Electric Vehicle Development Group)

Economic, social and technical factors have hindered the wide-spread introduction of electric road vehicles, and it is necessary to evaluate the changes which are taking place in each of these spheres if we are to assess the materials which will be required by large numbers of electric vehicles.

Economic

Throughout this century oil has been freely and cheaply available for transport, so there has been little commercial incentive to develop the technology for electric vehicles. However, Government is now beginning to take the lead and to help the development of electric vehicles through the difficult research and development stage, for the following reasons:

> Electricity can be obtained from renewable sources such as natural energy, fission and possibly fusion, and the mechanical/electrical energy obtained is utilised most efficiently by electric vehicles.
>
> Research indicates that the most promising future fuels for transport are liquid fuel derived from coal and electricity, and electric vehicles using advanced batteries will be more efficient in their use of primary energy than i.c.e. vehicles using synthetic fuel.
>
> There is also a need to improve the environment.

Financial support from Government is essential in the early stages, because only small quantities of vehicles are produced and their purchasers have to bear the entire costs of research and development. It is unlikely that rising fuel costs alone will be sufficient to bring about the development of electric vehicles because of the timescale involved. It is estimated that about 20 years is required to develop new designs for the vehicles themselves, the motors, components and batteries which will be required, as well as the appropriate infra-structure and support facilities, but the time at which there will be a strong commercial incentive to develop electric vehicles will coincide with the time when they will be needed, probably at the end of this century (McEwen, 1977). Operators of vehicles vary in their estimates about comparative costs for electric vehicles, because in certain applications they are already overall as cheap as i.c.e. vehicles (Scott-Hellewell, 1978), but if they are to replace entire fleets of present vehicles, some operators estimate that a 2 to 4 times increase in real terms in the price of oil would be needed to make this economic (Quarmby, 1978).

Social

It is anticipated that the disposable income of each household will continue to increase, although at a lower rate, and this will encourage a greater use of the private car (Hills, 1978). This would indicate that there will be a need for hybrid vehicles and short range battery electric cars for the second family vehicle. Although 90% of car travel in Great Britain could be in electric vehicles (Charlesworth and Baker, 1978), it is unlikely that people would be willing to travel for longer distances by rail or bus or to hire an i.c.e. vehicle for longer journeys. The use of the private car generates further traffic as people tend to move into isolated estates where they require their own transport. It is possible that Government could to some extent reverse this trend by substantial investment in public transport and careful attention to land use planning, but this would not be easy.

Technical

With present technology electric vehicles could be used in a great number of applications, for instance, a high proportion of the buses in service are used only during peak hours (Munro, 1977), delivery vans in London travel an average of 80 kms per day (Bayliss, 1977) and, as stated above, 90% of car travel could be in electric cars. However, although the speed and acceleration of present electric vehicles are alright for urban travel, they would not be up to the standards required on motorways.

Research into ways of increasing the range and performance of electric vehicles is going ahead in the following fields:

D.C. disc-armature permanent magnet motors are under development with a specific output of nearly 300 W/kg, and further improvements are expected from induction motors with specific outputs of around 470 W/Kg. (Corbett, 1978)

More efficient controllers are being developed, and the use of microprocessors in this context is also being examined.

Lead acid batteries with energy densities of 45Wh/Kg will soon be commercially available, and those with 50Wh/Kg are under development. (Acton, 1977). It is anticipated that alkaline batteries with energy densities up to 60 Wh/kg will soon be in use and high density batteries such as the sodium sulphur, lithium-iron sulphide and molybdenum disulphide should be available within the next decade.

Research is continuing into ways of recharging batteries quickly, and it is also possible to recharge while the vehicle is in operation, from overhead wires or power sources in the roadway. Vehicles can be refuelled by exchanging the battery, but this is not usually economic.

Vehicles designed for electric propulsion are more efficient in their utilisation of primary energy, and new modular designs are being developed.

Tests with various types of hybrid vehicles indicate that they are more efficient in their use of primary energy than their i.c.e. counterpart.

Materials requirements

Technical, economic and social factors will influence the number of electric vehicles we have in use by the end of the century, and the following table (Chapman et al, 1976) compares the materials which will be required for an electric vehicle using either lead acid or sodium sulphur batteries, as compared with an i.c.e. vehicle.

	Petrol	Electric
Iron and steel	0.780	0.663
Copper	0.015	0.035
Al, Zn and other non ferrous	0.036	0.020
Plastic		0.160
Glass	0.090	0.050
Other materials		0.172
Total	0.921 tonnes	1.100 tonnes
Battery		
Lead acid (weight of lead)		0.560 tonnes
Sodium		0.10 tonnes
Sulphur		0.10 tonnes

There will also be an increasing use of polymers for the bodywork of electric vehicles, and if electricity is used for transport wherever possible, hydrocarbon and biomass resources can be conserved for the petrochemical industry and other essential purposes.

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Metallic Hydrides for Use in Hydrogen-Fuelled Vehicles

N.J. BRIDGER and R.M. DELL
(UK Atomic Energy Authority, Harwell)

Introduction

Energy storage is increasingly being seen as a serious problem for the 21st century as petroleum is replaced progressively by other primary energy sources. Foremost among these is coal, which is quite unsuitable as a transport fuel but which may be converted to synthetic petroleum, hydrogen or electricity, all of which have potential for transport use. Hydrogen is produced from coal either directly by the water gas reaction, or indirectly by generating electricity and electro -lysing water. The latter route may also be used for producing hydrogen from renewable energy sources (solar, wind or wave generated electricity). Thus we may view hydrogen as a chemical store for electricity, an alternative to the secondary battery.

For transport applications hydrogen can be burnt in an internal combustion engine with only minor modifications. It is seen as the "ultimate" ICE fuel, being universally available from water and non-polluting in use. (Dell and Bridger, 1975). Alternatively, hydrogen can be burnt with higher efficiency in a fuel cell to generate electricity which then powers an electric vehicle.

In practice, this idealised concept of hydrogen fuelled vehicles still has a number of technical and economic problems. These include the low efficiency of the I.C. engine (which is particularly serious when using electrolytic hydrogen, 13% compared to 70% for a battery electric vehicle) the non-availability of a high power, low cost fuel cell, and the difficulties of storing hydrogen on-board the vehicle. Of the three possible methods of storing hydrogen, compressed gas is unsuitable because of the mass and volume of the cylinders, liquid hydrogen is unlikely on the grounds of cost and safety, leaving metallic hydrides as the only likely storage concept. In this paper we review the potential of hydride stores for use on-board vehicles.

Vehicle Hydride Stores

A metallic hydride must meet several criteria if it is to be an acceptable means of storing hydrogen. It must be capable of being decomposed and reformed (i.e. cycled) thousands of times without deterioration. Also its properties should include (1) An equilibrium dissociation pressure above one atmosphere at a temperature compatible with that obtainable from the engine exhaust. (2) A low heat of dissociation since this must be supplied by waste heat from the vehicle's exhaust or cooling systems. (3) Rapid hydrogen desorption kinetics to allow for a good power density. (4) High hydrogen capacity per unit mass. (5) Good corrosion resistance and (6) Low cost.

Although two classes of metallic hydrides have been selected as prime candidates and have received considerable attention, neither fulfils all the above requirements. They are represented by $FeTiH_{1.3}$, which is an ambient temperature hydride, and Mg_2NiH_4, which is a high temperature hydride. Table 1 compares the important properties of these two hydrides and it can be seen that while $FeTiH_{1.3}$ has good thermal properties it is heavy and expensive. Conversely, Mg_2NiH_4 is light and relatively cheap but its thermal properties are poor.

Table 1. Comparison of $FeTiH_{1.3}$ and Mg_2NiH_4

	$FeTiH_{1.3}$	Mg_2NiH_4
Temperature at which the hydride equilibrium pressure is 1 atmosphere (^oC)	0	250
Heat of dissociation (Kcal/g mole. Hydrogen)	-7.0	-15.6
Cost of hydride (raw material cost only) equivalent to 5 U.S. gallons of petrol ($)	1300	433
Mass of hydride equivalent to 5 U.S. gallons of petrol (Kg)	381	131

The quest for improved hydrides with the gravimetric and cost parameters of Mg_2NiH_4 but with the thermal properties of $FeTiH_{1.3}$ poses a major challenge to the materials scientist. This is not the only technical problem to be faced. As the alloy is hydride/dehydride cycled it breaks up into a fine powder which tends to pack down and consolidate. This, together with the large volume increase during hydriding, can cause severe distortion of the hydride containers. (Lynch and Snape, 1978). Since the volume of the powder bed is $\sim$ 6 times the volume of an equivalent amount of gasolene, there are major heat and gas flow engineering problems to be solved. An inter-disciplinary approach involving the materials scientist, physical chemist, chemical engineer and vehicle designer is needed.

Considerable success has already been achieved with experimental vehicles by Billings Corporation (USA) (Ruckman et al., 1978) and Daimler-Benz (Germany) (Buchner, 1978). These organisations are developing cars for use with a near-term coal-based hydrogen supply. A number of cars, vans and buses have been produced which are hydrogen powered from $FeTiH_{1.3}$ hydride stores. These vehicles demonstrate technical feasibility, although many problems remain to be solved. One advanced concept is a vehicle with a dual-bed of $FeTiH_{1.3}$, and the lighter, cheaper $MgNiH_4$ for running when hot. Another is a gasolene/hydrogen hybrid fuel car, with a hydride bed large enough to provide the fuel required for city driving. Vehicles of both types have been built by Daimler-Benz.

Refuelling presents certain technical and operational problems. The time required for refuelling (10-60 mins) is a limitation; exchange hydride beds can be visualised, although the practical problems may be considerable. Fleet operated vehicles, garaged and refuelled overnight, present the best market prospect. One interesting suggestion is to recover the heat evolved during refuelling for use in building heating, etc. In this way the overall fuel efficiency of the hydrogen engine could be raised well above that of the gasolene engine (Buchner, 1978).

Recently, some novel proposals have been made for hydride beds in which the powder is fluidized by hydrogen gas, thereby improving heat transfer and avoiding consolidation problems (Henault, 1977), (Atkins and Fisher, 1978). As yet these have not been investigated in detail and are likely to present their own materials and design problems.

In conclusion, hydrogen-fuelled vehicles are seen as a potential second option to battery electric vehicles for the long term future and at this stage both merit serious research and development.

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Energy Conservation Concepts in Construction and Maintenance of Highways

by

W. B. LEDBETTER, P.E.
(Texas Transportation Institute)

The fact that construction of highways in the United States consumes the equivalent of over 9.6 billion gallons of gasoline each year (NCHRP, 1977) makes it imperative that every facet of this area be examined with the goal of providing more energy efficient designs, methods, and materials. With this goal in mind there are many new and innovative concepts concerning the use of materials in transportation construction which effect significant reductions in energy consumption, while maintaining the standard of quality here-to-fore enjoyed. Some of these concepts are discussed below:

1. Increase the standardization of highway components and designs. Standardization, long practiced in other industries, can effect energy savings through repetitive use of forms, less testing and inspection, more reliable components, less material rejection, and improved quality control.

2. Move to greater use of performance-based construction specifications. In many areas of construction, such as asphaltic concrete, performance-based specifications can be written which do not specify the recipe. The result is the utilization more economical materials which often means less energy consumption. The States of Georgia and West Virginia have made significant strides in this area and other states could do the same.

3. Use asphalt emulsions rather than cutback asphalts in highway pavement structures. Cutback asphalts use the lighter petroleum products to cutback or soften the asphalt and, after constructing the pavement structure, the lighter products simply evaporate and leave the asphalt to bind the structure together. Emulsions use water to make the asphalt workable and the same end result is generally achieved. The energy savings can be enormous if emulsions are utilized.

4. Recycle asphaltic pavement materials. Although this concept is still in its infancy, tremendous strides are being made. Research and development work in this area is documenting the potential energy and dollar savings without loss of quality (Epps, 1978). Test sections are being constructed in many parts of the United States and more and more types of asphaltic concrete materials are being shown to be easily recyclable. Other materials such as portland cement concrete, can also be recycled.

5. Increase the use of lower energy by-products such as coal ash. There are in excess of 6.5 million tons of coal ash produced in the United States each year (Faber, 1978). Interestingly, coal ash is our nation's sixth most abundant material (Minerals Yearbook, 1977). The vast majority of this ash is fly ash which can be used as a partial replacement for either portland cement or hydrated lime - both high energy, costly materials. As the technology is developed, more and more of these by-products will be used, thereby reducing the amount of portland cement and lime required for construction of transportation facilities. Currently this is of considerable interest due to the critical shortages of cement and lime in many parts of the United States (Engineering News Record,1978).

To illustrate the potential energy savings through a modest program of incorporating these energy ideas, calculations for 200 lane miles of pavement construction or maintenance using each concept in 40 states results in the following "example" energy savings (Ledbetter, et. al., 1978):

Example Energy Savings

Concept	Potential Energy Savings (millions of gallons of gasoline equivalent)
Increased Standardization	12
Performance-Based Specifications	*
Asphalt Emulsion in Lieu of Cutbacks	33
Recycled Asphaltic Concrete	46
Replace Portland Cement with Lime-Fly Ash in a Base Course	115

These values are labeled "Example" because they are illustrative of the order-of-magnitude of energy savings possible through implementation of these concepts. While the actual energy savings will depend upon the specific designs which are developed to maintain the desired quality, these example savings amount to more than 2 percent of the energy consumed - certainly a good start.

The energy savings, through development and implementation of concepts such as those discussed, are indeed significant. Policy makers and decision makers at all levels of highway construction need to become better

*Value depends upon extent of specification development.

informed about the energy implications and trade-offs between various construction alternatives. By so doing, energy can be conserved in transportation construction without loss of quality.

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WORKSHOP 9

MATERIALS SCIENCE AND TECHNOLOGY FOR NEW ENERGY SOURCES AND MORE EFFICIENT ENERGY CONVERSION--NUCLEAR

CHAIRMAN: J. PHILIPPE BERGE (FRANCE)

ORGANIZER: ROBERT I. JAFFEE (U.S.)

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Role of Materials in the Safety and Reliability of Light Water Reactors

GUSTAF ÖSTBERG

(Lund Institute of Technology, Sweden)

From the point of view of safety and reliability it is obvious that a major loss of integrity of large reactor components might cause considerable damage to personnel and plant. The necessary repair and replacement would, if ever possible, become very expensive. Postulated or real material problems in connection with manufacture and operation have therefore been the subject of intensive studies by material specialists. However, a final solution to the safety and reliability problems can be arrived at only with due consideration also of the roles of a number of related factors such as design, manufacture, control, operation and maintenance.

The program committee has selected a few examples to be discussed under this heading:

- heavy section weld cracking
- fracture threat in pressure vessels after a loss-of-coolant accident
- corrosion in steam generators and turbines.

For the main pressure vessel the principal factors to be considered besides the properties of the steel, i.e. its fracture toughness, are the stress and the presence of crack-like defects. Using data for these parameters one can decide whether a defect is large enough to propagate catastrophically. A probabilistic treatment of such fracture mechanics calculations can, in principle, show the risk that this type of failure will occur due to statistical variations of the values of the parameters in question. A sensitivity analysis of the probabilistics mentioned might show the relative role of material properties in determining the risk of catastrophic failure.

The weldments are of particular interest in this respect, since welding involves certain risks of introduction of defects and deterioration of material properties. A phenomenon which has aroused some attention in recent years is so-called reheat cracking. It has been found that sometimes small cracks may develop in the heat-affected zones of weldments when subjected to stress-relief annealing. Such cracks form due to insufficient ability of the material to relieve residual welding stresses by plastic deformation. However, most specialists in this field consider this type of cracking, if it should occur to any considerable extent, to be relatively harmless.

A special situation for the lower part of the main pressure vessel is emergency cooling. In order to cool the core, if the ordinary coolant system fails, cold water is dumped into the vessel. When this water hits the vessel a severe temperature gradient is established, leading to high thermal stresses. The question was raised early whether these high stresses at the internal surface might exceed the critical level for catastrophic propagation of cracks, even below the size which is normally possible to detect. An analysis of this situation showed, however, that PWR vessels of common design are safe from this point of view.

For the steam generator tubing the main cause of failure is corrosion. This may take different forms: stress corrosion on both the inside and the outside surfaces, so-called denting at the tube plate, and wall thinning. All types of stainless steels and nickel alloys in use appear to be sensitive to stress corrosion attack in water, although the extent differs with alloy composition and water chemistry. In the denting process corrosion products of the tube support plate exert an outer radial pressure on the tubes, causing them to deform and eventually to break.

All these corrosion phenomena have been found to vary with water chemistry. As regards denting, the corrosion of the tube support plate is connected with the low pH and high chloride environment prevailing in the narrow space between the tubes and the plate. To minimize the consequences of leakage of sea water from the condensers into the secondary circuit, additives are used. Earlier they consisted of phosphate which has nowadays mostly been replaced by volatile hydrazine. A phenomenon which was thought to contribute to stress corrosion was the deposition of phosphate on the outside surface of the tubing. This in turn was caused by stagnant boiling due to insufficient circulation of the water. Problems of this kind should disappear when volatile treatment is introduced, but in some reactors the last traces of phosphate have proved difficult to remove.

To reduce the leakage responsible for the corrosion effects mentioned, the condenser tubing is usually no longer made of copper base alloys but of titanium, the tubes being welded to plates of the same material. Also the replacement of mild steel in the steam generator tube plate by stainless steel should assist in the attempts to eliminate denting. Such remedies are already applied in several plants.

This brief review shows that the stage on which materials play a role is set by a script with many actors. Furthermore, materials in nuclear reactors are part of a large system involving even several important factors of a non--technical nature.

<u>Material Considerations in Assessing Safety and Reliability of Light-Water Reactor Pressure Vessels*</u>

D. A. CANONICO
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Light-water nuclear pressure vessels and nozzles are fabricated from essentially two grades of low-alloy steel. The ASME specifications for these steels are SA-533 grade B class 1 plate and SA-508 classes 2 and 3 forgings. Studies conducted by the HSST program at ORNL involving flaws (approximately 75 mm deep by 200 mm long) in intermediate-size pressure vessels (about 1 m diam by 2.5 m tall) indicate that these steels and their welds can withstand internal pressures nearly 3 times those permitted in Section III of the ASME Code for class 1 construction. The vessels withstood nearly limit-load stress levels before failure, even at test temperatures at which the materials undergo a transition in fracture morphology. At temperatures corresponding to the Charpy V-notch upper-shelf energy levels for these materials (about 90°C), the vessels withstood strain levels of up to 2% before failure.

In summary, the materials from which light-water reactor pressure vessels and nozzles are fabricated are quite tolerant of large flaws, even at temperatures where frangible behavior occurs. Specifically, the vessel and nozzles are a high-quality product before being placed in service. During service the properties of the vessel materials can change as a consequence of exposure to irradiation, and small Code-allowable flaws can extend and grow. The influence of such material behavior on safety and reliability continues to be assessed, particularly under potential but remote accident conditions. Of main concern is the unlikely but possible loss-of-coolant accident (LOCA). Analyses backed by experiments have been conducted by the HSST program and show that the pressure vessel materials, when initially placed in service, can sustain a LOCA without jeopardizing the integrity of the vessel. Nevertheless, a number of areas should be considered. The four areas of primary concern, particularly in the event of a LOCA, are:

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1. Irradiation causes loss of toughness, as indicated by Charpy V-notch (C_V) tests. Quantitative fracture mechanics data are required to determine whether low C_V upper-shelf values (approximately 55–65 J) are cause for concern. Materials studies involving the analytical procedures of fracture mechanics are being conducted to determine the validity of C_V data for assessing vessel integrity at operating temperatures.

2. The heat-affected zone of the pressure vessel may contain small grain boundary decohesions (reheat cracks). Specifically, concern has been cited regarding the effect of these decohesions on crack initiation and growth.

3. The probability that in-situ repair welding of a pressure vessel, nozzle, or piping will be required during the lifetime of the equipment is quite high. Tests at ORNL have shown that the residual stresses that are present after repair welding do contribute to crack extension at low temperatures. Repair procedures must be developed that will minimize these residual stresses. Some work is in progress in this area and should be discussed.

4. Finally, data describing the influence of the above factors on crack growth (in particular) are essential. The relationship between crack growth, material embrittlement, and the improbable but possible LOCA event must be considered.

In-Reactor Creep Deformation of Zircaloy Fuel Cladding*

D. O. HOBSON
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Creep of Zircaloy fuel cladding under light-water-power-reactor operating conditions (i.e., under a compressive biaxial stress state) is a relatively unquantified phenomenon. It is important, however, because the pellet-to-cladding gap in a fuel rod controls much of the thermal behavior of that rod. Gap conductance and pellet-cladding interaction are examples of fuel rod properties that strongly depend upon the geometrical relationship of the cladding to the fuel.

A Nuclear Regulatory Commission program has been under way for four years to study the effects of temperature, external pressure, and fast neutron flux on cladding creepdown. Creepdown is a coined word denoting the time-dependent, inward movement of cladding. Out-of-reactor creepdown tests have been run at 371 and 343°C with net external pressures ranging from 17.2 to 13.1 MPa. A highly accurate and precise monitoring system was developed capable of continuously measuring the radial movement of 20 points on the surface of a cladding specimen to within ±2 μm each. This system is capable of operation at temperatures to 427°C and pressures to 21 MPa in reactor. A joint program with the Dutch at ECN-Petten has produced four in-reactor tests in the High Flux Reactor. These tests were conducted at 371 and 343°C at pressures of 15.9, 14.5, and 13.1 MPa.

Out-of-reactor tests to date have shown that creep deformation occurs in a relatively simple manner with two types of deformation — ovalization and circumferential shrinkage. The latter strains are biaxial after the cladding contacts the simulated fuel pellets — that is, a plane strain condition exists in which circumferential shrinkage produces wall thickening with little axial strain. Extrapolation of these data to pressures typical of beginning-of-life reactor conditions, nominally 9 MPa, indicates that firm pellet-cladding contact may occur in approximately 2000 h.

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In-reactor data are not yet fully processed, but preliminary indications show that circumferential creep rates are faster than for uniaxial creep data reported in the open literature. For example, the first in-reactor creepdown tests, conducted at 371°C and 9.4×10^{17} n/m^2·s (>1 MeV) with a compressive hoop stress of 106 MPa, had a circumferential strain rate of 1.8×10^{-5}/h.

Further testing will elucidate the creepdown phenomenon and will provide a better understanding of fuel element behavior under reactor operating conditions.

What is the role of materials in the safety and reliability aspects of LWR's?

J. BARFORD
Central Electricity Research Laboratories,
Central Electricity Generating Board,
U.K.

1. Recent proposed changes to PWR pressure vessel fabrication methods may have fundamental implications on materials behaviour in the event of a LOCA. In particular come to mind the use of mono-bloc shell/nozzle construction. What investigations are in hand or planned to determine the effect of such techniques on materials properties and is it thought likely that such developments will change the effects of segregation in thick section forgings? I am thinking not only of impurity elements, S,P,As,Sb, etc. but of carbon too. Further it would be interesting to know what compromise is emerging between the higher carbon levels in pressure vessel steels, preferred because of some mechanical property consideration, and the lower levels preferred for weldability. Is there an adequate data base for the lower carbon materials?

2. Fracture assessment methods have progressed significantly in the past few years particularly in techniques and supporting materials data for post-field fracture mechanics analyses. I should welcome delegates' views on the current recommended methods for taking into account secondary stresses (residual welding or thermal) into such assessments.

What are the prospects that materials performance will be better and systems reliability higher in gas-cooled reactors than in LWRs?

J. BARFORD
Central Electricity Research Laboratories,
Central Electricity Generating Board,
U.K.

The fundamental question to consider in any engineering concept is whether we are faced with a design difficulty or a materials difficulty. Arguably we are faced with both in reactor technology since although demonstrably both LWR's and GCR's work, the material's performance is inextricably linked with what we wish it to do and the final behaviour is a very complex function of its total environment - temperature, stress, chemical - as well as its size and shape, method of manufacture and detailed physical properties.

It continues to be a combination of surprise, gratification and disappointment to me that the majority of difficulties experienced so far with nuclear systems have had their origins in common metallurgical and chemical causes - corrosion, fatigue, creep and possibly fast fracture - and with ostensibly well characterised engineering materials rather than with the more esoteric conditions experienced by core and fuel components. A glance at component behaviour in nuclear systems suggests that where novel materials and designs have, of necessity, been used they have generally performed well. There are two reasons for this; firstly the relatively short life span expected of many of the highly irradiated components, and secondly the obvious and critical importance attached to their reliability. The latter led to the expenditure of vast effort on developing and proving them in the right environment, that is a small, prototype reactor. The latter was not generally true for materials in the rest of the system and the effects of scale changes from small prototype to large commercial reactors were more apparent and possibly too much reliance was placed on non-nuclear experience. Thus many difficulties have been confined to the least novel part of the system - the boiler. Although several nuclear powered turbines have suffered major failures, it was not, I believe, because they were nuclear powered, per se. I shall therefore confine my comments largely to the boiler and pressure circuit.

The purpose of this session is to consider GCR's and by these I mean the carbon-dioxide cooled Magnox and Advanced Gas Cooled (AGR), the helium cooled High Temperature (HTR) and the Gas-Cooled Breeder Reactors (GCBR).

In comparing GCR technology in general with LWR, three major differences leap to mind. Firstly, the higher temperature range of the former, secondly the heat transfer medium is a single phase gas, and thirdly the primary containment, currently a pre-stressed concrete pressure vessel (PCPV). The first has implications for materials behaviour in creep, corrosion and thermal fatigue, and in fabrication and operational techniques; the second has fundamental implications in corrosion mechanisms; the third in operational fault conditions, fabrication and inspection.

That modern GCR's employ materials in the creep range might be thought disadvantageous. However, this is not necessarily so since it is common experience with fossil fuel plant that very few, if any, components fail in creep when employed under conditions close to their design basis. Given that creep failures do occur in fossil boilers, the most common cause is that of excessive temperatures causing either, or both, excessive corrosion and general loss of creep strength. This is an unlikely event in GCR's since the core gas outlet temperature is not particularly high (excepting HTR) and, more importantly, is well controlled. However, an effect that might prove more difficult to analyse and design for is that of combined creep/fatigue in heavy section components arising from a requirement for frequent load cycling. Whilst this is not of such concern in GCR's as LMFBR's, I believe we need more effort on improving the design basis of components operating in creep fatigue conditions. This should incorporate the rapidly increasing sophistication in analytical techniques and knowledge of materials behaviour as commonly used at present for fitness for purpose assessments, but not so widely in the design stage.

For AGR and GCBR's the metallic fuel clad limits gas temperatures to 650°C maximum and with steam conditions of about 560°C there are a number of alloys available for superheater tubing. The mainstay is the 300 series of austenitic stainless steels of which AISI 316 is probably the best characterised. Even so, we know less than is desirable about its long term properties and NDE capabilities, especially in weldments.

Stress corrosion cracking susceptibility prohibits the use of these steels for the evaporator for which a ferritic steel is usually specified. This requires a large number of austenitic/ferritic steel welds. In fossil-fired plant these are well recognised as a source of concern, but with modern production techniques and well controlled stress and temperature conditions they should not prove a design life limiting feature.

The alternative is a single material boiler and then we must seek less well established materials. Alloy 800 is probably the best known contender, but there is still some doubt whether its composition and heat treatment can be optimised to give acceptable long term behaviour.

For the HTR with its multiplicity of possible uses - either for direct steam generation, or combined gas turbine/steam cycle or process heat/steam cycle we must consider much higher temperatures. Core gas outlet temperatures up to 950°C for the latter uses will require the introduction of alloys novel to nuclear applications. There are a number of large material evaluation programmes devoted to this topic currently and while the situation looks promising, there is a good deal of work to do.

For corrosion problems on the primary side, the GCR's arguably have a marked advantage over LWR's in that with a single phase gas it is unlikely that concentrations of corrosive species will occur as is inevitable in a steam/water cycle. That is not to say the gas side of GCR's is immune to corrosion problems - those of the Magnox and AGR have been well publicised. For Magnox the phenomenon of 'breakaway' corrosion became manifest in 1968 in the form of a broken mild steel bolt, the failure being caused by a non-stifling form of corrosion at all surfaces in a bolted assembly and resultant straining of the bolt by oxide growth (jacking). The implications for core integrity required a reduction in core gas outlet temperature to allow continued operation.

I note that 'breakaway' corrosion in CO_2 was observed in the laboratory in 1959, and that Pilling and Bedworth made their observations on corrosion in 1928, but neither for Magnox nor for PWR's were the implications appreciated.

Similar behaviour has not been observed in helium based coolants. The composition is now well defined from prototype reactor operation and the impurity levels of moisture, hydrocarbons, etc., in both normal and fault conditions appear to give little cause for concern.

The numerous mechanisms in GCR's leads to a requirement for materials with good rubbing and wear resistance. These tribological effects are often difficult to allow for in design both because of the difficulty in specifying and performing tests, and in translating the data to real components. Similar care must be used to avoid fretting wear in high velocity gas streams.

An important feature of GCR's is the graphite core which serves both as a moderator and structural member. Specimen and in-reactor examination of commercial and prototype reactors over many years has shown that although oxidation and dimensional changes have occurred, this has not been to unacceptable limits. However, the greater complexity of a GCR core makes initial design, construction and life assessments more difficult than for LWR's.

A further fundamental difference is that of the pressure vessel. Modern GCR's invariably employ a PCPV. While these are bulky structures, a 660MW AGR vessel, for instance, measures ≃30m diameter by

≃35m high with walls ≃5m thick, they have some inherent advantages over a steel vessel. The ability to check and restress the tendons and to insert instrumentation within the wall to determine temperature, creep displacement and stress is extremely valuable. The thickness of the wall and the insensitivity of the material to irradiation damage are further advantages over a steel vessel. Conversely, elastic/plastic deformation analysis of large concrete structures in creep is not so well understood as the equivalent LEFM or post yield analysis of steel structures. But the chief disadvantages of concrete is its restriction to low operational temperatures. The existing AGR concrete vessels are designed for an operating temperature of about 60°C. This requires the steel liner to be cooled on the outside and insulated on the inner. However, as with the concrete vessel itself, a good deal of redundancy can be incorporated and operation so far is very good.

Further studies of long term effects of higher temperatures on creep and moisture migration both for the possibility of loss of insulation and to allow greater design flexibility are desirable.

What of the operating experience to date? The first commercial GCR and LWR were commissioned in the early 1960's. By the end of 1974, out of a world total of about 10^{12} megawatt hours of nuclear generated electricity, the U.K. Magnox reactors had contributed nearly 30%. One still holds the world's operating record, 653 days nonstop until shutdown for a statutory inspection. The prototype Magnox have been operating for over 20 years and commercial ones for over 16 and a recent CEGB exercise to investigate design life limiting factors failed to determine any.

Four final points: initial capital cost gives LWR a clear advantage, but whether the total lifetime costs will be the same is problematical. Clearly the much higher efficiency of GCR's, whether thermal or breeder, provides a balance when coupled with high availability and long lives. Thirdly, consideration of decommissioning should not be postponed. Finally, in what is arguably the most complex and sensitive civil technology man has devised, we must ensure in any kind of reactor that we really know what the operating conditions are and what are the real material properties, not just the notional 'design' conditions and the behaviour of a piece of virgin metal, but the total response of a fabricated, operating structure.

Materials Performance and Systems Reliability in High-Temperature Gas-Cooled Reactors*

F. J. HOMAN
Metals and Ceramics Divison,
Oak Ridge National Laboratory

Systems reliability for a nuclear reactor must be discussed in terms of both normal operating conditions (NOC) and accident conditions. Further, reliability is determined by both the performance of the materials used and the probability that during reactor operation the components made from these materials will always operate under the conditions for which they were designed. It is not possible to discuss, in a meaningful way, the reliability comparisons between LWRs and gas-cooled reactors under NOC, because LWRs have been operating commercially for some time and there is no large-scale commercial experience with gas-cooled reactors. Experience with small scale HTGRs has been good (Peach Bottom Reactor in the U.S. and the AVR in Germany) relative to reliability, but the Fort St. Vrain Reactor (FSVR) has not yet achieved full power. It is not clear whether the FSVR problems are materials related or due to design deficiencies.

While systems reliability comparisons under NOC must await the accumulation of some commercial operating experience for HTGRs, meaningful comparisons can be made for reliability associated with accident conditions. The LWR core will reach temperatures that will severely damage fuel rods within seconds of a severe loss-of-coolant accident. Even if the emergency cooling systems work as designed, the occurrence of such accidents would require an extensive shutdown of the reactor while fuel is removed and inspected, and new fuel is inserted to replace damaged rods and bundles. The HTGR core, on the other hand, heats up very slowly during an accident (General Atomic, 1973; Ball, 1976). During a loss-of-forced-convection (LOFC) accident the maximum fuel temperature increases 250 to 400°C/h. Under a design-basis depressurization accident (DBDA) the heatup rate is about 250°C/h. With the reactor operating at full power but with no cooling, the average core heatup rate is about 200°C/min. Experiments have shown that fuel particles can survive temperatures above 2000°C for periods of up to 1 h with no apparent damage. Normal operating temperatures for HTGR fuel range from 900 to 1350°C.

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The greater response time available for HTGRs, than for LWRs, increases the probability (for HTGRs) that emergency cooling systems will cool the core before the fuel is damaged, in the event of an accident. Delays associated with fuel removal, inspection, and supplying new fuel to replace damaged fuel can thereby be avoided, resulting in better system reliability.

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HOW THE CHOICE OF MATERIALS AFFECTS THE COST (CAPITAL EXPENDITURE + OPERATION) OF A FAST BREEDER POWER PLANT

by
Michel WEISZ

Optimization computations use a dozen independent parameters, which allow a relatively complete definition of the characteristics of the power plant. These include geometric parameters (volume, core height, fuel element diameter, spacing between fuel pins, diameter of heat exchangers and pumps), which are relatively unaffected by the type of material. They also include thermal parameters (primary ΔT, secondary sodium temperatures, water and steam input temperatures), only the last of which has a critical effect on the choice of materials for the steam generator, essentially from the standpoint of their compatibility with sodium and their high temperature mechanical strength.

Three essential characteristics must be added to these adjustable parameters which are the technological limits imposed by the materials employed for the fuel element :

- maximum linear power of the fuel pin,
- maximum clad temperature T,
- maximum burnup τ.

It is essentially through the properties of the materials used to set these maximum values that the choice of materials can affect the kWh cost ; the rest of this discussion focusses on this point.

LINEAR POWER

By definition, this is the power liberated per unit length of the fuel pin. It can be shown that it sets the temperature profile in the fuel, and consequently the inner fuel temperature which is generally limited to the melting point. Hence the important factor can be seen to be the thermal conductivity of the fuel. For mixed oxides of uranium and plutonium, the conductivity depends on density, on the type of porosity introduced by sintering techniques, and on the stoichiometry, hence on the fabrication process. Moreover, all these characteristics may vary during irradiation because of densification and redistribution of oxygen. These ceramic mixed oxides are mediocre conductors of heat, but they have high melting points. In view of the design criteria which are adopted, they do not provide for linear powers far above 500 W/cm. On the other hand, other compounds such as carbides and carbonitrides exhibit conductivities closer to that of the metallic state, allowing for double the linear power levels. Furthermore, the higher heavy nuclei density gives grounds for anticipating interesting breeding ratios and doubling times. For these reasons they are now eagerly investigated as fuels for the future. Their use, still raises difficult problems of preparation, in-core behavior (risk of mechanical or physicochemical interaction with the clad) and reprocessing.

MAXIMUM CLAD TEMPERATURE T AND MAXIMUM BURNUP τ

These are not independent variables, because the phenomena which limit them depend both on temperature and time, which is proportional to τ.

These phenomena are the following.

High temperature mechanical strength of the cladding material

The continuous release of gaseous fission products creates an internal pressure which increases with time, and which, in the hot portion of the fuel pin (> 600 °C) causes creep deformation of the clad. This deformation ε increases rapidly with time (hence with burnup) and with temperature, according to the equation :

$$\varepsilon = \frac{A}{n+1} \exp \frac{-Q}{RT} \sigma^n$$

where :

A, n and Q are parameters set by the material,
σ hoop stress,
ε is limited to εo corresponding to fracture.)

To take account of the irradiation embrittlement, εo has very low values (a fraction of 1 %) for the 316 type clad steels generally employed.

Naturally, action can be taken in designing the fuel pin to limit ε by limiting σ, for example, by increasing the plenum volume. However, these manipulations have serious repercussions on the economic level. At present, plenums have a length approaching that of the active portion of the core, this weighs heavily on the fuel fabrication costs and affects the dimensions of the vessels, of the handling machines, etc ...

It is far better to adjust the material characteristics An and εo and to try to minimize the effects of irradiation by thermomechanical treatment, or by the addition of stabilizing elements for 316 type steels, or by employing ferritic steels, as sometimes suggested.

PHYSICOCHEMICAL INTERACTION BETWEEN CLAD AND IRRADIATED FUEL

These are complex reactions between certain fission products and the constituents of 316 type steel. The thickness of the layers involved increase by solid state diffusion according to the following expression :

$$K\tau^{1/2} \exp \frac{-Q'}{RT}$$

This has different values according to whether bulk attack or intergranular penetration is involved. It does not appear that simple solutions have been found with new clad materials. This phenomenon is considered rather as a necessary evil, with relatively limited effects.

SWELLING OF CLAD MATERIALS

This is a typical irradiation effect of the high neutron fluxes of breeder reactors, and was only recently discovered.

Without going in detail into the physics of the phenomenon, it may be stated that it involves the growth of submicroscopic cavities by condensation of vacancies formed by irradiation. This is reflected by a drop in density and an increase in all dimensions. This variation in volume depends on the neutron flux and on temperature (with a maximum at a certain temperature) and grows rapidly with time and hence with burnup.

In the compact fast reactor fuel element, dimensional variations must be restricted to a few per cent, which leads to severely limited core residence times. This is so because they have serious consequences such as :

- partial clogging of sub-channels, changes in flow rates and overheating,
- plastic deformation by crushing of the clads against each other or gainst the hexagonal wrapper tube.

In the core regions with high flux gradient, they can cause bending which hinders fuel handling operations. Swelling is now the factor which most seriously hampers the achievement of high burnups ($\sim$ 100,000 MWd/ton), which are necessary for the economics of the power plant.

Metallurgical research has shown how swelling of 316 type steels can be reduced by work hardening, by the strict control of the solution of certain elements (carbon), and by limited additions of other elements such as Ti, Si and P. This have given rise to optimized steel grades and fabrication processes, and far better performance, yet probably still inadequate. The best possibility of an answer to the problem lies in completely different alloys. One of these are the complex nickel-base alloys on which considerable development and fuel element irradiation test work still remains to be done with this type of clad, before a definitive solution will be available. Ferritic steels can also be used for the wrapper tube.

These solutions are developing slowly. Our experience shows that about eight years are required to validate a clad steel grade . This is perhaps not excessively serious in the case of a consumable element such as fuel, on which changes can be made and progress achieved normally, throughout the service life of the power plant, unlike the remaining components.

Materials Technology for Steam Generators in Liquid-Metal Fast Breeder Reactor Systems*

P. PATRIARCA and C. R. BRINKMAN
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

While critical to successful operation of conventional fossil and nuclear power plants, the steam generator plays an even more vital role in the Liquid-Metal Fast Breeder Reactor (LMFBR) system. In existing and planned fast breeder systems, for instance, these units must function reliably for lifetimes of up to 30 years at temperatures often within the creep range of the materials of construction and in a fashion to preclude failure and resultant adverse effects of reactions of liquid sodium with water. Sodium, while explosively reactive with water, serves as a near-ideal heat transfer medium in LMFBRs because of its high thermal conductivity, relatively low density, high boiling point, and low corrosion-erosion rates in selected structural materials. Therefore, special considerations have to be emphasized during the design, fabrication, inspection, and installation of steam generators for liquid metal service to prevent steam leaks into the sodium and to minimize the impact should leaks occur during service. A highly disciplined engineering approach had evolved in overall LMFBR development to obtain the required reliability, and it has been applied to steam generator design as follows:

1. Overall performance is analyzed in terms of normal or expected operating conditions as well as malfunctioning or hypothetical accident situations to ensure that all possible failure modes are accounted for. Failure by corrosion, fatigue, creep-fatigue interaction, lack of toughness, wastage, etc., all must be considered.

2. Design practice is conservative and generally exceeds minimum requirements specified in existing codes and standards such as given by the *ASME Boiler and Pressure Vessel Code*.

3. Structural parts are prepared from well-characterized material of known metallurgical behavior.

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4. Fabrication follows prescribed practice to yield sound structures with known performance characteristics, and adequate quality assurance procedures are invoked to ensure that defects above allowable limits are not present in the finished product.

5. Performance tests are required on first-of-a-kind items to ensure expected behavior.

6. Operating procedures must be followed to ensure that stress on the component never exceeds design allowables.

Materials engineering has played an important role in steam generator development, and the objective of this presentation is to review materials development needs and present the current state-of-the-art experience for both foreign and domestic LMFBR steam generators.

First-Wall Materials Problems in Magnetic and Inertial Confinement Nuclear Fusion Reactors

RYUKITI HASIGUTI
(Science University of Tokyo, Kagurazaka, Shinjuku-ku, Tokyo)

It is considered that the controlled nuclear fusion reaction would be the major energy source for mankind in the future. This would be most true in such countries as Japan which have almost no fossil nor uranium resources.

In several countries, facilities for criticality experiments of plasma are being constructed. For instance, the criticality experiment facility of Tokamak type named JT-60 is under construction at Japan Atomic Energy Research Institute. Experimental fusion reactors will be constructed in several countries by the end of this century.

As pointed out by Kulcinski (Kulcinski, 1976), next to the plasma physics problems, the effects of radiation damage to reactor structural materials represent the second most serious obstacle to fusion power. Therefore, problems concerning first wall materials including partly blanket structural materials which suffer from serious radiation damage will be discussed in this paper.

Although there are different types of magnetic confinement, the effects and the extents of radiation damage are not very much different in different types of magnetically confined reactors. But the situation is quite diverse in the case of inertially confined reactors depending on the protective mechanisms of the first wall (Conn, 1978; Hunter and Kulcinski, 1978).

The radiation damage of structural materials in fusion reactors is considered to be much more serious than that in nuclear fission reactors in the following points. The radiation consists of 14MeV neutrons produced by D-T reactions and charged particles, neutral atoms and electomagnetic waves from plasma. The radiation effects in the fusion reactor environment include heavy atomic displacements of the order of 100 to 1000 dpa or even more during the wall life, and swelling, blistering, sputtering and nuclear transmutation effects including helium production and induced radioactivity, in addition to the radiation embrittlement. Mechanical properties such as creep and fatique, and chemical compatibilities are also affected by irradiation.

The selection of first wall materials cannot be made based only on irradiation properties of materials. Various non-irradiation mechanical and thermal properties, various compatibilities, fabrication and welding properties of large constructions, resource availability, etc. must be considered.

At this stage of research and development toward future fusion reactors, the selection of structural materials cannot be unique. Different answers are being proposed by different research groups in different countries. We made a report to the Nuclear Fusion Division of Atomic Energy Commission of Japan in July, 1978. In this report we proposed several solutions assuming a Tokamak type experimental reactor to be constructed in early 1990's and future Tokamak type power reactors (Fusion Reactor Materials Committee, 1978). The summary of our report will be given below.

For the 1990 experimental reactor, which would operate at about 500°C of wall temperature, there is almost no choice other than 316 austenitic stainless steel or commercial heat-resisting Fe-Ni-Cr alloys, because of the extensive existing industrial data base. From the point of view of induced radioactivity the above materials are not necessarily favorable. But this is not too serious as far as the neutron wall loading is small.

In the longer term researches of future power reactors which will operate at higher temperatures, more heat-resisting Fe-Ni-Cr alloys should be studied. But for the still higher operating temperatures, namely above about 650°C, alloys of refractory metals such as V, Nb and Mo must be considered. Vanadium alloys are most attractive, because of the low induced radioactivity, although the operating temperature cannot exceed about 800°C. Above about 800°C remaining possible materials are niobium alloys and molybdenum alloys.

As was mentioned earlier, the radiation flux is quite different according to the protective mechanisms of the first wall in inertial confinement reactors. The Osaka University group proposes even an extreme case of zero radiation damage in the first wall which is protected by a thick liquid lithium wall (Yamanaka, 1978). On the other hand the bare wall would melt in the case of most metallic materials with reasonable sizes of the reactor chamber (Conn, 1978). These two extreme cases suggest that the radiation damage level in the inertial confinement reactor can be controlled by appropriate protection mechanisms, which increases the freedom of selection of first wall materials. However, in the inertial confinement reactor, there is another problem of radiation damage, namely that of the laser mirrors, which are exposed to a rather high explosive flux of radiation. This produces high atomic displacement rates, which result in somewhat different radiation damage as compared to that in magnetic confinement reactors (Hunter and Kulcinski, 1978).

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The Engineering Test Facility Can Serve a Major Role in Materials Development for Fusion Reactors*

E. E. BLOOM and J. L. SCOTT
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

In the national policy statement on fusion energy (DOE/ER-0018, September 1978) prepared by the Fusion Review Committee (J. M. Deutch, Chairman), Engineering Test Facilities (ETFs) are identified as essential elements of both magnetic and inertial-confinement development. Recently, an ETF Design Center was established at the Oak Ridge National Laboratory under the direction of Don Steiner. A workshop to define the mission of ETF was recently held in Knoxville, Tennessee. Specialist subgroups on blanket, first wall, and shield testing technology and on materials testing concluded and recommended that a major function of the facility should be to provide a test bed for development and qualification of materials, design methods, and components for the Experimental Power Reactor (EPR) and the Demonstration Reactor (DEMO).

Advances in materials technology are required in many different areas for the success of fusion as an economical energy source. A major research and development program will be required in the following areas:

- First-Wall and Blanket Structural Materials
- Ceramic Materials (Thermal and Electrical Insulators)
- Heat-Sink Materials
- Breeder Materials
- Magnet Materials
- First-Wall Coatings or Shields

The materials development function of the ETF can be summarized by examination of one essential component, the first-wall structural material. Design of EPR and DEMO will require an extensive engineering data base on all critical materials and properties. Design methods will have to be validated and questions relating to the effects of surface damage on bulk properties, such as fatigue crack initiation and growth, will have to be examined in detail. For commercial fusion

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reactors development of new alloys will be required. A fusion reactor materials test facility with a significant test volume ($\sim$0.1 m^3) in which to examine the effects of the fusion reactor environment (high energy neutrons producing atomic displacements and transmutations, surface damage from energetic ions and surface heating, atomic hydrogen, etc.) is necessary. To accomplish these goals, the ETF must have several fully instrumented test stations each with independent cooling. It should produce exposure levels near 2 MW/m^2 and operate more than five years. The use of ETF as a materials test facility increases requirements for neutron fluences, access, and facility life beyond those needed for the physics and blanket-engineering missions of the device.

The Nuclear Industry - Where Are The New Materials?

SPENCER H. BUSH

(Battelle Memorial Institute - Pacific Northwest Laboratory)

If one looks for new materials specifically designed for the needs of the nuclear industry whether light water reactors (LWR), high temperature gas reactors (HTGR), liquid metal fast breeder reactors (LMFBR), or the Canadian deuterium oxide natural uranium (CANDU) reactors, one finds none, other than zirconium alloys used in CANDU pressure tubes or LWR fuel cladding.

Since materials conventional to the chemical and electric utility industries have been used, the obvious questions are:

1. How successful have the conventional materials proven to be during operation?
2. How successful have substitutions of one conventional material for another conventional proven to be?
3. Do enhanced requirements typical of the nuclear industry in areas such as non-destructive examination pose additional limitations?
4. Are changes anticipated in operating conditions (P,T, etc.) in any of the existing or proposed reactor systems that will necessitate new materials?
5. Are there potential long term degradation mechanisms that may require replacement of materials late in life?

A general idea of the materials for various reactor systems is given in Table 1; not a complete listing.

The new material, if it can be considered such, is zirconium or more specifically alloys of zirconium; namely, Zircaloy-2 or Zircaloy-4. Their justification is obvious. They have low neutron absorption cross sections minimizing the level of enrichment in thermal reactors. While one may call them new materials, they are not a commercial development, being an outgrowth of the United States Naval Reactor Program used initially as fuel cladding and picked up for commercial use in the LWR's and as pressure tubes in the New Production Reactor and the CANDU's.

Returning to the earlier series of questions:

TABLE 1

MATERIALS USED IN VARIOUS REACTOR SYSTEMS

COMPONENTS	LWR			
	BWR	PWR	HTGR	LMFBR
Reactor Pressure Vessel				
Original	A-302-B	A-302-B	SA-212-B	Stainless 316
Current	A-533 GRB or A-508 Cl 2	A-533-GRB or A-508 Cl 2	PCRV	"
Piping				
Original	304	304	--	316 S
Current	304 A-106 < 10-in welded	Cast SS		
Pumps and Valves				
Original	Carbon Steels	Alloy Steels or	--	316 S
Current	or Cast SS	Cast SS		
Steam Generator Tubing				
Original	-	304/316	Incoloy-800	316 SS
Current	-	Inconel-600	Incoloy-800	316
Core Internals				
Original	304	316	-	316
Current	304	316	Graphite	
Fuel Cladding				
Original	304	304	Stainless	316 SS
Current	Zr-2	Zr-4	Graphite	316 SS

1. How successful have the conventional materials proven?

   Austenitic stainless steels (304, 306) in boiling water reactors (BWR's) have relatively poor records due to many incidents of stress corrosion cracking.

   Austenitic stainless steels used as steam generator tubing in pressurized water reactors (PWR's) had a spotty record due to corrosion or stress corrosion, primarily from the secondary side. Incidents of stress corrosion cracking in the discs of large steam turbines used with PWR's may require changes.

2. How successful have been substitutions of materials?

   Inconel-600 used in BWR safe-ends have sustained stress corrosion cracking in some instances. Ferritic materials generally have proven more successful.

   PWR steam generator tubing of Inconel-600 have relatively poor records due to secondary side corrosion or primary side corrosion fatigue.

3. Do enhanced requirements typical of the nuclear industry pose limitations?

   Section XI of the ASME Boiler and Pressure Vessel Code required extensive inservice examination primarily by ultrasonics. Options include changing materials or improving nondestructive examination (NDE). To date most of the effort is in improving NDE.

4. Will reactor operating conditions change sufficiently to require changes in materials?

   Probably not since the core region is more susceptible to increases in pressure and temperature than the pressure boundary and reactor reliability in remaining on-line has a bigger payoff than the limited changes in thermal efficiency.

5. Are there long term degradation mechanisms that might require new materials?

   I consider this possible but improbable. An obvious area is irradiation damage of reactor pressure vessel steels; however, recent data indicate a greater degree of in-situ damage recovery than had been anticipated. It is more profitable to control residual elements such as copper, phosphorus and sulfur in both base material and weldments than it is to develop new materials.

   With regard to LMFBR's, it is possible that long term creep and or creep-fatigue may pose problems; however, behavior to date has been quite good.

   HTGR's simply do not have sufficient operational history to permit a prediction of problems.

For future trends I see conventional ferritic steels used more in piping and other components in both PWR's and BWR's. These may be weld overlay clad to reduce crud formation,although they are being used more and more without cladding.

I visualize no move toward new reactor pressure vessel materials other than more forgings in PWR's rather than plates to reduce the weldments requiring NDE.

With the changes made to zero solids on the secondary side the steam generator tubing problem may have stabilized for new PWR's. If there is one area where materials changes may occur, it is in steam generator tubing.

I am unaware of any moves toward new materials in future HTGR's or LMFBR's.

A New Class of Long-Range Ordered Alloys With Superior Structural Performance at Elevated Temperature*

C. T. LIU, H. INOUYE, AND A. C. SCHAFFHAUSER
Metals and Ceramics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

The successful operation of advanced nuclear power systems, including fusion, breeder, and advanced gas cooled reactor systems, depends on the performance of structural materials used in the construction of in-core components. The systems are currently limited in their operating temperature and efficiency by inadequate strength and stability of commercial superalloys and austenitic steels at elevated temperatures. Recent alloy development work at Oak Ridge National Laboratory (ORNL) has demonstrated[1,2] that long-range-ordered (LRO) alloys with a controlled crystal structure in the Fe-Co-Ni-V system have overcome these material limitations and constitute a new class of high-temperature structural alloys having a unique combination of high-temperature strength, fabricability, and long-term stability.

The LRO alloys are distinctly different from conventional or disordered alloys in atomic arrangement. The atoms in conventional alloys tend to be randomly mixed, whereas the atoms in LRO alloys form a long-range-ordered crystal structure. Because of their unique atomic structure, LRO alloys generally offer significant advantages over conventional alloys for high-temperature applications. However, the main difficulty that limits their use has been their tendency to be brittle in the ordered state. By controlling the electron density and alloy composition, we have developed a series of ordered alloys based on the $(Fe,Co,Ni)_3V$ system. These alloys with a controlled ordered structure are ductile, fabricable, and formable with elongation in excess of 30% at room temperature — a major breakthrough in alloy design.

Tensile tests of the ordered alloys at elevated temperature indicate an unusually attractive mechanical behavior. Their strength, instead of decreasing as with conventional alloys, increases with temperature because of atomic ordering. As a result, the ordered alloys are much stronger than commercial fabricable superalloys at elevated temperatures. For instance, their yield strength and tensile strength at 850°C reach 480 and 660 MPa, which are 300% higher than those of Hastelloy X.

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The high-temperature creep and corrosion of these alloys are also exceptional. The LRO alloys are extremely resistant to creep deformation, and their creep rate is lower than that of conventional alloys by three orders of magnitude. Initial corrosion tests in helium gas-cooled reactor environments show that the LRO alloys are significantly more resistant to carburization than Hastelloy X in terms of the extent as well as the temperature dependence.

To date, we have demonstrated the superior mechanical properties of the ORNL-developed ductile LRO alloys. Further, characterization of their resistance to radiation damage, fatigue, and corrosion in other environments is in progress. We expect that these ductile LRO alloys will contribute significantly, in the years ahead, to more efficient and reliable nuclear power systems.

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Gel-Sphere-Pac Fuel is Easier to Fabricate and Performs Better Than Conventional Pellet Fuel*

W. J. LACKEY
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Interest in proliferation-resistant nuclear fuel cycles and the desire to reduce radiation doses received by personnel during fuel recycle are incentives for performing fuel fabrication operations remotely in thickly shielded hot cells or canyons. Engineers at Oak Ridge National Laboratory are developing a fuel fabrication process that is especially suited for remote processing. The ORNL process is based on fuel microspheres rather than the conventional cylindrical fuel pellets. Microspheres of several different sizes are produced by a chemical gelation technique from a broth (solution) containing the heavy metal. These spheres are then washed, dried, and sintered to form essentially theoretically dense oxides. Fuel rods loaded from a blended mixture of these microspheres achieve a smear density equal to that of stacked pellets.

This fabrication method, called the gel-sphere-pac process, is equally suited for all candidate fuel cycles. The great advantage in this fabrication technique for a remotely operated plant resides in the simplified processing steps. Unlike the conventional pellet fabrication process, no milling, pressing, or grinding operations are required. All feed streams consist of either liquids or spherical particles, which can be easily conveyed around the plant in closed pipe systems.

In addition, there is evidence from initial irradiation tests (Lotts, 1973; Lackey and Selle, 1978; Beatty et al., 1979) that sphere-pac fuel has significant performance advantages over pellet fuel. Specifically, there is less chemical and mechanical interaction between the fuel and the cladding. This may permit reactor on-line time to be increased because of greater freedom for power cycling and increased fuel lifetime. An increase in fuel lifetime also means improved resource utilization. Assessment reports showing the applicability of the gel-sphere-pac process for fabrication of both

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*Research sponsored by the Division of Nuclear Power Development, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

light water and breeder reactor fuels have recently been completed (Lackey and Selle, 1978; Beatty et al., 1979).

The gel-sphere-pac program currently under way is focused on both light-water and breeder reactor fuel geometries. Progress is being made both in identification of optimum microsphere parameters for each fuel type and in the development of equipment concepts suitable for remote applications.

A blend of at least three particle sizes is required to obtain adequate smear density with the sphere-pac process. Feed microspheres presently can be produced over a working diameter range of from 20 to 1400 µm with close size control and excellent shape retention. The actual sphere sizes to be used in loading a fuel rod depend on the loading method and rod diameter. One common loading method involves the simultaneous loading of two larger particle types followed by infiltration of much smaller spheres into this prepacked bed to obtain the needed density. This method provides a good packing structure, which leads to high uniform density, but it requires a long vibration time to fully infiltrate the small particles.

A faster process feeds all size fractions simultaneously into the cladding for compaction. Our recent activity has been directed toward this process. We have determined the proper particle diameters and volume fractions for each cladding size. A workable range of volume fractions exists over which acceptable smear densities can be obtained by the triple blend technique.

Results achieved to date have been encouraging. Fuel columns have been compacted to the densities required for both FBR and LWR applications. The process will soon be demonstrated as practicable and attractive for remote fabrication by the loading of full-length LWR fuel rods and rods of FBR geometry. Successful loading of these fuel types will bring the advantages of sphere-pac fuel much closer to commercial application.

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Effective Utilization of Nuclear Energy and Associated Materials Research Programs in Japan

HIROSHIGE SUZUKI

(Tokyo Institute of Technology, Japan)

In Japan, electric power of approximately 10,000 MWe is now supplied by nuclear reactors (mainly by LWR), and efforts are being made to proceed R&D (research and development) on LMFBR and controlled thermonuclear fusion reactors. On the other hand, the R&D program on direct utilization of nuclear heat energy by means of multi-purpose Very High Temperature Gas Cooled Reactor (VHTR) started about 10 years ago. According to the design plan of VHTR, the nuclear heat energy is available with He outlet temperature at about 1000°C and direct steelmaking system is going to be combined with it. In all of the above mentioned big projects, the development of new materials of high performance plays one of the essential roles in their success. In this article, I would like to describe the present status of R&D program on materials for use in VHTR and nuclear steelmaking technology in Japan.

In order to construct the experimental VHTR of 50 MWt, it is necessary to assure that materials such as nuclear fuels, graphites, or heat resistant alloys can withstand considerably higher temperature than that of previous HTGR, and efforts have been made to improve their performance. For example, fabrication and inspection techniques of coated particle fuels with LEU-oxide kernel have been established. And now extensive researches on "amoeba" effect, reaction between β-SiC and F.P. and irradiation tests have been carried out. In addition, high density isotropic graphite with large size (600 mm$^{\phi}$ × 700 mm long) is now available commercially, and we are able to make nondestructive evaluation of flaws and inhomogeneity in microstructure for the graphite by means of ultrasonic methods. Researches on resistance to oxidation, creep strength, fatigue in graphites are also carried out. These researches are conducted by JAERI (Japan Atomic Energy Research Institute), while universities and venders are also supporting the research activities.

The project on nuclear steelmaking is now promoted by cooperation of Agency of Industrial Science and Technology* and ERANS (Engineering Research Association of Nuclear Steelmaking). In the project, the R&D in materials is conducted by two working-groups: one is engaged in the development of superalloy for use in high temperature intermediate heat exchanger (IHX; He/He, max temp. 1000°C), and creep rupture strength tests have been done for more than 10,000 hr in air and nearly 10,000 hr in helium atmosphere respectively, and the rupture strength of 50,000 hr of one of the superalloys could exceed 1 kg/mm^2 in both atmospheres. Also, other metallurgical tests like tests on welding are carried out. The other is engaged in development of high temperature insulating materials for IHX, steam reformer and high temperature pipings. Heating tests of more than 30,000 hr are successfully accomplished and fundamental data necessary for the design have been obtained.

On the other hand, a R&D on high strength ceramic materials such as Si_3N_4, SiC, sialons which could be used in a heat exchanger for higher temperature use is proceeded. By using these materials, it is aimed to construct small gas turbine, thereby to serve for energy conservation, also.

In the nuclear fusion reactor systems, there are so many materials which have to be newly developed. At present, fundamental studies on materials such as SUS 316, Mo, low Z materials(e.g., C, SiC), Li_2O, and superconducting materials are being carried out in various research institutes.

* It belongs to the MITI(The Ministry of International Trade and Industry)

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WORKSHOP 10

INSTITUTIONAL AND ORGANIZATIONAL PATTERN AND STRATEGIES FOR INTERRELATION OF MATERIALS AND ENERGY RESEARCH AND DEVELOPMENT, TECHNOLOGY, PRODUCTION, COORDINATION, AND PLANNING

CHAIRMAN: RUNE LAGNEBORG (SWEDEN)

ORGANIZER: FRANKLIN P. HUDDLE (U.S.)

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MULTILATERAL AND BILATERAL COOPERATION IN ENERGY RESEARCH AND DEVELOPMENT BETWEEN CMEA COUNTRIES.

Dr. George KORÁNYI

(Ministry for Heavy Industry.
Budapest. Hungary.)

In the framework of the Council for Mutual Economic Assistance (CMEA) between the participating countries (Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Poland, Rumania, USSR) bilateral and multilateral cooperation exists in several important R. and D. fields. One of these is energy.

International cooperation has different forms and methods and to reach satisfactory results from this activity, forms and methods have to be selected carefully. The experiences of the CMEA countries prove that the adoption of adequate organizational forms may give support to increase the effectivity of common efforts. In the past years the Permanent Committees for coal mining oil and gas electric energy, and atomic energy created subordinate bodies to study and to develop cooperation. In several cases expert groups elaborate common projects which are then approved by the competent authorities of the participant states.

Multilateral cooperation.

The projects are assessed by the Permanent Committees and working parties are invited to submit programmes including the participants and their particular tasks. A leading institution is designated by one of the countries for collecting and synthetizing reports and presenting them to the expert group. If the consolidated report is accepted by the group, it is submitted to the Permanent Committee with a recommendation to introduce the results of the work done in practice.
Some examples of the most important multilateral projects in energy R. and D. field:

- Utilization of intersystem effects in electric energy networks.

- Development of advanced telecommunication systems for electric energy transport and distribution networks.
- Mechanization and automation of work in open cast collieries.
- Development of new techniques for entirely mechanized mining in great depths.

An important development in multilateral cooperation was the organization of Coordination Centers. In one of the member countries in the framework of an appropriate institute (research, or development, or documentation) a small group has been formed from representatives of the member countries. This kind of an international team gives effective support not only to synthetize reports but to maintain a permanent contact between institutions participating in the elaboration of the project. The most important projects steered by Coordination Centers are:

- Advanced utilization methods for coal (e.g. gasifying, liquefaction.)
- New technologies for processing and utilizing natural gas.
- Development of new catalysts for hydrocarbon processing.

The Geophysical Coordination Center is steering quite a number of projects, like: development of new methods for computing data on geophysical exploration and drilling, or, research on well geophysics.
To demonstrate particular advantages of multilateral efforts, some examples are quoted.

Hungary has been invited to investigate geophysical instrumentation for deep wells because in Hungary the geothermal gradient strongly differs from other countries.

While in Europe generally the gradient is 30 meters/1^{o} Centigrade increase of rock temperature in wells, in Hungary it only amounts to 18-20 meters. This way in depths of 4200-5400 meters, conditions entirely correspond to depths of 7000-9000 meters elswhere. Instruments and processes for very great depths can so be tested in Hungary at convenient circumstances.

Research and development work is going on for the recuperation of residual oil in exhausted fields by secondary and tertiary methods. Here again the projects are divided among the member countries of CMEA. Hungary for instance developed a new method of recuperation by inserting CO_2 pressure to oil bearing zones. As in Hungary important reserves of natural carbon dioxide are available in the region of the potential fields, costs of the experiments and tests showed a minimum in selecting Hungary for the project.

Similar advantages may be assesed in multilateral R.and D.work between CMEA countries.

Bilateral cooperation.

Numerous energy R.and D. fields offer possibilities to bilateral cooperation. Problems to be investigated are studied and discussed by Commissions for Economic and Technical Cooperation functioning with the participation of the two countries' competent Ministrys. Once the projects are approved by the Commissions, the specialized institutes in both countries are invited to prepare and submit a programme for bilateral cooperation. The programme may include:

- exchange of information and documentation,
- specialization of experimental activity,
- organization of common teams to elaborate studies and to make experiments in one, or the other, or in both institutions,
- to accomplish field experiments or to erect pilot plans,

After the approval of the programme, the participating institutes may sign a contract which forsees:

- programme of work and distribution of costs,
- programme of mutual visits,
- agreement on eventual patenting and licensing of the new results.

Hungarian research and development institutions participate in the following R.and D. bilateral projects with different CMEA partners:

- Electronic and automatic protection of power stations and electric energy transmission systems,
- New and effective water cooling systems for power stations,
- Advanced methods for projecting and installing 750 kV overhead transport systems,
- Development of advanced hydraulic systems for mining machinery,

- Recultivation of the environement in open cast mining sites,
- Development of new hydrocarbon-drilling methods for inclined drilling,
- Utilization of foams in drilling.

International cooperation in R. and D. between CMEA countries prove that it can and does increase effectivity; considering the actual world-energy situation, advantages from these experiences cannot be neglected.

Certain Activities of the United Nations System Related to Energy

GYÖRGY DOBOS
Advisor to the Deputy Executive Director
United Nations Industrial Development Organization (UNIDO)

> "The world community is concerned with energy, which, with all its diversity of sources and alternatives, is the heartbeat of contemporary life in all countries. What must be emphasized here, however, is that there is now a new situation with regard to energy as compared with that which prevailed during the last 30 years. The problem, with all its global dimensions, calls for international co-operation. There is a diversity of views and needs that demands attention. There are also great challenges and opportunities that the problem presents to all the Member States of the United Nations. For these reasons I propose the establishment of a framework that will lead to a World Energy Order. This will make possible the kind of co-operation on energy that our interdependence makes essential for all countries."
> (Secretary-General, United Nations)

The Secretary-General raised these points when commenting on the possibility of establishing an international energy institute. He felt that the work of such an institute should reflect the growing concern for the protection of the environment and the searching questions now being raised with regard to the nuclear option. The institute should be endowed with certain essential functions such as:

- monitoring of resources
- analyzing and exchanging information on alternative energy sources
- advancing global planning to avoid shortages in the future

- orienting research and development towards meeting the requirements of widely differing situations
- promoting cooperation between those who have the financial and technological resources and those who do not
- assisting in the transfer and adaptation of technology
- encouraging development of indigenous or regional energy capacities
- training of personnel

At present, however, no one single organization has been created within the United Nations system concerned with the entire range of energy problems. Nevertheless, the United Nations is closely associated with these problems through individual organizations developing programs in the energy field within their areas of responsibility.

For example, the Centre for Natural Resources, Energy and Transport is the central unit of the United Nations on primary energy resources and distribution. The Centre serves as the focal point within the United Nations for reporting to the General Assembly on international cooperation within its field of competence. In addition, the Centre has a program to assist developing countries in the formulation of energy policies, the organization and strengthening of national energy institutes and the preparation of appropriate energy legislation.

Another organization with a growing program in the field of energy is the United Nations Educational, Scientific and Cultural Organization. The concern of this organization is centered on education and research on the basic and engineering sciences related to the fundamental problems of resources, production, cooperation, transmission, storage and utilization of energy.

The United Nations Environment Programme has developed a strategy in the energy/environment context which consists of two main elements: (a) assessment of the impact of production and the use of all sources of energy of the environment; (b) use of appropriate technology for the harnessing of renewable sources of energy for the improvement of the human environment in rural areas in the developing countries. At the same time, the United Nations Institute for Training and Research is active in monitoring and evaluating energy research and development and disseminating information on research break-throughs on technological developments.

These represent examples of the type of energy-related activities being undertaken by the United Nations. To these can be added the work of the United Nations Conference on Trade and Development, the United Nations Development Programme, the Food and Agriculture Organization, the International Atomic Energy Agency and the Regional Economic Commissions, all of which have specialized energy programs within their field of interest.

Activities of UNIDO in the Field of Energy

The Lima Declaration and Plan of Action in Industrial Co-operation and Development, adopted at the Second General Conference of UNIDO, convened in Peru in March 1975, calls for an increase in the share of developing countries in total world manufacturing to at least 25 percent by the year 2000. Considering that industry is the largest single consumer of energy, accounting for approximately 30 percent of overall demand, the close concern of UNIDO in ensuring that the energy resources of developing countries are adequate to meet their industrial objectives, is readily apparent.

Fundamental to UNIDO's operation is the provision of technical assistance to developing countries and here a modest energy program is already in operation. The following indicative list of projects outlines the span of requests received from developing countries in the field of energy:

(a) Egypt -- Establishing of a solar energy desalination plant at Safaga Port on the coast of the Red Sea;

(b) Poland -- Integrated coal conversion, mainly concerned with coal liquefaction and coal pyrolysis;

(c) Philippines -- Establishing a demonstration plant to foster indigenous energy research development through a pyrolitic converter using rural wastes;

(d) Cuba -- Improvement of heat economy in the cane sugar industry;

(e) Upper Volta -- Installation of ten pilot scale bio-gas generators together with demonstration facilities in gas utilization.

While the Organization's experience in this area is relatively limited it has been sufficient to identify the priority fields for the development of a broader program to assist developing countries. These are:

(a) Accounting and energy conservation in industry;

(b) Energy related capital goods production in developing countries;

(c) Development and commercialization of proven technologies relating to non-conventional and non-network sources of energy.

In developing these priority areas the entire range of UNIDO's activities will be involved including technical assistance, training, the program of studies and the system of consultations for world-wide industrial cooperation. A number of projects indicate the direction of the organization's endeavors such as the organization of a training program in energy utilization and saving in industrial enterprises in cooperation with the International Centre for Advanced Technical and Vocational Training, Turin, a Group Study Tour in the Field of Medium and Small-scale Hydro Power Plants in China and a Workshop on Fermentation Alcohol to be held in Vienna.

While UNIDO's energy related program is at an early stage of development, the organization has a well established program to assist developing countries in the development, processing and testing of materials. This program encompasses the range of industrial sectors and extends throughout the Third World. UNIDO's contribution has been largely in the technologies for upgrading materials and the establishment of institutions for testing fabrication methods. In the field of metallurgy, for instance, large-scale projects were carried out offering assistance to the Central Metallurgical Research and Development Institute in Egypt; the Metal Advisory Service in Pakistan; the Marmara Industrial and Technological Research Institute in Turkey; and the Welding Research Institute as well as the Central Creep Testing Laboratory in India. In another sector UNIDO has assisted in developing the pilot plastic processing and demonstration center in Bangladesh. From an overall viewpoint the organization has also been associated with the major effort to improve standardization and quality control facilities in Brazil.

UNIDO has therefore gained a knowledge of the requirements of the developing countries for the different materials concerned with the protection of both renewable and non-renewable forms of energy. The findings of this Congress will be studied in detail in the UNIDO Secretariat as they relate to the requirements of the developing countries and the organization will cooperate fully in any coordinated international approach which may result from the Congress.

THE ENERGY-MATERIALS EMERGENCY: THE SITUATION, OBJECTIVES, ACTION (SUGGESTIONS)

LUIZ C.CORRÊA DA SILVA

1. INTRODUCTION

The OPEC action in 1973 caused the world, developed countries especially, to wake up to the fact that the existing energy-materials base of the international economy is unbalanced and untenable. It would lead to certain catastrophe within a generation, if gone on unchanged. The present materials-energy Conference, thus, is not just one more technical/professional meeting: it is a first opportunity for looking imaginatively and in depth, into the "energy-materials emergency".

2. THE ENERGY-MATERIALS EMERGENCY (E-M-E)

The following empirical observations seem relevant and essential for identification of the broad magnitude, nature and boundaries of the E-M-E.:

a) A materials-energy crisis was in incubation long before 1973. By then it was "mature". OPEC did nothing but force international awareness/recognition of a serious problem.

b) The E-M-E is the more grave and complex because it coincides with two other developments of "world size":

i) The growing instability of the existing international monetary system (dollar based); for which no solution is as yet in sight.

ii) The growing full and general awareness by Dg.C. of their true problems and opportunities; an irreversible process which reached "half life" (50% reaction...) in the seventies.

c) The E-M-E is further characterized by the following realities:

i) Unbalanced geographic distribution of existing materials-energy resources.

ii) Problems of access, availability and distribution originating in social and political considerations (ecology; labour; international conflicts of interest).

iii) "Exhaustion" of reserves of non-renewables; meaning: increasing cost of extraction and price of exchange.

iv) Foreseeable great expansion in demand, in the short (1985) and medium term (2000) due to increasing needs of Dg.C.

3. POSSIBLE OBJECTIVES

In the face of the growing E-M-E the need for international cooperative efforts at various levels is apparent. One might propose the following "ad hoc" objectives for an effort at the professional-technical level:

a) Intrinsic goals (addressed to the ends of the effort). With two main thrusts:

i) Decrease "energy cost" and "energy content" (in energy units) of processes, products and services ("materials" would be a specific area within this broad goal).

ii) Increase use of "renewables" (energy or materials).

b) Instrumental or methodological goals (addressed to essential means to the ends of the effort). With at least two main directions:

i) Development of a quantitative method to analyze and deal with processes and products (structure and kinetics of production systems) in terms of energy "cost" and "content", input and output ("energomics"?).

ii) Development of new and imaginative approaches for identification, analysis and action in connection with problems and opportunities in the materials-energy area. For example: examine impact of the "genetic revolution" ("gene-synthesis"), particularly regarding "renewables" obtained through a new "photo-synthesis industry".

4. POST-CONFERENCE FOLLOW UP ACTION

It would seem appropriate and useful to ensure a significant and continued follow up effort to the present Conference. Some kind of international cooperative effort should be considered, planned and implemented. This is an area where discussions are essential, to gather good ideas and strive for consensus. Let us assume such I.N.C.E.M.E.[1/] is created and consider its possible output, structure, inputs, aegis.

a) Output

i) Information exchange: highly selective and processed. Possibly with help specialized publication characterized by quality, not volume of information. Including organization of special working meetings.

1/ International Nucleus for Cooperation in the Energy Materials Emergency (ad hoc and temporary abbreviation).

ii) Cooperative work to identify specific problems and opportunities of international interest, in the light of the general framework suggested in item 3 above.

iii) Actual sponsorship of specific projects which may result in significant contributions towards attainment of the goals suggested in item 3 above. I.e.: set terms of reference, obtain financing, select "agents", ensure application or use.

b) Structure, inputs, aegis

It is suggested that the INCEME could have a small but highly qualified team of international experts who might catalyse cooperation by and among technologists and scientists of high caliber. The size of the nucleus should be above "critical mass" but its weight (in terms of prestige and competence) should be such as to ensure mobilization of necessary resources and support. Aegis: to be negotiated. In view of the substance (mainly related to industry) and scope (involving both Dd. and Dg.C.) the involvement, support or insertion of or in UNIDO should be considered, if its flexibility and effectiveness could be assured.

MATERIALS, ENERGY AND THE ENVIRONMENT : THE NEED FOR A SYSTEMS POLICY

DR. ADENIYI A. AFONJA
Dept. of Metallurgical & Materials Eng.
University of Ife, Nigeria

Materials, energy and the environment constitute the resource triangle which forms the physical base of any economy. So far there has been a tendency to treat each in isolation in policy planning and research. However, they do relate and interact in a very complex way and must be treated as three components of a system to evolve a realistic and useful resource policy. Nature, by accident of design, has caused a significant proportion of the vital world material and energy resources to be located in developing countries which have little direct use for them, thus ensuring a global economic and technological interdependence.

Much of the efforts made so far in attempting to solve the problems associated with the material resource system have been intranational but there is a growing awareness of the need for a multi-national approach to problems of mutual interest. Some progress has been made in respect of energy and the environment. There is now an urgent need for the establishment of an international institute for materials to provide a permanent forum for the disemination of knowledge and information and co-ordination of research efforts. In view of the strategic nature of energy and materials and their inter-relationship with the environment, it would be overoptimistic to expect an integrated world policy in the foreseeable future. Nevertheless, an international body on materials could initiate a mechanism for the continuous evaluation of world trends in material reserves and utilization, develop guidelines on the formulation of integrated materials, energy and environmental policies, encourage nations to adopt material conservation policies which emphasize waste reduction, substitution and recycling, and work in close co-operation with existing bodies on energy and the environment with a view to promoting a better understanding of the interactions within the system.

This conference should resolve to initiate the sponsorship of a resolution at the United Nations to hold an international conference on materials, energy and the environment to examine the associated problems in detail and recommend guidelines on the establishment of a permanent institute or agency either under the aegis of UNESCO or as an autonomous body. Considering the wide spectrum of international patronage and success of the recent United Nations sponsored Stockholm conference on the Human Environment, this initiative stands a very good chance of succeeding.

Institutional and Organizational Patterns and Strategies for Interrelation of Materials and Energy: Reflection before Action

ELIANE MORIN
(French Scientific Mission)

Workshop 10 may well be, and by far, the most ambitious of all the specific workshops of this Congress. The mere length of its title is the first indication of the range of problems that should be tackled. Not only is the interrelation of materials and energy poorly understood today because of the limited interest and the scarce studies conducted so far in that area, but the workshop plans to address the issue from many different viewpoints, scientific and technical (R-D), industrial and economic (production) and organizational (coordination and planning). This is a very large task indeed.

Quite a few international agencies or bodies already deal with energy and materials: OPEC, OECD, UN and Cnuced, the International Rubber Study Group, the International Bauxite Association, CIPEC... But they all share two characteristics:

- Apart from Cnuced and OECD, most of those agencies and bodies tend to be either producers' or consumers' groups. The discussions held within them are more politically than technically or industrially oriented.

- They are concerned either with energy or materials, but not yet with both, although the world is fearing a shortage of both in the long run, particularly when the world population reaches a level of 10-12 billion people.

As a first step, it would be helpful to assess the needs felt by many different countries when they try to understand and to solve the relationship between energy and materials:

a) Does the international community feel the need of another political forum dealing with the North-South dialogue, buffer stocks and a more balanced sharing of revenues and wealth?

b) Is it interested in a more economic and technical approach to energy and materials problems?

c) If so, is there a need for an exchange of information and in what area?

a. Economic: demand and supply, markets; b. industrial: means of production, technologies, costs of production; c. financial: investments required, national and international loan availability and procedures; d. technological: improved or new exploration methods, mining and exploitation methods, production methods, recovery methods.

d) In each of those four areas, would the international community be interested simply:

a. in an exchange of information?
b. in establishing data banks?
c. in making analyses of the present markets, of the technologies involved, of the policies of the supplying companies?
d. in modelling and forecasting?

Depending on the answers to these questions and the tasks assigned to a new organization, it may well be that the latter should be created under a different aegis. Cnuced or the UN might be the best solution if it is mainly political, ICSU or IASA if it is more economic and technical. In any case, it probably should represent both producers and consumers, and OECD is therefore too limited in its present membership.

If in fact the problem to be studied is the relationship between energy and materials, and not energy on the one hand and materials on the other, then the issue becomes more economic and technical than political and requires a systems approach. The most appropriate institution might then be an agency conducting technical and economic studies, not unlike OECD in its approach but broader in its membership. It may well be of mutual interest to both producing and consuming nations to understand the evolution of the use of energy and materials in both industrialised and developing nations, the impact of increased mining and refining of metals on energy consumption, the influence of increased energy needs and production on materials in the next fifty years, of new production technologies on energy and materials consumption, the consequences of increased recycling and substitution on energy and materials use, of any shortage of natural hydrocarbons or chromium. . This kind of study is just beginning in some countries, such as France and the US, and could be largely expanded with benefits for all nations.

Deficiencies in the Institutional Patterns of Materials R&D for World Energy Needs

HARRIS M. BURTE
(Director, Metals & Ceramics Division
Air Force Materials Laboratory
Wright-Patterson AFB, Ohio)

Deficiencies exist in the institutional patterns for that critical portion of the energy related materials R&D spectrum that extends from focussed fundamental research through initial exploration of reduction to practice potential. These deficiencies are world wide.

The very existence of this Congress testifies to the importance of new materials technology for "advances in many key areas of energy development and cost reduction." Throughout the world the recognition of this has led to increased activity in "truly basic" materials research which although primarily "knowledge driven" is in general areas which might eventually contribute to the solution of energy related problems or the development of new technological approaches. The institutional patterns for this portion of the R&D spectrum are not deficient. A variety of effective means for support of such research exist and the current or evolving scientific societies and literature, supplemented by special symposia, provide adequate forums for individuals to communicate with and stimulate each other.

At the other end of the R&D spectrum - design, scale-up, test, correct unforeseen problems, and introduce into use - existing institutional patterns are also generally adequate. Here, quite specific and well defined materials R&D often flourishes under the stimulus and guidance of the specific goals of (sometimes) very large "end-item" development programs. Forums exist for the dissemination of knowledge through the engineering societies and literature supplemented by speial symposia or workshops, and governmental systems for storing and disseminating technical reports. The problems of finding the time to extract the results of the materials R&D from all the other work done in such programs, to write it down, to overcome proprietary barriers to releasing such information outside a project, a company or a nation, and of handling the sheer mass of information which can result are real, but they are not unique to energy and are generally recognized. I will not treat them further here.

End-item development programs usually must operate within time and budget constraints. To minimize risk in meeting their goals, they tend to use only technology which is fairly well developed. In fact the very goals are usually predicated upon what can be done with finite time and money to extend and apply an existing state of the art. Possibilities for new materials and processes which can significantly benefit the project, or even allow attacking more aggressive goals will not be included if they exist only as an inference to be drawn from the results of basic research. Thus, there must be a middle ground where focussed fundamental research and development independent of specific end-item programs matures a state of the art to the point that the risk of using it for end-item programs becomes acceptable. It is here that deficiencies exist.

A recent analysis of the health of the materials science base in the United States (by myself and Frank Kelley) indicated that there are major gaps when it is evaluated from the viewpoint of needs (i.e., the status of focussed fundamental research which attempts to respond to areas of perceived need was being evaluated, not the health of the truly basic portion of the science base which is motivated by the extent of new understanding which can be obtained irrespective of the predictability of its utility). Two of the areas where U.S. research effort is inadequate, which are of great importance for world energy needs, are in processing science and the science underlying nondestructive evaluation. During a visit to Western Europe last year, I discussed these conclusions with a variety of senior individuals and concluded that although significant efforts to improve the situation are underway, the deficiencies may be worldwide. Note that both of these require extensive cooperation between specialists in the different classical scientific disciplines. Institutional barriers in most universities (which still exist despite many efforts to overcome them) tend to inhibit this cooperation. Further, as in much focussed fundamental research, it is highly desirable that there be close coupling between the university or research institute where the work is often done, and industry which must use the results. The effectiveness of such coupling is very variable throughout the world.

Applied research and initial development of materials technology independent of end-item programs also often suffers from the fear that the products will not be useful to anyone. It is safer to retreat to very fundamental research or to short range developments for specific end items. Yet, as discussed above, the middle ground effort must be pursued. In areas where the government itself is the prime customer for the end items (e.g., aerospace and defense) or the probability of financial return to industry is large compared to the risk and cost of such middle ground R&D (e.g., many areas of communications and computers) one finds significant activity underway. However, in many areas of energy related R&D, the risks and uncertainties are so large that government support of some nature will be required. A variety of mechanisms to do this - to provide a suitable infrastructure whereby government, industry, research institutes and universities can effectively interact - are evolving in different countries. Sharing experiences to learn from each other, and to develop mechanisms for international cooperation is appropriate, and should be started at this Congress.

Two factors are important if we are to stimulate the multidisciplinary activity required for focussed fundamental research, the industry-university coupling required for rapid progress, and the validation of applied R&D goals to acquire resources. They may not require new institutional patterns, but must at least receive special emphasis within current patterns. The first of these is a special kind of leadership - individuals with both horizontal and vertical inter/multidisciplinary capabilities. (Horizontal refers to the different classical disciplines such as chemistry, physics, mechanics, etc.; vertical refers to the coupling from research to design, production and in-service engineering.) This will be an increasingly important aspect of materials technology for energy needs. Universities should pay special attention to starting selected individuals along paths which can help them become such leaders.

Although many say that there is no time for a student to develop both the necessary firm grounding in at least one discipline and to obtain meaningful exposure to horizontal and vertical interdisciplinary activity, I have seen scattered examples throughout the world, where it is done successfully, and believe it can become more widespread. After school, management should make a special point of identifying, nurturing and providing suitably diverse challenges to such individuals. Their presence is a common factor in most past examples of successful, rapid progress in the middle ground of the R&D spectrum. They are needed in universities, research institutes, industry and government.

The second factor is forums to help with the definition of "windows" or potential windows. In aerospace materials R&D in the United States, the term "window" is used to describe that part of the goal of a development or manufacturing technology program that can be expressed as a realistic potential application, or even a specific first generation use of the technology. Defining a credible window involves answering difficult and sometimes embarrassing questions such as: "Even if I successfully meet these technical goals, who will use my product and for what application?" A suitable window provides a baseline against which the new technology can be evaluated. The possibility of actual near term production and use stimulates enthusiasm in both program participants and potential sources of support. The problem, of course, is to define a specific potential initial application that will provide these advantages, and also be sufficiently generic that it can act as a vehicle for advancing the technology along a broad front toward potential uses well beyond the window selected.

When trying to apply this approach to focussed fundamental research it is rarely possible to define specific windows for specific first generation use. Not only does the time scale involved prohibit it, but as has often been said, "if one can define the outcome of a fundamental research project, it may not be worth doing." As the research proceeds, the prediction of what is possible will change and the goal or window must be modified. However, it is possible to express goals in terms of potential windows. For example, one might postulate the microstructures, properties and geometries desired for a specific component and then ask who would use the lower cost process, or the improved performance component, etc., if it can be attained. This, of course, requires an intimate knowledge of the state of the science to predict what might be possible and an alert awareness of how this can and does change with time. Such an evocative way of describing the potential for a particular area of research will not only help generate support, it can provide the integrating emotional issue -- the enthusiasm building -- to help overcome many of the institutional barriers to coupled multidisciplinary research mentioned above. It also provides a focus for multidisciplinary cooperation enabling people from different fields to find a common ground for communication.

There are many forums at which general requirements are stated, but less often are people familiar with possibilities arising from science brought together with those familiar with potential needs to try to define credible specific windows or potential windows. I suggest that technical societies and other organizations which sponsor meetings like this Congress increase their attempts in this direction. In my experience the definition of potential windows is hard work, and usually requires leadership by the sort of people mentioned previously, but it can lead to very satisfying results.

An International Materials Organization

EDWARD L. BRADY
(National Bureau of Standards)
(U.S. Department of Commerce)

The organizers of this International Materials Congress have pointed out that materials, energy, and environmental quality are interrelated on a global basis and hence that none of these matters can be considered in an isolated fashion. The need to have as much information as possible for the purpose of making decisions has led to this conference being held as an experiment - an experiment in international information sharing and in communal planning and thinking. Clearly, the events and trends that have led to this conference will continue. Some continuing mechanism to examine international developments together and possibly to reach joint decisions for action by individuals and governments seems to be needed. Indeed, this is envisioned in the prospectus for the meeting which states: "The broader and farther reaching objective of the Congress is to establish a continuing international, non-governmental channel of communication for the discussion of materials-related issues of world concern, since at present there is no one mechanism to provide such an exchange in this broad area."

At least two aspects of this statement seem to call for detailed analysis: first, the conclusion that since no one mechanism exists, one should be established, and second, that such a mechanism (if it is established) should be non-governmental. Before a decision on the establishment of a mechanism and its type of structure can be taken, a number of issues should first be examined in some detail.

Chief among these issues are the functions that the institution is to carry out. Possible functions listed by the organizer of this particular workshop include consultation, information exchange, serving as a scientific data repository, analysis of materials supply and demand, energy generation technology transfer, buffer stocks recommendation, economic impact analysis, conflict mediation or arbitration, and trend forecasts. Probably the easiest of these to justify and to obtain support for is information exchange on a multidisciplinary scale. To some extent the other functions, with the possible exception of conflict mediation or arbitration, already are, or could readily be, within the scope of action of existing international organizations, with very little extension of their mandates.

For example, in the field of energy the International Energy Agency, an agency of OECD, has the directive to carry on several of these functions. In the more specialized field of nuclear energy, the International Atomic Energy Agency is active. For the environment, the U.N. Environmental Program has already undertaken some of these functions. Many relevant statistics are already being collected by other agencies of the U.N. However, it is unlikely that any individual or group has yet surveyed the numerous national and international organizations that might conduct relevant activities to find out what actually is being done now and how one gets access to it. Thus a minimum essential function would seem to be to serve as a sort of "clearinghouse" for information sources and services. Extension into the mandates of existing organizations should be undertaken warily, and only with good justification.

Another important question to be addressed is whether the international mechanism is to be primarily a channel of communication among experts or whether it is intended to influence government policies. If the objective is communication, a non-governmental structure is undoubtedly to be preferred; its operation is much simpler and is relatively free of politics. However, if the principal objective is to be to affect government policies, the preferable route might be to attach any desired new functions to some existing intergovernmental organization, despite the inevitable complications and politics. An entirely new intergovernmental organization does not seem practical.

The workshop that we are participating in should provide an opportunity for varying viewpoints to be put forward, so that a general consensus can be reached on future steps to be taken by the individuals and organizations that have supported this conference.

<u>A plea for an International Materials Institute</u>

DR BALINT BALKAY
World Economy Institute of Hungarian Academy of Sciences, Budapest

As far as materials are concerned, the world is a closed system.

Almost every material is substitutable in almost every one of its uses; all it takes is development effort and a higher cost.

The obvious limit to mutual substitutability is the closedness of the system (of the world). Hence, despite recycling, all materials tend monotonically to exhaustion, some slower, some faster.

Nevertheless, nowhere is exhaustion in sight as yet for any set of mutually substitutable materials collectively suitable for this or that specific purpose.

The monotonic real-term price rises predicted by exhaustible-resources theory do not yet operate for a majority of materials, because many regions of the world remain unexplored and many technologies undiscovered or undeveloped. From the sight of humanity today, then, the world is still a quasi-open system.

Right answers to issues of global sufficiency, exhaustion, substitution, the chances of finding new resources &c. are much needed for a realistic situation assessment that avoids both under- and overreactions. The present writer posits that no realistic assessment is available at present, largely owing to lack of a reliable data base.

The issues are not merely geological and mining ones; the situation is qualified at any time by available and foreseeable technology. A third principal dimension is, what materials, what substitutions and what conditions of extraction and processing are economically affordable at any given time.

Complex research into these issues must have for one of its main tools the collation of world-wide evidence furnished by diverse disciplines, with a view to developing globally consistent quantified models and inspired intuitions. This requires great concentration in men, facilities and information, best realized in an independent International Materials Institute.

Research of the type envisaged must be underlain by the bookkeeping-type relationships applicable to global (closed) systems. That is, the research must be global if it is to be efficient. This implies an Institute holding a world-wide brief.

The Institute should encompass both fuels and non-fuels, in view of the similarity of research methods and objectives, and of the strong interaction between the two sectors. It should comprise a Department of Geology and Mines, a Department of Technology, and a Department of Economics, plus backup facilities.

What the present writer has in mind is a cross between the International Institute for Applied Systems Analysis, Schloss Laxenburg, Austria, and certain departments of the US Bureau of Mines/Geological Survey, somewhat bigger than the former but more research-oriented and perhaps more unconventional than the latter.

The best plan would be for the Institute to operate under the authority of the UN, as a means of ensuring its impartiality. Also, UN authority would give it access to information not usually made available to organizations of lesser authority, and give weight to its requests for men and facilities. It should, however, preferably not be one of the UN agencies or organs, as it would in that case probably inherit the ponderousness and bureaucracy of that great organization.

As to funding, the case of IIASA/Laxenburg might be followed, where contributions come from many countries of different social systems. However, the Institute might soon become a self-supporting non-profit organization catering to a variety of customers.

The following tasks may be envisaged.

(1) At present, the data base required for the research outlined above is inadequate. Not only the obvious items like the material requirements of novel technologies and new ways of life, or the global resources of this or that mine-

ral are missing, but also more unexpected ones such as figures of yearly production, labour involvement, factor costs of production etc. A data base adequate in all respects should therefore be set up.

(2) A rational world-wide materials policy blueprint including forecasts of world-wide materials economy patterns should be prepared. Even if not accepted by individual countries or regional groupings, this blueprint could serve as a guideline clearly stating global long-term constraints and interests (including notably the issues of environmental impact) as opposed to the short-term local ones which generate the "market forces".

(3) On this basis, the Institute would be in a position to identify those issues demanding action in the short term, dress up lists of priorities, and submit recommendations to international fora, the UN above all; it would further be in a position to vet outside forecasts, recommendations and priority proposals.

An Institute such as this is a need long felt by all the specialists concerned. If it plays its cards right, it should have the potential to become an international institution of considerable authority and high standing.

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APPENDIX B

SELECTED PAPERS

The following papers used in workshop sessions were selected by the workshop organizers as useful additions to the workshop reports and also of general interest to the Congress.

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THE ULTIMATE ENERGY DEMANDS OF METALS AND MATERIALS

W. O. Alcxandcr

This view of materials for engineering and structural applications considers metals, plastics, and other nonmetals such as concrete and timber, and evaluates likely developments in the light of energy and material availability and their properties.

ASSESSMENT OF TOTAL ENERGY CONTENT OF A MATERIAL

Publication of energy utilization data in metallurgical and materials processing operations has been widespread in recent years. However, such data is in rather an early stage of compilation. In come cases there are discrepancies between values in different countries of two to three times. Recent work in the U.K. aluminum industry is also revealing that energy auditing in routine metallurgical establishments covering extended periods is indicating double the hitherto assumed values.

In the United Kingdom, difficulties have been experienced in assessing true works production data on total energy increments at each step. This is partly because metering of individual production units on a complex works site is not carried out. Other errors stem from various assumptions as to the overall energy uses on a site, e.g., space heating, furnace stand-by losses, etc. Other difficulties stem from the overall estimate of the total energy already incurred by an ore as raw material when it has arrived in the United Kingdom. Since so very little is now indigenous in the United Kingdom this factor is important. Yet another factor not revealed in the U.K. Department of Energy statistics is the quantity of bunker fuel that is shipped in foreign or British ports for bulk transportation of incoming raw materials.

Considerably more detailed work and agreed conventions will be necessary on an international basis before total energy data on materials is truly comparable. The Energy Audit Series by the Departments of Energy and Industry are detailed reviews of energy usage in industry in the United Kingdom but so far they have only covered iron castings, bricks, dairy products, and bulk refractories.

TOTAL ENERGY PER UNIT OF PROPERTY

Though we can evaluate the total energy consumed per kilogram of finished material, such information does not convey the inherent value of the product to prospective users. The concept of evaluating the value in total energy terms of the range of properties is of equal relevance. An outline of the properties of tensile strength, modulus of rigidity, and fatigue strength for some common metals and materials is given in Table 1, together with their specific energy, i.e., total energy per kilogram of material.

As would be anticipated, total energy criteria throw a completely different light on the true values of some materials to mankind. For example, timber uses far less energy for a given strength, 24 kWh per meganewton unit of strength, than any other material. Reinforced concrete is attractive at 145-250, followed by steels at 125-350, while cast irons can vary from 300-1825 in the United Kingdom. The newer materials--aluminum, plastics, and titanium--all use total energy contents of 400 for duralumin, to 700 for other aluminum alloys, 600-2000 for plastics depending on the type of polymer and whether energy content of the feedstock is included. Roughly the same order of merit obtains for modulus of rigidity and fatigue strength.

This type of analysis can be extended to cover other properties of engineering and life performance. Furthermore, by a system of weighting and scaling the significance of a property in the overall performance sense, it is possible to determine the cheapest material in total energy or in cost terms for any predetermined combination of properties. Such estimates can be readily carried out by computer.

AVAILABILITY

Other aspects which may affect the longer term future availability of the basic raw materials or ores are their metal content and costs of importing and refining at the place of usage. The most common metals are unlikely to be significantly affected by such shortcomings at least until the 21st century. Concrete and timber are also safe. Plastics are unlike metals which once extracted are re-circulated and re-made if necessary to their original purity and properties. So far, oil is a once only benefit to mankind either for energy sources or as feed stock for plastics, and plastics are not re-usable in the way that metals are, nor do they have the long life cycle of most metals.

Another consideration is the possibility of radically new materials inventions and possible innovations. All the metals are known, and it is inherent in their properties and the nature of the metallic state that properties of all metallic alloys are circumscribed, i.e., of limited further improvements. There may be certain areas, e.g., superconductivity, superplasticity, where some further significant improvements are possible, but usually at great cost or excessive energy requirements. For the vast majority of tonnage metals, further substantial improvements in properties are unlikely. Also, further large reductions in manufacturing costs are equally unlikely unless total energy costs can be substantially reduced.

Concrete might be further improved as a type of composite with another binder such as a cheap resin and possibly another reinforcing material such as glass matts. There is scope for considerable improvement in the properties of such aggregates, but this may be at a price that will prove too great on the price per unit of property criteria.

In recent years, many new chemical compounds such as nitrides, oxides, carbides, and complexes thereof have been synthesized and tested. Many are expensive and have limited property advantages over existing materials, but there are some, such as SiB, BN, and pyrolytic carbon which have useful high-temperature properties and which will certainly increase in use.

Plastics and polymers are in many ways more open-ended in potential development than metals, because the possible property ranges of undiscovered polymers are not quite so circumscribed by their molecular structure. However, they do have severe limitations in properties from the engineering point of view. In particular, they are susceptible to creep under load, relatively poor durability to oxidation or radiation, high notch sensitivity, insignificant conductivity, and, as yet, inability to develop significant strength at temperatures of 100^{o}-$300^{o}C$, except in special and expensive polymers. Despite this, and bearing in mind that probably well over 3000 organic-type molecular monomers and their polymers have now been made and examined by chemists throughout the world during the past 40 years, it is possible that a new and relatively cheap polymer or mixture of polymers has yet to be discovered, though the chances now look remote.

In sum it seems that the world community is in for a short period of intense rivalry between metals and other nonmetallic materials. Later, and assuming that the Third World continues to greatly improve its material standards of living, demand for all energy sources and materials would exceed supply, and allocations for specific applications will become essential.

FUTURE PROSPECTS

The longer term greatest promise is concrete or a ceramic-type material using a base such as silica or alumina and finding a cheap new bonding agent which would, in combination with strengthening under tension--such as by steel rods, glass, or carbon filaments--show cheap strength, low total energy, and more reproducible and durable properties.

Putting materials in their proper perspective for engineering and structural applications, one must concede that reinforced and prestressed concrete and timber are already the major tonnage and volume materials and will remain so.

Next is steel, which, if one believes that total energy per unit of tensile strength is one of the ultimate principal factors determining usage, coupled with its great toughness and ductility, has a great deal in reserve over all its other competitors. Aluminum and plastics as the newest tonnage materials are expanding rapidly in usage, but aluminum has probably reached maturity in properties, and the one hope of continued rapid expansion is in maintaining low selling prices relative to its chief competitive materials such as steels, concrete, plastics, and timber.

Plastics at present appear to offer a threat on a supply and availability basis but have mechanical property and other long-term limitations. They are not so attractive as some metals and alloys when one considers the total energy per unit of property. This fact is a major handicap inhibiting the continued expansion in usage of plastics relative to other metals and materials. There are portents for further improvements of which the most apparent is the composite approach by reinforcing plastics with glass fibers.

The fact that oil is both the feedstock and main energy source for most plastics means that their prices and whole economics relative to many metals and other materials will regress.

BETTER RECYCLING IS ESSENTIAL

There is no doubt that many current metals and materials will slowly level out in growth due to a variety of circumstances. The reasons are the availability of only lower grades of ores, and the increasing cost of energy to mine and extract these ores. The same problem will also confront plastics largely because oil is both the energy source and the feedstock.

Other, much more readily available, materials will supplant many applications--a continuation of the competition for usage which has been intensifying over the past 200 years.

In such a steady state situation, i.e., no growth rate for many single materials, the availability and ease of recycling old scrap becomes vital.

Unfortunately, the world's performance in recycling old or used scrap as distinct from new or reprocessed scrap is poor. For many metals which are likely to be in short supply such as cadmium, cobalt, or tungsten, the dissipation rate is in the range of 90 percent. But even for metals such as copper, the quantity of old scrap recycled is only about 20 percent. The best performance is for lead and antimony at about 30 percent, while for glass it is only about 10 percent. For plastics it is virtually nil and recycling of such old or used scrap back to its original properties is extremely unlikely without a pyrolysis route which is bound to be expensive and of low yield.

In the short-term, major savings in energy can be made by improving processing efficiency and concentrating on those materials that can be recycled from old scrap without deterioration in properties and also those of low total energy content such as timber, concrete, and steels. In the longer term, however, either the cost per unit of property or the energy content per unit of property should be used to point the way to efficient utilization of our overall resources, i.e., energy and materials.

There may be future shortfalls in certain key materials, and hence we should exploit every material to its optimum in total energy terms. In the light of such an overall review of the tonnage metals and materials of the world, and the development of specialist metals, materials, and composites, man could probably manage without some of the resources likely to be in short supply or demand excessive total energy. The reasons are that there is an abundance of some materials and many properties overlap among them. Furthermore, the ingenuity of engineers and scientists ensures that there is always more than one way to achieve a desirable end whether it is to produce a structure or an instrument, even if at a relatively high cost.

With foresight and adequate facts available to the world community, we need not be too downcast by the forecasts of the prophets of doom.

TABLE 1. Energy Consumption Related to Material Properties

Material	Tensile Strength MN/m^2	Modulus of Rigidity MN/m^2	Fatigue Strength MN/m^2	Density kg/m^3	Specific Energy kWh/kg	Total Energy per Unit of Tensile Strength	Total Energy per Unit of Modulus of Rigidity	Total Energy per Unit of Fatigue Strength
Steels								
EN1 Low alloy-free cutting	360	77000	193	7850	16.0	349	1.63	651
EN24 1.5% Ni	1000	77000	495	7830	16.0	125	1.63	253
AISI 309 23/14 C & Ni	750	86000	360	7900	32.0	337	2.94	702
Cast Iron castings	400	45000	105	7300	16.0-100.0	292-1825	2.60-16.2	1112-6952
Non-Ferrous Metals								
Brass 60/40 Cu-Zn	400	37300	140	8360	16.5	345	3.70	985.3
Aluminum Alloys	300	26000	90	2700	79.0	711	8.2	2370
Duralumin	500	26000	180	2700	79.0	427	8.2	1185
Magnesium Alloys	190	17500	95	1700	115.0	1029	11.17	2058
Titanium Alloys 6A2/4v	960	45000	450	4510	155.0	728	15.53	1553
Plastics								
Polypropylene	30	360	7.5	900	20.0-40.0	600-1200	50.0 -100	2400-4800
Polythene L.D.	13	84	3.25	920	15.0-30.0	1062-2124	165.0 -330	4246-8492
Rigidex 2000	30		4.0	950	15.0-30.0	475-950		3563-7126
Nylon 66	80	1450	20.0	1360	50	850	47	3400
PVC (R)	50	1680	12.5	1400	20.0-50.0	560-840	17.0 -25	2240-3360
Reinforced Concrete	38	10000	23	2400	2.3-04.0	145-253	0.55-0.96	240-417
Timber (Oak)	14	4500	6	670	0.5	24	0.07	56

RECENT ENERGY-SAVING TRENDS IN MATERIALS PROCESSING

Erkki Laurila

Striving for an energy-efficient society would seem to be motivated mainly by two facts: that the reserves of exploitable energy sources on the globe are finite, and that an uncontrolled growth of energy consumption would sooner or later turn out to be a danger for the biosphere. As important as these philosophical facts may be it is, however, doubtful how much they will be considered when decisions concerning industrial investments are to be made. The management of an industrial organization can hardly accept any but economical criteria. If an investment is made that will improve the energy economy of an industrial process, it must also be more economical than the old, more energy-consuming one.

Finland is a country of few energy resources and costly energy. As a consequence, it has always been sensible to strive for energy-efficient technologies. Back-pressure power plants have been widely used both in industry and in municipal systems as sources of process heat or heat for district heating. The overall efficiency in burning fossil fuels in Finland is clearly higher than in general. With good reason one can say that Finnish industry, including mining, already has a long tradition in the art of finding energy-saving solutions in industrial processes.

Without doubt the best known Finnish achievement in the development of energy-saving processes for mining is the Outokumpu flame melting process for treatment of copper ores. When Bero Makinen, president of Outokumpu, decided that this kind of revolutionary process would be developed, built, and taken into practical use, the country was deficient in power plant capacity; Finland had lost about 30 percent of its hydropower to the Soviet Union as a result of the war. The construction of new capacity seemed expensive and time consuming. Together with the high price of energy the background was set for the risky decision to start a very costly development project that depended on the financial and technological capacity of a company alone. As a result of this project, Outokumpu was able to run a process which instead of being a big consumer of electric energy could deliver electricity in the grid. At the same time the process was shown to be environmentally sound.

Finland's leading scientist in mineral technology, Professor Hukki, has during his long career, directed his interest to many problems in ore-dressing technology. For at least 20 years he has had as a central research objective the classification of crushed and ground ores, which has led to the construction of new types of classifiers. Before starting this long-term project Hukki touched on the energy problems of comminution processes. He also had more than once pointed out that some 3-4 percent of the total consumption of electric energy is used in industrial crushing and grinding processes. On the basis of this I take the liberty of assuming that Hukki, working in a country with limited energy resources and where the price of energy continues to be very high, had accepted, consciously or unconsciously, the idea of energy conservation and was fully aware of the importance of energy-efficient industrial processes.

From the beginning, Hukki seems to have been aware that the key for improved comminution technology could be found from the deeper understanding of the behavior of the closed grinding circuit. As a starting point Hukki had the results of the pioneer work of Edward W. Davis, the essense of which was published in a 1925 report as a curve showing the fundamental relationship between the new feed rate and the circulating load.

The phenomena behind the Davis curve were the object of a very thorough and detailed investigation by two of Hukki's coworkers and former students, Allenius (1968) and Heinonen (1973).

When describing the investigation Davis states: "In all of the tests great care was taken to operate the equipment as efficiently as possible." Allenius and Heinonen, on the other hand, have deliberately performed their tests in such a way as to unveil the differences in the performance of closed-circuit grinding under different degrees of size separation. It should be noted that the investigations by Allenius and Heinonen have been extraordinarily thorough: their tests include two different materials, quartz and cement; two different degrees of fineness; hundreds of grindings; and over 1000 screen analyses and specific surface determinations.

The Davis Curve was exatly reproduced by Allenius and Heinonen when plotted with the same coordinates but only for the ideal sharpness of separation value of 100 percent. The Finnish investigation brings out the practical result under conventional nonideal operating conditions.

The typical case in closed-circuit grinding, both wet and dry, is where the sharpness of classification is 50 percent at a circulating load of 200 percent. By increasing the sharpness of classification from the normal value of 50 percent, e.g., to 80 percent while the circulation load is maintained at 200 percent, the feed capacity and, thus, the production capacity of the same grinding circuit will be increased 25 percent and at the same time the energy consumption will be reduced by 20 percent. The final net saving in the energy consumption depends, of course, on the amount of energy needed by the improvement of the sharpness of classification.

THE KEY FOR ENERGY-EFFICIENT GRINDING: TWO STAGE HYDRAULIC CLASSIFICATION

Based on preceding analysis, the key for improvement in closed-circuit grinding operations is the major improvement in the sharpness of size separation, i.e., classification. It may not be impossible to construct new types of classifiers, that perform better than the hydrocyclone. However, it is unrealistic to assume that a new type of classifier giving a sharpness of 80 percent would soon be available. Therefore, one may accept the limitations of one-stage classification, but for the primary step the shortcomings should be corrected by reclassification of the impure sand product in a separate independent secondary step.

Today the hydrocyclone is the most common industrial classifier. In spite of its limitations, it can no longer be expelled from the thousands of wet grinding circuits around the world. For industrial two-stage hydraulic classification, one apparently must accept as the primary step the conventional cyclone separation. For the second stage one needs a classifier that fills at least the following requirements:

- its feed material is the impure cyclone sand products;
- its capacity must be great, and sharpness of separation good;
- it must be simple, foolproof to operate, wear resistant, and economical on energy; and
- it must be small enough to fit easily into the existing circuit.

The construction of the new hydraulic cone classifier is based on Hukki's 15 years' research and development.

The cyclone sand product is introduced into the apparatus with plenty of additional water via a feed tube. The separating fine product overflows into the launder; radial vanes make the ascending flow substantially laminar. The grains not carried away in suspension proceed outward on discs into a cone where they are kept in continuous motion to prevent accumulation of sand layers on the inside wall of the cone. For this purpose the classifier is equipped with a vertical mechanism rotated at a low speed, carrying two sets of radially projecting blades. A multitude of wash water jets are introduced from a ring via 100 holes across the settling sand layer against a conical projection. The fines removed with jets obtain a flow component upward via the central flow tube and return to the upper classification space proper. Washed and cleaned sands are discharged via the apex opening.

The biggest cone classifier built so far has a diameter of 160 cm, and requires a 7.5 kW motor. Its feed capacity is over 100 tons of solids per hour.

With a two-stage hydraulic classification circuit, if the sharpness in the first-stage cyclone is 50 percent and is the same in the second-stage cone classifier with respect to the remaining fines, the overall sharpness of classification is 75 percent.

The tests carried out in Finland have shown that:

- the hydraulic classifier is a foolproof and dependable unit;
- the wear and power consumption are very low;
- the capacity of the existing grinding circuits has increased substantially; and
- the metallurgical results in flotation (grade and recovery) have shown to be at least equal to previous results in spite of greater tonnage treated.

TWO-STAGE PNEUMATIC CLASSIFICATION

Hukki also investigated the technology of dry grinding, the most important application of which is in the cement industry, where 7,000-10,000 miles of different sizes are used, most often in open circuit. It is estimated, that about 1 percent of all electric energy produced in the world is used in grinding cement clinker to cement.

The tightened specifications for cement have gradually forced the industry to increase the fineness of its product. With increased fineness, pneumatic classification and closed-circuit grinding have become more and more important.

> The pneumatic classifier used in cement industry usually represents a modification of the Mumford-Moodie-principle invented about 100 years ago. The unit classifiers have grown to impressive dimensions with diameters up to 10 meters and total heights up to 30 meters. The vertical central mechanism carries a multitude of massive discs and vanes and may require power up to 1000 kW's for rotation.

So said Hukki, describing his development of a new type of pneumatic classifier.

In Hukki's pneumatic classifier the classification space includes stationary internal parts only. The energy is fed to the system by a medium pressure blower placed on the outside. Material to be classified is gravity fed. The upper primary air stream from the blower disperses the material curtain, forming a suspension that proceeds upward to the top circular section of the apparatus where the coarser middling grains are rejected by centrifugal force toward the inner periphery while the finest fraction only follows the medium stream vai an eccentrically placed discharge opening into the fine product cyclone. The separated middling grains return at a high speed as a continuous stream of shot downward toward the entrance point of the new feed, and disperse the feed. The coarsest fraction not carried away with the primary suspension proceeds downward where the curtain opens once more by the secondary air stream. The secondary suspension joins the primary suspension. The air medium returns via blower back to the classification space in a closed circuit. The cleaned sand fraction is discharged from the bottom of the apparatus.

Field experience over a number of years has shown:

- the capacity of the new classifier is great compared with its size;
- the classifier is well suited to separation of cement and other powders of similar fineness;
- energy consumption is low; and
- the overall sharpness of size separation can now be raised to a new level by placing two classifiers in series or by adding a relatively small and light secondary classifier of this new design to the existing circuit including one conventional classifier.

A two-stage classification system of this kind is currently in operation in Finland. The units are rather small, the production rate being 30 t/h of Portland cement. A similar system for 90 t/h is at the draftboard stage.

The last step in Hukki's development in the field of pneumatic classifiers is a microclassifier. It has been built as a small prototype which has been tested in industry. From rapid class cement (95 percent at 40 μm) it has been possible to separate fine powders in the range of 95 percent at 6 μm to 95 percent at 16 μm at a respective production rate of 100 kg/h and 2.5 t/h in a one-step process. The respective energy consumption figures have been 250 and 10 kWh/t of fine product.

POSSIBILITIES OF DRY PROCESSES IN CONCENTRATION TECHNIQUES

Many factors call attention to dry processes in mineral concentration, not least of which are the many otherwise promising mineral deposits in the arid areas on the globe. One can neither overlook the harm that the use of huge amounts of water would cause the environment in many cases nor the energy requirement. The key operations in dry concentration are low- or high-intensity magnetic separation and electrostatic separation. Well established apparatuses are already available for these operations. The main practical difficulties, however, are related to proper preparation of the feed to the various processes, and the dust caused by dry processes.

It is known that the best metallurgical results can only be obtained on relatively narrowly defined size fractions which under all circumstances must be dust-free. The practical means of dedusting have so far been sadly inadequate. With the new classifiers it has become easy not only to obtain well dedusted fractions at a high production rate but also to extend dedusting to the range of micropowder rarely practiced before in industrial mineral processing operations. In the size range of 100 µm, a combination of pneumatic classification and screening may lead to superior feed fractions. Dry concentration tests carried out in Finland on a number of well dedusted size fractions of various products have produced some rather surprising results.

NOVELTY IN FLOTATION: GIANT FLOTATION CELLS

In mineral concentration, the flotation process is the key operation. The main requirements are for excellent metallurgical results at a low energy consumption. In these respects the new OK-flotation machines developed in Finland seem to be the world leaders of today. Their design is based on a far-reaching analysis by Kai Fallenius of the hydrodynamic phenomena in the cell. On the basis of this analysis, a mathematical model has been developed which aids the easy and accurate determination of the design parameters for any size of flotation cell. The heart of the development is the entirely new energy-saving mechanism which allows foolproof operation both in small and big units equipped with only a single mechanism.

The mechanism consists of rotor and stator. The rotor system allows large volumes of air to be dispersed into fine bubbles throughout the cell. The slurry is maintained in complete suspension with minimum power consumption. Coarsely ground flotation feeds can also be handled without difficulty. OK mechanisms can be restarted after a total shutdown under any circumstances.

More than 100 OK-flotation cells with a volume of 16 m^3 are in operation in Finland; the first ones have already been in use over five years without any change of parts. So far the biggest units built are

38 m^3 in volume. The energy consumption of OK machines is 1.3-1.5 kW/m^3; by comparison the Fagergren and Agitair machines consume 3-5kW/m^3.

DEVELOPMENT IN THE TECHNIQUES OF DEWATERING

In most cases where wet processes are used in concentrators the dewatering of wet mineral concentrates is necessary. It includes three steps: thickening, filtration, and drying to a desired final moisture content. Today, water removal by drying is an expensive process because it is based on evaporation by heat. Drying, however, has remained an unavoidable step because the conventional filtration process has not been effective enough in lowering the moisture content of the cake produced. A new approach applied in Finland to simplify the dewatering process is to use automatic pressure filters which in a number of cases can replace all the three earlier steps by a single-step operation, and which in all cases minimize the heat energy required in the drying process.

Essentially, the automatic pressure filter includes a series of modular unit filters stacked vertically. One continuous filter cloth zigzags through the pack of filter units. The operation takes place in cycles, each cycle including an automatic sequence of:

- mechanical closing of the filter units;
- feeding pulp to be filtered simultaneously into all filter units;
- filtration by pressing rubber diaphragms by water under pressure;
- washing cakes when desirable;
- drying cakes by air under pressure;
- mechanical opening of the filter units;
- discharging all cakes simultaneously by driving the filter cloth a certain distance; and
- washing a section of the filter cloth.

For uninterrupted continuous operation a minimum of two separate units is necessary. The automatic pressure filter is already used in a large number of industries.

CONCENTRATION OF WEAKLY MAGNETIC MINERALS WITH THE AID OF HIGH INTENSITY PERMANENT MAGNET SEPARATOR

The magnetic concentration of minerals by both low- and high-intensity separators is already, by standards of today's technology, energy efficient. The magnetic field of all high-intensity separators in use is produced by electromagnets. This means an unnecessary consumption of energy because a magnetic field as such does not do any physical work. In some cases this energy consumption may be faintly harmful. In the whole energy economy of the concentration processes this part of the energy consumption does not, however, play any remarkable role. A new kind of high-intensity and high-gradient magnetic separator has as the source of the mganetic field, permanent magnets; it provides a small but real energy saving.

Naturally, the construction of a permanent magnet, high-intensity seperator must differ radically from the design principles of electromagnetic separators. It is constructed as a cylindrical array of a large number of magnetic circuits. The pole gaps of these circuits, which are dimensioned so that grad B^2 has the desired value throughout the gap, appear as axial slots on the surface of the drum. When the material to be separated is fed onto the surface of the rotating drum, the magnetic particles are caught by these slots.

An essential element of the system is the second cylindrical permanent magnet array, situated inside and eccentric to the primary cylinder. At the point of osculation there is a strong attractive force between the pole shoes of both magnetic cylinders, causing the inner cylinder to follow the rotation of the outer cylinder. In the neighborhood of osculation, the magnetic field in the slots will be reduced and momentarily cancelled making it possible to remove the magnetic particles.

The separator can be used for both dry or wet separation.

OPTIMIZATION OF MINERAL PROCESSING SYSTEMS

I have described above some individual apparatuses and machines that can lead to energy savings by unit processes, grinding, dewatering, flotation, and high-intensity magnetic separation. A different way to save energy is to build up the process as a whole, so that one has the energy efficiency of the process as the most important criterion for optimization. If the price of energy is high--as it has been in Finland--this is not in contradiction with the common practice to strive for the best plant economy.

The optimization of industrial processes will be based on the science of systems analysis using as tools sophisticated mathematical models of the planned process. When a real industrial process has to be optimized on the basis of theoretical analyses, many kinds of information concerning the actual values of process parameters are needed continuously and without delay.

It was not only the high price of energy but also the fact that most ores in Finland are rather low grade or otherwise difficult to beneficiate that caused the Finnish mining industry to accept the necessity of optimization of processes. One of the results during the last three decades has been the amount of work done in Finland to develop process instruments of different kinds. The first on-line X-ray analyzer was installed in Finland as early as 1957; much work especially by Outokumpu, has been done in this field. A result has been the well known Courier analyzer. The basic Courier 300 system can analyze 14 slurry streams, measuring the content of six elements from each. The time required for one cycle, i.e., for the analyses of 14 slurries, is seven minutes.

Evidently, the Courier systems are suited only to large concentrators. However, Minexan, a new product of Outokumpu, is also suited to smaller processes. The compact radioisotope probes of the Minexan 202 system are self-sufficient measuring units, each with its own microcomputer. Each probe contains the excitation source, X-ray pulse height detector, and associated electronics. The three or more probes, can be immersed directly into the slurry to be analyzed. The computer controls the operation of probes, converts the primary pulse data into element concentrations, and reports the results to the recorders or process control computer.

Courier and Minexan are mentioned here as examples of a large variety of a different kind of instruments for on-line measurement of the values of different process parameters in real processes.

THE CHANGING IMPORTANCE OF MATERIAL AND MATERIAL COSTS IN THE WORLD ECONOMY

Wassily Leontief

Visualize an economy in which a bundle of goods delivered to the final users is eliminated. By how much would the amounts of the commodity, primary resource, or service in question, absorbed by industries contributing directly or indirectly to the production of the bundle of final deliveries be reduced? Detailed input-output tables describing the flows of all goods and services between all sectors of the economy contain the information to numerically computate the answers to such questions.

The structural coefficients used in the input-output computations can be interpreted as representing the "recipes," that is, the technologies employed in various industries. Hence, a shift from one technology to another can be represented concisely by substituting in an economic matrix one vector of technical coefficients for another. The implications of such change described in terms of its effect on the input-output flows of different goods throughout all parts of the economy can be assessed by means of similar computations.

In dynamic input-output analysis, the computation of investment demand, i.e., the magnitudes of commodity and service flows directed toward construction of new productive facilities, involve the use of appropriate sets of capital coefficients. These specify the amounts of structures, equipment, and inventories of materials, i.e., "pots and pans" required to provide a unit of additional productive capacity of a particular sector.

The approach described above was employed in constructing a number of alternative hypothetical projections of future states of the world economy from the base year 1970 through the year 2000. The United Nations report The Future of the World Economy describes the results of several of these alternative projections. In respect to the supply of mineral resources, the general conclusion is that it will not be a problem of absolute scarcity in the present century, but at worst, a problem of exploiting less productive or more costly deposits of minerals and of intensive exploration of new deposits. Among the six metals considered, only in the case of lead and zinc do present estimates allow one to envisage the exhaustion of the reserves by the year 2000.

In addition to the scenario presented in The Future of the World Economy, a number of projections were made to assess more closely the influence of alternative projections of future population trends on the developmental prospects of various developed and less developed regions. As should have been expected, over the relatively short interval of 30 years, a shift from one to another demographic projection can have only a very small effect on economic growth and, in particular, on production and consumption of various materials. The direction of that influence is of some interest since, over a longer period, its absolute magnitude is bound to become greater.

The important role that arms production plays in determining the level of production and consumption of iron and steel and of nonferrous metals becomes clear when one compares the projections described above with others incorporating lower rates of military spending. One of these is based on the admittedly unrealistic assumption that military spending (in developed regions), instead of growing in step with the gross national product as it has in the past, first be slightly reduced and then kept on a nearly constant level (Figures 1-4).

A major study, "Production and Consumption of Basic Minerals Analyzed within the Framework of Multiregional Input-Output Model of the World Economy," is being carried out at the Institute for Economic Analysis of New York University under the sponsorship of the National Science Foundation and the Bureau of Mines. An additional feature of that study is the systematic use of technological information received directly from major elements of the mining and metal processing industries.

Figure 1. PROJECTED CONSUMPTION* OF IRON UNDER SCENARIOS A AND Y (DISARMAMENT) (thousand of metric tons of metal content)

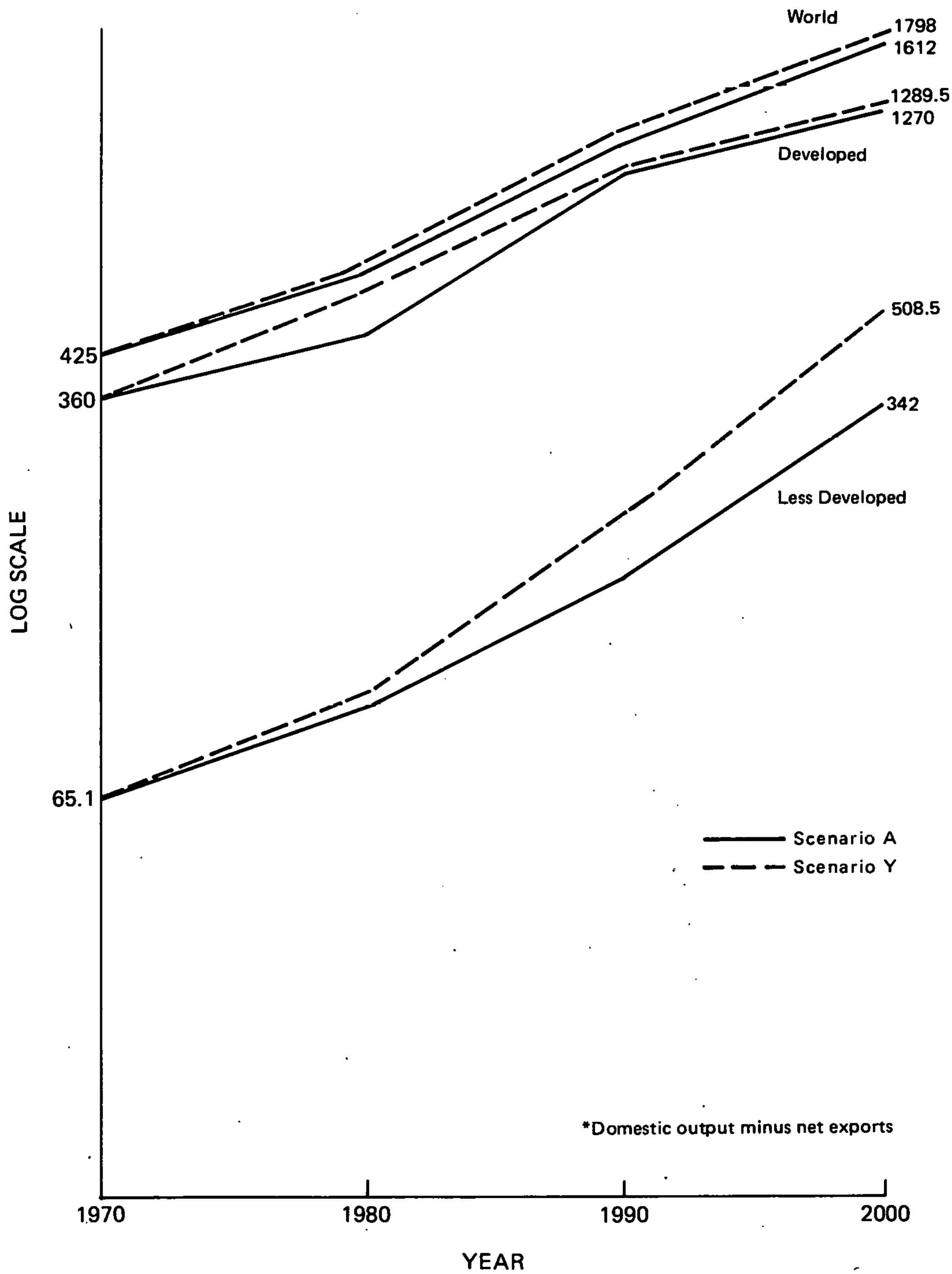


Figure 2. PROJECTED CONSUMPTION* OF COPPER UNDER SCENARIOS A AND Y (DISARMAMENT) (thousand of metric tons of metal content)

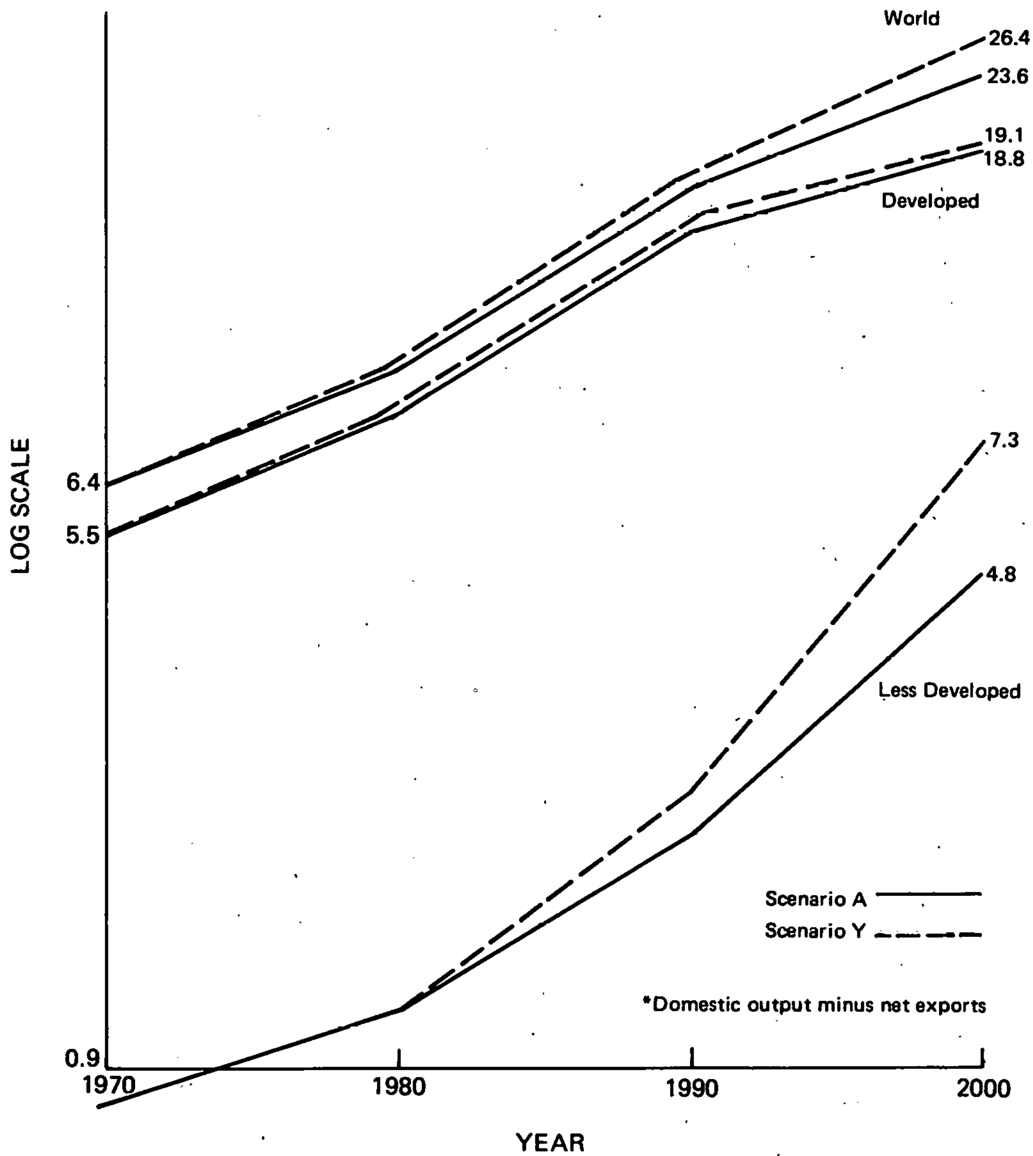


Figure 3. PROJECTED CONSUMPTION* OF IRON UNDER ALTERNATIVE POPULATION ASSUMPTIONS (thousand of metric tons of metal content)

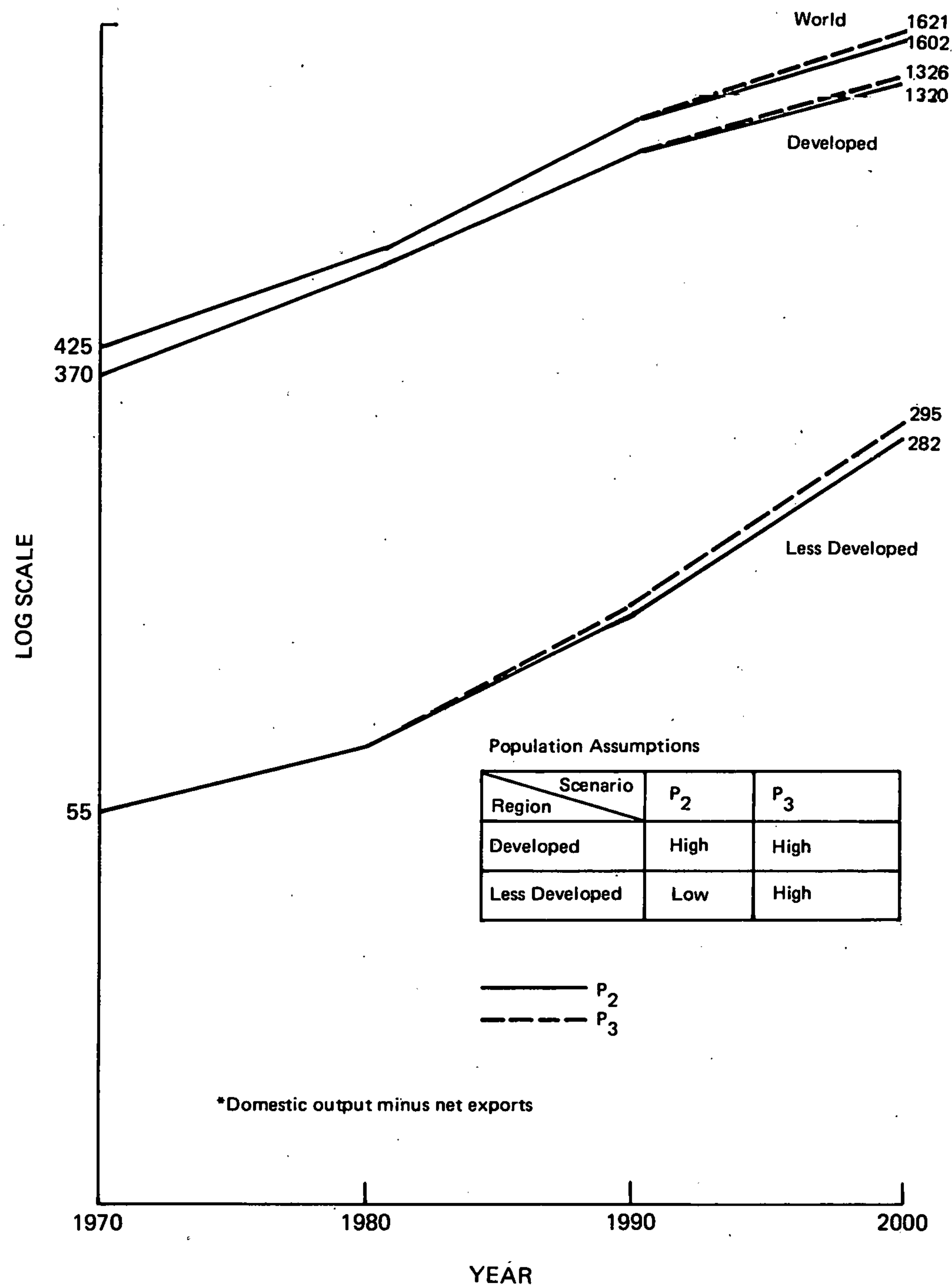
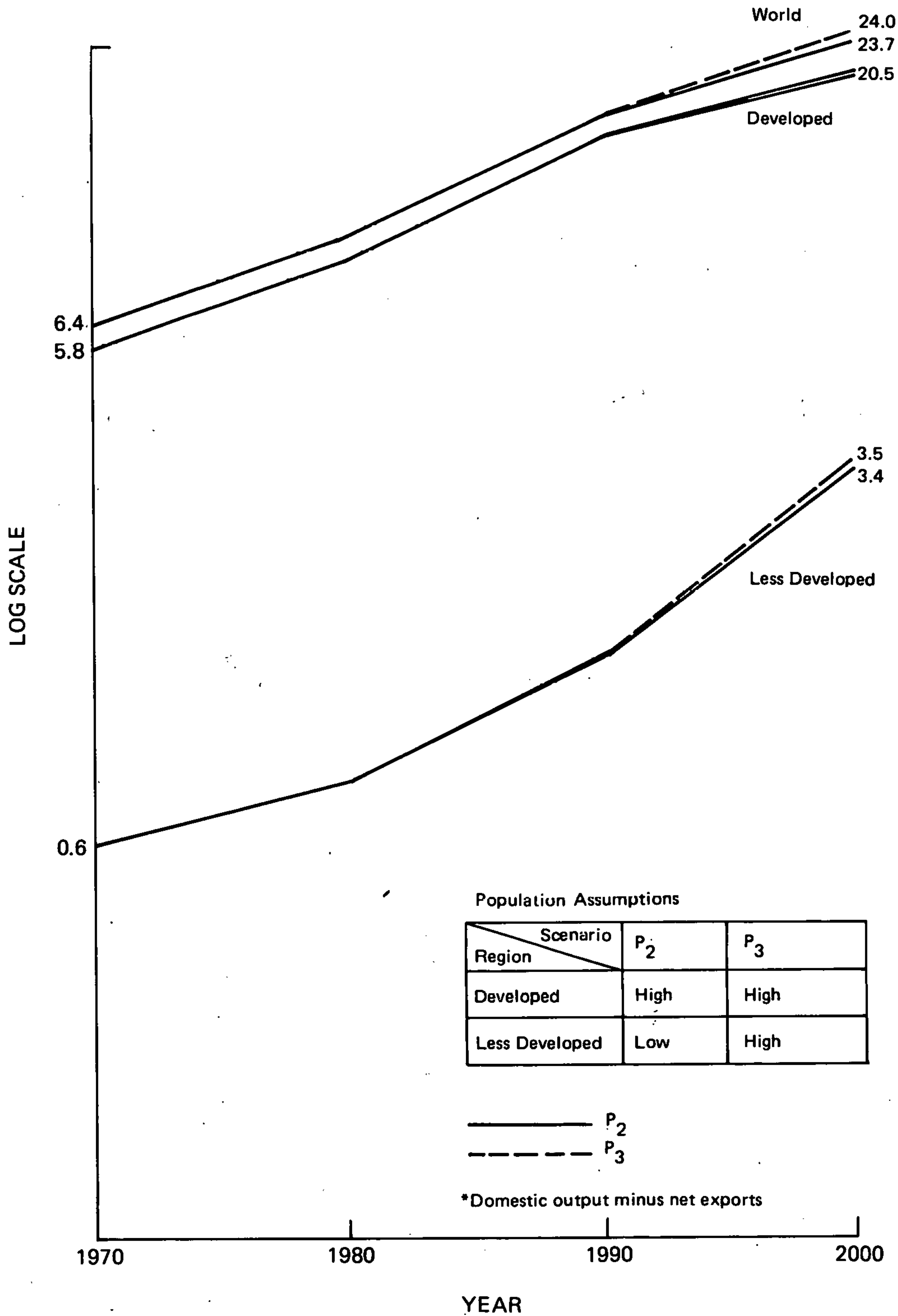


Figure 4. PROJECTED CONSUMPTION* OF COPPER UNDER ALTERNATIVE POPULATION ASSUMPTIONS (thousand of metric tons of metal content)



MATERIALS USE, RISING ENERGY COSTS, AND INVESTMENT REQUIREMENTS

Shamsher Singh

This paper briefly reviews broad historical trends in production, and prices of major raw materials, examines the effect on production costs of rising energy prices, projects the relevant variable to 1990, and examines the investment requirements.*

In spite of the nonrenewable nature of most industrial raw materials, there is no evidence that, on the whole, materials are likely to become scarce, or the security of their supplies become endangered for the consumers. The broad trends, however, vary from commodity to commodity, illustrated in this paper for a selected number of products.

Globally, with the notable exception of tin, the supply of most materials has been expanding faster than the rate of population growth and commensurate with income growth. This is unlikely to change for the foreseeable future. However, production expansion during 1975-1990 would be slower than in 1960-1975 due to a variety of reasons including slackening of world demand (Table 1).

There is a strong relationship between the demand for materials and income growth in the developed countries, the principal consumers of minerals and metals. Real growth in the Organization for Economic Cooperation and Development (OECD) countries averaged about 4.2 percent per year in 1960-1975. Since then, their rate of expansion has been sluggish. These economies, preoccupied as they are with controlling inflation, are likely to grow at only 3.9 percent per year in 1975-1980. But, they are expected to resume the historical rate of growth (4.2 percent) in the 1980s. The economic expansion in the developing countries will also be slightly lower than in the past, as would also be the overall growth for the world (excluding centrally planned economies) (Table 2). At the same time, the income elasticities of demand in the main consuming countries have been declining. Thus, a decline in the rate of production expansion in 1975-1990 should not be viewed with concern.

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*The views and interpretations in this paper are those of the author and should not be attributed to the World Bank group.

Another crucial element in the materials scene is the availability and the price of energy as reflected by petroleum. Changes in petroleum prices directly affect the costs and prices of petroleum-based products, such as synthetic fibers, synthetic rubbers, and energy-intensive products such as aluminum. The ripple effects of changes in petroleum prices are much wider: direct effects on production and transport costs; indirect effects on economic growth (thereby reducing demand for other primary products); and both direct and indirect effects on inflation.

Historically, petroleum was a cheap product, priced far below substitute fuels. It was also cheap in another sense; the economic rent inherent in this gift of nature was flowing chiefly to the consumers (Hughes and Singh, 1978). The situation was largely rectified in 1974.[1] Prices, in real terms, have since fluctuated around the new higher level of about $12 per barrel for Saudi Light (1977 dollars). The higher prices have given impetus to new investments in exploration and development of energy resources (both conventional and nonconventional) and to conservation measures. Although the future is clouded by uncertainties about government policies, the market outlook can be postulated under a set of assumptions.

Demand for petroleum, as also for other products, would be affected by the real GDP of the OECD countries; this is expected to grow at about 4.2 percent per annum in 1980-1990. The supply will be affected by the production policies pursued by the OPEC countries since supplies from new finds in Mexico would still be relatively small during this period. If OPEC countries continued to produce at their capacity and developed countries took further conservation measures, world supply and demand would be in near balance at unchanged real prices. However, if real growth in the OECD countries were to be lower (3.5 percent per annum), demand for petroleum would fall. But this may not lead to lowering of petroleum prices because capital-surplus OPEC countries would most likely reduce their production. On the other hand, if real growth proved to be faster, demand would exceed supplies inducing a price rise of the order of about 2 percent per annum (Table 3).

The effect of such developments in the price of petroleum on the cost of production of materials will depend on their energy intensity. Highly energy-intensive primary materials include aluminum, tin, nickel, and copper (Table 4).

Aluminum is the most energy-intensive among these products, requiring 244 million Btu per ton of ingot produced (1973 U.S. estimate). An alternative source (Hashimoto and Takeuchi, in preparation) reckons the energy component in the production of primary aluminum at 50-66 million Btu for alumina reduction and 76-107 million Btu per ton of ingot. The differences may be in definition. In general, power costs are estimated to account for 30 percent of total production cost.

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[1] Prices of substitutes still remain significantly higher.

Cost pressures will affect the location of processing facilities as well as demand for aluminum. Countries with cheap energy (hydro-electricity and natural gas) have good opportunities to establish aluminum processing. Demand for aluminum is expected to remain strong even though higher energy (and capital) costs may adversely affect the price advantage of aluminum over its substitues. Energy conservation measures are raising aluminum use in various industries: in vehicles its use is increasing because of its reduced weight and improved energy efficiency; in the housing industry--storm windows, storm doors, siding, and foil-backed insulation--it is increasing to reduce energy loss.

Energy inputs into the smelting and refining of primary metals in the developed countries may have risen since 1973. Pollution controls mean greater energy cost. At the same time, the rise in energy prices relative to the prices of other factor costs also means added cost increases. But such increases are not alarming by any means. For example, the 1972 data for the United States demonstrated that energy accounted for 5 percent of the total (operating and indirect) costs in steel-making; these costs rose to 7 percent in 1977 (Council on Wage and Price Stability, 1977). The industrial sector has historically shown its capability of adjusting itself to gradual changes in factor costs. Apart from possible shifts in the location of processing facilities, as mentioned in the case of aluminum, cost increases in energy will certainly give greater impetus to savings in fuel costs through technological innovation. In steel-making, new technology already makes it possible to use ferronickel instead of pure nickel.

Energy cost is, of course, only one of the components determining long-run production costs which in turn affect long-run world market prices. The latter depend on the range of general factors such as economic growth, population, inflation, and exchange rate changes. More importantly, commodity prices depend on specific factors which lead to shifts in supply and demand and changes in the structure of the market. Detailed analysis undertaken by the World Bank staff concludes that during the 1980s world market prices for major materials will rise in real terms from their generally depressed levels of 1975-1978 (tin being an exception). The general trend of price increases will be moderate and the overall index for 1990 will remain below the levels experienced in the late 1960s. The data shown in Table 5, pertain to average trend values for 1985 and 1990; the actual figures for particular years may markedly diverge from these values. Commodity prices are notorious for their short-run instability.

The projected level of world production associated with the price forecasts is summarized in Table 6. (For brevity, the assumptions and methodology underlying these forecasts are not presented.) As already indicated in Table 1, petroleum is the only product whose production is forecast to expand at a significantly lower rate than historical growth. Petroleum's share in world energy output, having expanded sharply during the past two decades, will decline during the coming decades. None of the other products is expected to experience a similar development.

The expansion in output volumes forecast for 1990 implies corresponding expansion in new investment. These investment requirements until 1985 have been estimated (Takeuchi et al., 1977). The same are extended here to 1990 and to cover developed countries as well. The methodology assumes that production capacity, at normal capacity utilization (93 percent) will be consistent with the forecast production volumes. Capital requirements per ton of capacity, estimated on the basis of fragmentary information gathered from a variety of sources were obtained by multiplying the two variables. The estimates presented in Table 7 should be taken as rough magnitudes because of the difficulties of obtaining a representative or average cost of capital per unit of annual capacity.

A large part of the investments required have already been made since it takes five to seven years to establish mining, smelting, and refining projects. Moreover, most of the required investments would need to be in place by 1985.

Given the improvement forecast in the prices of primary metals during 1979-1990, economic development prospects during the 1980s, and the general investment climate, sufficient capital (doemstic and foreign, including resources from international development institutions) would be available to realize the needed scale of investments.

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TABLE 1. World* Production of Selected Metals and Minerals (Growth Rates % per Annum)

	Petroleum	Bauxite	Aluminum	Copper	Lead	Zinc	Tin	Iron Ore	Steel	Manganese Ore	Population	Gross Domestic Product (GDP)
1969-1974/76	6.3	7.7	7.3	3.5	2.1	3.9	1.8	3.6	4.4	5.5	2.1†	4.5†
1974/76-1990	1.9	6.7	6.7	2.6	3.4	4.9	1.4	3.1	3.5	4.6	1.9‡	4.4‡
Income elasticity of demand	0.9	1.5	1.5	0.8	0.9	0.9	0.3	1.0	1.4	0.9		

*Excludes Centrally Planned Economics (CPEs).

†1960-1975.

‡1975-1990.

SOURCE: World Bank.

Table 2. REAL GDP GROWTH RATES
(% per annum)

	1960-75	1975-80	1980-90
North America	3.5	4.1	4.0
Japan and Oceania	7.9	5.1	5.9
Western Europe	4.0	3.2	3.7
Total OECD	4.2	3.9	4.2
Developing Countries	5.8	4.9	5.6

Source: World Bank: World Development Report, 1978.

Table 3. PETROLEUM PRICES (US$/barrel)

	OECD GDP Growth (1980-90) (% per annum)		1970	1973	1975	1977	1980	1990
Low	3.5	Constant 1977$	3.0	4.3	11.6	12.4	12.4	12.4
Medium	4.2	Current	1.3	2.7	10.7	12.4	16.4	28.1
High	4.9	Constant 1977$	3.0	4.3	11.6	12.4	12.4	15.0
		Current	1.3	2.7	10.7	12.4	16.4	34.0

Saudi Arabian light crude oil, 34°-34.9° API gravity, average realized price f.o.b. Ras Tanura.

Source: World Bank.

Table 4. ENERGY CONSUMPTION IN PRIMARY MATERIALS
(million Btu per ton)

Aluminum (ingot)	244
Tin (ingot)	190
Copper (refined)	112
Zinc slab	65
Lead (ingot)	27

Source: Herbert K. Kellogg, Sizing up energy requirements for producing primary materials, Engineering and Mining Journal, April 1977 (based on 1973 data from Battelle-Columbus Laboratories).

TABLE 5. Prices for Selected Metals and Minerals (in Constant 1977 Dollars)

Commodity	Unit	1955	1960	1965	1970	1975	1978	1985	1990
Copper	¢/kg	280.6	178.4	323.3	327.8	137.9	118.7	198.8	209.3
Iron ore	$/ton	55.9	45.0	39.3	35.3	25.2	17.4	22.0	24.3
Tin	¢/kg	592.5	577.6	975.7	852.4	765.8	1120.5	1002.9	1016.2
Nickel	$/kg	4.1	4.3	4.3	6.6	5.1	4.0	6.0	5.9
Bauxite	$/ton	21.7	19.7	18.8	27.8	28.2	29.8	32.6	32.9
Aluminum ingot	$/ton	1514.5	1508.0	1353.0	1469.0	978.0	1170.0	1240.0	1260.0
Manganese ore	$/m.t. unit	263.8	229.2	188.5	126.2	153.6	124.0	110.0	105.0
Lead	¢/kg	84.6	51.8	78.9	70.3	46.1	57.3	68.0	69.0
Zinc	¢/kg	72.5	64.4	77.4	68.1	82.2	51.6	80.0	85.0
Index of metals and minerals (1977-100)		165	127	168	164	107	90	121	126

SOURCE: World Bank, Economic Analysis and Projections Department.

Table 6. WORLD PRODUCTION OF SELECTED METALS AND MINERALS*

Commodity	Unit	1960	1970	1974/76	1977	1990
Petroleum	mill.b/day	18.7	40.1	46.2	48.8	61.9
Bauxite	thous. tons	22,491	50,828	68,869	73,531	183,000
Aluminum	thous. tons	3,618	8,056	10,401	11,316	27,500
Copper	thous. tons	3,614	5,168	6,055	6,500	8,800
Lead	thous. tons	1,810	2,567	2,478	2,511	4,090
Zinc	thous. tons	2,563	4,360	4,534	4,825	9,315
Tin	thous. tons	138	185	179	185	222
Iron ore	mill. tons	348	517	590	526	930
Steel	mill. tons	241	422	459	443	765
Manganese ore	thous. tons	2,759	4,948	6,201	5,425	12,100

*Excludes CPEs.

Source: World Bank.

Table 7. PROJECTED WORLD[a] INVESTMENT IN THE NONFUEL SECTOR, 1980-1990
(in constant 1977 US$)

Commodity	Capital Cost/Ton of Capacity	1977-1990 Increase in Capacity[b]	Investment Required[c]
	($)	(million tons)	(billion $)
Bauxite	95	100.0	9.5
Aluminum	2,000	16.0	32.0
Copper	6,700	2.5	16.8
Lead	1,200	1.7	2.0
Zinc	1,250	4.8	6.0
Tin	13,500	0.04	0.5
Iron ore	100	400.0	40.0
Manganese ore	350	7.2	2.5

[a]Excludes CPEs.

[b]Based on forecast increases in petroleum.

[c]Excludes replacement requirement.

Source: World Bank.

APPENDIX C

LIST OF ATTENDEES

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INTERNATIONAL MATERIALS CONGRESS

Sheraton Inn International Conference Center

Reston, Virginia

March 26-29, 1979

PRELIMINARY REGISTRATION LIST

Mr. Bernard Achhammer
Consultant
10614 Margate Road
Silver Spring, MARYLAND 20981

Dr. A. A. Afonja
President
Department of Metallurgical and Materials Engineering
University of Ife
Ile-Ife, NIGERIA

Dr. L. Alberts
President
National Institute for Metallurgy
Private Bag X3195
Randburg 2125
SOUTH AFRICA

Dr. C. Albertson
Assistant Director
Mfg. Processes Research
Borg-Warner Research Center
Wolf & Algonquin Roads
Des Plaines, ILLINOIS

Mr. Alan Aldous
Director
Electric Vehicle Development Group
59 Colebrooke, Row
London N-1, ENGLAND

Professor William O. Alexander
University of Aston in Birmingham
Gosta Green
Birmingham, UNITED KINGDOM

Professor Dieter Altenpohl
Vice President Technology
Swiss Aluminium Ltd.
P. O. Box 495
Ch-8034 Zurich, SWITZERLAND

Professor Alexander Animalu
Department of Physics
University of Nigeria
Nsukka, NIGERIA

Mr. Amarquaye Armar
Research Assistant
World Bank (Science and Technical Unit)
Room D1054
1818 H Street, N.W.
Washington, DC 20433

Professor Richard J. Arsenault
National Science Foundation
1800 G Street, NW
Washington, DC 20550

Dr. Manuel Aven
General Electric Company
P. O. Box 43
Schenectady, NEW YORK 12301

Dr. W. T. Bakker
Fossil Energy Program
Department of Energy
Room C 157
Germantown Office
Washington, DC

Professor J. Barford
Head of Materials Division
Central Electricity Research Laboratories
Kelvin Avenue
Leatherhead, Surrey, UNITED KINGDOM

Mr. Robert Barnes
Principal
Queen Elizabeth College
University of London
Camden Hill Road
Kensington, LONDON W8 7AH

Mr. Robert C. Bates
Manager, Materials Evaluation and
Appliance Department
R7D Center
Westinghouse Electric Corporation
Beulah Road
Pittsburgh, PENNSYLVANIA

Mr. Walter E. Becker
Director
Mobay Chemical Corporation
Penn Lincoln Parkway West
Pittsburgh, PENNSYLVANIA

Dr. Arden L. Bement
Director, Office of Materials Sciences
DoD/DARPA
1400 Wilson Boulevard
Arlington, VIRGINIA 22209

Dr. Herbert S. Bennett
Director, Division of Materials
Research
National Science Foundation
1800 G Street, NW
Washington, DC 20550

Colonel William R. Benoit
Commander/Deputy Director
Army Materials & Mechanics
Research Center
Arsenal Street
Watertown, MASSACHUSETTS 02172

Dr. Charles A. Berg
Consultant
RFD 1, Box 165
Buckfield, MAINE 04220

Mr. Philippe Berge
Ingenieur
Electricite de France
Les Renardieres, route de Sens
72250-Moret-Sur-Loing, FRANCE

Dean James S. Bethel
College of Forest Resources
University of Washington
115 Anderson Hall, AR-10
Seattle, WASHINGTON

Professor Michael Bever
Massachusetts Institute of Technology
Room 13-5026
Cambridge, MASSACHUSETTS 02139

Mr. James H. Bick
Environmental Systems Scientist
MITRE Corporation
Metrek Division
1820 Dolley Madison Boulevard
McLean, VIRGINIA 22102

Mr. Heraldo Biloni
Director OAS Metallurgy Project
Comision Energia Atomica
Argentina
Av. Libertador 8250
Buenos Aires, ARGENTINA

Dr. Adli Bishay
Professor of Materials Engineering
& Director, Desert Development
The American University in Cairo
Cairo, EGYPT

Mr. R. Andrew Blelloch
Senior Environmental Engineer
Louis Berger & Associates
100 Halsted Street
East Orange, NEW JERSEY 07019

Dr. S. L. Blum
Vice President
Program Development
Northern Energy Corporation
70 Memorial Drive
Cambridge, MASSACHUSETTS

Dr. Alberto Bonfiglioli
Science Policy Research Unit
University of Sussex
Brighton, Sussex BN1 9RF - ENGLAND

Dr. T. R. Boulos
Professor of Mineral
Beneficiation
National Research Centre
Cairo, EGYPT

Mr. Phillipe Bourdeau
Head of Division
Commission of the European Communities
Rue de la Loi, 200
Brussels, BELGIUM

Dr. D. H. Bowen
United Kingdom Atomic Energy
Authority
Harnell, Didcot
Oxfordshire Ox11 ORA, ENGLAND

Professor H. Kent Bowen
Department of Materials Science
and Engineering
Massachusetts Institute of Technology
Cambridge, MASSACHUSETTS 02139

Mr. J. Parker Boyer
Senior Research Scientist
Battelle-Columbus Labs
505 King Avenue
Columbus, OHIO 43201

Mr. R. A. Bradley
Manager, Fossil Energy Materials
Program
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TENNESSEE 37830

Mr. Edward L. Brady
Associate Director for
International Affairs
National Bureau of Standards
Washington, DC 20234

Dr. Robert Bragg
Department of Materials Science &
Mineral Engineering
University of California-Berkeley
Hearst Mining Building
Berkeley, CALIFORNIA 94720

Professor David G. Brandon
Technior
Department of Materials Science
Haifa, ISRAEL

Dr. C. v.d.M. Brink
President
Council for Scientific and
Industrial Research
P. O. Box 395
Pretoria 0001
SOUTH AFRICA

Mr. David Brown
Vice Chairman
Halcon International, Inc.
2 Park Avenue
New York, NY

Mr. B. W. Burgess
President and Chief Executive Officer
Pulp & Paper Research Institute
of Canada
570 St. John's Blvd.
Pointe Claire, Quebec, CANADA

Mr. Harold Bullis
Specialist, Science & Technology
Congressional Research Service
Library of Congress
Washington, DC

Dr. J. E. Burke
Manager, Special Projects
General Electric Company
Corporate Research & Development
P.O. Box 8
Schenectady, NEW YORK 12027

Dr. John J. Burke
Associate Director
Army Materials and Mechanics
Research Center
Watertown, MASSACHUSETTS 02170

Professor Kerry Burns
Professor of Geology
Syracuse University
220 Heroy Labs
Syracuse, NEW YORK

Dr. Harris M. Burte
Director, Metals & Ceramics
Division
Department of the Air Force
AF Materials Lab (AFSC)
Wright-Patterson AFB, OHIO 45433

Dr. Spencer H. Bush
Senior Staff Consultant
Battelle Northwest
P.O. Box 999
Richland, WASHINGTON

Mr. Robert L. Butenhoff
U.S. Department of Energy
20 Massachusetts Ave., N.W.
Washington, DC 20001

Dr. Barry L. Butler
Chief Materials Branch
Solar Energy Research Institute
1536 Cole Blvd.
Golden, CALIFORNIA 80401

Dr. Audrey Buyrn
Group Manager for Materials
Office of Technology Assessment
Congress of the United States
Washington, DC 20510

Dr. D. A. Canonico
Group Leader
Pressure Vessel Technology
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TENNESSEE 37830

Mr. William F. Carroll
Jet Propulsion Lab.
4800 Oak Grove Drive
Pasadena, CALIFORNIA 91103

Professor Anne P. Carter
Department of Economics
Brandeis University
202 Brattle Street
Cambridge, MASSACHUSETTS 02138

Dr. Cynthia Carter
Executive Secretary
Numerical Data Advisory Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, DC 20418

Mr. Robert L. Caton
General Manager Alloy Development
Carpenter Technology Corp.
P.O. Box 662
Reading, PENNSYLVANIA 19603

Dr. Muammer Cetincelik
M.T.A. Research Institute
P.O. Box 231
Bakanliklar
Ankara, TURKEY

Mr. Mario Cellarosi
National Bureau of Standards
Department of Commerce
Washington, DC 20234

Dr. A. A. L. Challis
Director
Polymer Engineering Directorate, Science Research Council
P.O. Box 271
London WC2H OHW, UNITED KINGDOM

Mr. Sen-Fuh Chang
Assistant Specialist in Farm Machinery
Joint Commission on Rural Reconstruction
37 Nan Hai Road
Taipei, TAIWAN, ROC

Mr. Weng-Tse Cheng
Deputy Chief, Energy Resources Department
Mining Research & Service Organization
No. 1, Tun Hwa South Road
Taipei 105, TAIWAN, ROC

Professor Chen-Hwa Cheng
National Tsing Hua University
855 Kwang Fu Road
Hsinchu, TAIWAN, ROC

Dr. Richard S. Claassen
Director, Materials & Processes-5800
Sandia Labs.
Albuquerque, NEW MEXICO 87185

Dr. J. B. Clark
Head, High Pressure Physics
Council for Scientific and Industrial Research
P.O. Box 395
Pretoria 0001
SOUTH AFRICA

Mr. & Mrs. Beresford N. Clarke
President
Metallurgical Processing, Inc.
3724 Maumee Road
P.O. Box 842
Ft. Wayne, INDIANA 46801

Mr. Gilles G. Cloutier
Director of Research
Research Council of Alberta
11315 87 Avenue
Edmonton, Alberta, CANADA

Professor Morris Cohen
Massachusetts Institute of Technology
Room 13-5046
Cambridge, MASSACHUSETTS 02139

Dr. Umberto Colombo
President, Nuclear Energy
National Committee
Viale Regina Margherita 125
00198 Rome, ITALY

Mr. William Compton
Director, Research
Solar Turbines International
2200 Pacific Highway
San Diego, CALIFORNIA 92138

Mr. Stephen D. Cramer
U.S. Bureau of Mines
Avondale, MARYLAND 20782

Mr. John E. Cunningham
Associate Director, Metals and
Ceramics Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TENNESSEE 37830

Dr. Luiz C. Correa da Silva
Coordinator, Special Projects
Fundacao C.E. Commercio Exterior
Av. Rio Branco 120
(Grupo 807)
Rio De Janeiro, BRAZIL

Mr. S. J. Dapkunas
Senior Project Engineer
U.S. Department of Energy
20 Massachusetts Ave., N.W.
Washington, DC 20545

Mr. M. N. Dastur
Chairman & Managing Director
M.N. Dastur & Co., Ltd.
p-17 Mission Row Extension
Calcutta 700 013, INDIA

Mr. P. J. Detmold
Special Consultant
Canadian Pacific, Ltd.
P.O. Box 6042
Station A
Montreal, Quebec, H3C 3E4
CANADA

Angela Menin Teixeira De Souza
Electric Engineer
Fundacao Centro Tecnologico De Mg - CETEC
Av Jose Candido Da Silveria
200 - HORTO
Belo Horizonte, BRASIL/MG

Mr. Jack H. Devan
Oak Ridge National Labs.
P.O. Box X
Oak Ridge, TENNESSEE 37830

Dr. Ferdinand Dierkens
Director
Electronucleaire
Rue de La Pepiniere 41
Brussels, BELGIUM

Mr. Frank A. DiMatteo
Director, DS/Engn.
Office of Engineering
AID
330 Durbin Place
Falls Church, VIRGINIA 20523

Mr. G. Dobos
Advisor to the Deputy
Executive Director
United National Industrial Development
Organization
UNIDO P.O. Box 707
A-1011 Vienna, AUSTRIA

Mr. Miroslav Dopita
Czech Embassy
Scientist Department
3900 Linnean, N.W.
Washington, DC 20008

Mr. David L. Douglas
Technical Manager
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CALIFORNIA

Mr. J. Dubow
Engineering Research Center
Electrical Engineering Department
Foothills Campus
Colorado State University
Ft. Collins, COLORADO 80523

Mr. Walter G. Dupree, Jr.
Physical Scientist
Department of the Interior
Bureau of Mines
2401 E Street
Washington, DC

Dr. George Economos
Staff Scientist
National Materials Advisory Board
National Research Council
National Academy of Sciences
2101 Constitution Ave., N.W.
Washington, DC 20418

Mr. J. Rodney Edwards
Vice President
American Paper Institute
260 Madison Avenue
New York, NEW YORK 10016

Mr. & Mrs. John R. Edwards
Senior Metallurgist
Deere & Co. Technical Center
3300 River Drive
Moline, ILLINOIS 61265

Professor A. E. El-Mehairy
Metallurgical Department
University of Cairo
Cairo, EGYPT

Mohamed Mostafa El-Said
Building Research Center
Tahrir Strat
Cairo, EGYPT

Dr. Edward Epremian
Executive Director
Commission on Sociotechnical Systems
National Research Council
National Academy of Sciences
2101 Constitution Ave., N.W.
Washington, DC 20418

Robert Ethington
Director, Forest Products
and Engineering Research
USDA Forest Service
P.O. Box 2417
Washington, DC 20013

Dr. Ingemar Falkehag
Renewing Systems
706 Creekside Drive
Mt. Pleasant, SOUTH CAROLINA 29464

Mr. William Fitzgerald
Economist
1325 Buttermilk Lane
Reston, VIRGINIA 22070

Mr. W. W. Fitzgibbons
Research Associate
SOHIO
3092 Broadway Avenue
Cleveland, OHIO 44115

Mr. Curry Ford
Consultant
143 Parish Road South
New Canaan, CONNECTICUT 06840

Mr. Robert B. Fulton
Basic Materials Planning
E.I. duPont deNemours & Co.
Energy & Materials Department
Wilmington, DELAWARE 19898

Dr. S. William Gouse
Chief Scientist
The MITRE Corporation
1820 Dolley Madison Blvd.
McLean, VIRGINIA 22102

Mr. Farno Green
Executive Engineer
General Motors Corp.
Manufacturing Development
GM Technical Center
Warner, MICHIGAN 48090

Mr. Gerald C. Groff
Director, Research Laboratories
Carrier Corporation
Research Division
Carrier Parkway
P.O. Box 4808
Syracuse, NEW YORK 13221

Dr. Perfecto K. Guerrero
Scientific Attache
Philippine Embassy
1617 Massachusetts Ave., N.W.
Washington, DC 20036

Professor L. Habraken
Centre de Recherches Metallurgiques
Abbaye de Val-Benoit
B-4000 Liege, BELGIUM

Mr. William C. Hagel
Manager of Research
Climax Molybdenum Co. of Michigan
1600 Huron Parkway
Ann Arbor, MICHIGAN

Dr. Leonard Hagn
Allianz-Zentrum für Technik GmbH
Krausstrasse 14
8045 Ismaning, GERMANY

Ms. Ruth Haines
Scientific Assistant to the Director
National Bureau of Standards
B354, Bldg. 223
Washington, DC 20234

Professor Gunnar Hambraeus
Royal Swedish Academy of Engineering Sciences
Box 5073
S102 42 Stockholm, SWEDEN

Dr. N. Bruce Hannay
Vice President
Research and Patents
Bell Laboratories
Murray Hill, NEW JERSEY

Mr. Leonard A. Harris
Chief, Structures & Materials Branch
Aircraft Energy Efficiency Office
National Aeronautics & Space Administration
Washington, DC 20546

Dr. W. J. Harris, Jr.
Vice President
Research and Test
Association of American Railroads
1920 L Street, N.W., Suite 620
Washington, DC 20036

Mr. Douglas J. Harvey
Staff Research Engineer Metallurgy
General Motors Research Laboratories
Warren, MICHIGAN 48090

Mr. Julius J. Harwood
Director, Materials Science Labs.
Ford Motor Company
P.O. Box 2053
Dearborn, MICHIGAN 48121

Professor Ryukiti R. Hasiguti
Science University of Tokyo
Faculty of Engineering
Kagurazaka, Shinjuku-ku
Tokyo 162, JAPAN

Professor John G. Haygreen
Professor and Department Head
University of Minnesota
220 Kaufert Lab
St. Paul, MINNESOTA 55108

Dr. Robert V. Hemm
Executive Secretary
National Materials Advisory Board
National Research Council
National Academy of Sciences
2101 Constitution Ave., N.W.
Washington, DC 20418

Mr. H. Herman
Materials Science Department
Stoneybrook University of New York
Stoneybrook, NEW YORK

Dr. Fritz Hinzner
Professor de Cincias de los Materials
Facultad de Ciencias Fisicay y
Matematicas, Universidad de Chile
Santiago, CHILE

Mr. C. G. Hide
Scientific Counsellor
South African Scientific Office
2555 M Street, N.W.
Washington, DC 20037

Mr. Donald E. Hipchen
Director of Development
Jim Walter Research Corp.
10301 9th Street, North
St. Petersburgh, FLORIDA 33702

Mr. Joel S. Hirschhorn
Project Manager
Office of Technology Assessment
U.S. Congress
Washington, DC

Mr. David O. Hobson
Metallurgist
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TENNESSEE 37830

Dr. H. E. Hoefdraad
Ministry of Economic Affairs
P.O. Box 20101
2500 EC The Hague, THE NETHERLANDS

Dr. Michael O. Holowaty
Senior Advisor
Inland Steel Company
3001 E. Columbus Drive
East Chicago, INDIANA

Dr. Eng. H. Hoog
Chairman, Energy Research Foundation
ECN
Scheveningseweg 112
The Hague, THE NETHERLANDS

Dr. M. C. B. Hotz
Science Administrator
North Atlantic Treaty Organization
Scientific Affairs Division, NATO
1110 Brussels, BELGIUM

Mr. F. J. Homan
Project Manager
Oak Ridge National Lab.
P.O. Box X
Oak Ridge, TENNESSEE 37830

Mr. Barry J. Hornabrook
South African Consultant General
425 Park Avenue
New York, NEW YORK 10022

Mr. Thomas E. Howard
Director of Technical Development
JOY Manufacturing Company
P.O. Box 39J
Denver, Colorado 80239

Mr. Wuu-Liang Huang
Associate Research Fellow
Institute of Earth Sciences
Academia Sinica, Nankang
Taipei, TAIWAN, ROC

Dr. Franklin P. Huddle
Senior Specialist
Science and Technology
Congressional Research Service
Library of Congress
Washington, DC 20540

Dr. R. A. Huggins
Department of Materials Science and Engineering
Stanford University
Stanford, CALIFORNIA 94305

Dr. Gunnary M. Idorn
(Private Consultant)
Tovesvej 14 B, DK -2850
Noerum, DENMARK

Dr. Bernard R. Ilschner
University of Erlangen
Martensstr. 5
D8520 Erlangen
Fed. Rep. GERMANY

Mr. William Jackson
U.S. Department of Energy
20 Massachusetts Ave., N.W.
Washington, DC 20545

Dr. R. I. Jaffee
Technical Manager
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CALIFORNIA 94304

Mr. Thomas J. Jones
Physical Scientist
U.S. Bureau of Mines
2401 E Street, N.W.
Washington, DC

Mr. William J. Kaestner
Program Manager
Department of Commerce
14th & Constitution Ave., N.W.
Washington, DC 20795

Dr. Roland Kammel
Institut für Metallurgie
Metallhuttenkunde
FB 17 Werkstoffwissenschaften
Technische Universität Berlin
1 Berlin 12, Strasse des 17. Juni 135
GERMANY

Mr. Dieter G. Kamphausen
Deutsches Institut fuer
Wirtschafts Forschung
Koenigin Luise Strasse #5
Berlin, GERMANY

Dr. Bernard H. Kear
Senior Consulting Scientist
United Technologies Research Center
Silver Lane
Manchester, CONNECTICUT

Dr. Anthony Kelly, F.R.S.
Vice Chancellor
University of Surrey
Guildford Gu 2 5XH, ENGLAND

Professor P. G. Kihlstedt
Royal Institute of Technology
Stockholm
Molinvagen 13
S-16155 Bromma, SWEDEN

Mr. R. C. Kirby
Assistant Director for Metallurgy
Bureau of Mines
U.S. Department of the Interior
2401 E Street, N.W.
Washington, DC 20241

Mr. Peter Koch
Chief Wood Scientist
U.S. Forest Service
615 Kindall Avenue
Alexandria, LOUISIANA

Professor Per Kofstad
Department of Chemistry
University of Oslo
P.B. 1033, Blindern
Oslo 3, NORWAY

Dr. Eugene G. Kovach
U.S. Department of State
Washington, DC 20520

Professor Pieter C. Kreijger
Eindhoven University of Technology
P.O. Box 513
Eindhoven, THE NETHERLANDS

Dr. Gyorgy Koranyi
Ministry for Heavy Industry
Budapest, HUNGARY

Mr. Walter L. Lachman
Chairman of the Board
Fiber Materials, Inc.
Biddeford Industrial Park
Biddeford, MAINE

Mr. W. J. Lackley
Group Leader
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TENNESSEE

Dr. Rune Lagneborg
Director
Swedish Institute for Metal
Research
Drottning Kristinas Vag 48
Stockholm, SWEDEN

Dr. Helmut Lange
Science and Technology Attache
Embassy of the German
Democratic Republic
1717 Massachusetts Ave., N.W.
Washington, DC

Mr. Hans H. Landsberg
Director
Center for Energy Policy Research
Resources for the Future
1755 Massachusetts Ave., N.W.
Washington, DC

Professor Giuseppe Lanzavecchia
Montedison
Largo Donegani 7-3
Milano, ITALY

Mr. R. G. W. Laughlin
Assistant Director
Ontario Research Foundation
Mississauga Ontario, CANADA

Professor Erkki A. Laurila
Academy of Finland
Tarkkinen 58
06100 Porvoo, FINLAND

Professor Frederick V. Lawrence, Jr.
Professor of Civil Engineering
and Metallurgy
Coordination of Materials Engineering
University of Illinois
2129 CEB
Urbana, ILLINOIS 61801

Mr. Frank H. Laxar
Assistant to the Manager,
Product Research
Bethlehem Steel Corp.
Homer Research Laboratories
Bethlehem, PENNSYLVANIA 18016

Mr. W. B. Ledbetter
Research Engineer
Texas Transportation Institute
Texas A&M University
College Station, TEXAS

Mr. Martin H. Leipold
Member Technical Staff
Jet Propulsion Lab
4800 Oak Grove Drive
Pasadena, CALIFORNIA

Mr. R. D. Leonard
MZ67-2502
Chief of Plant Engineering
General Dynamics Conair Division
P.O. Box 80877
San Diego, CALIFORNIA

Professor Wassily Leontief
Institute for Economic Analysis
251 Mercer Street
New York, NEW YORK 10012

Mr. Joseph E. Lester
Research Chemist
Gulf Research and
Development Company
P.O. Drawer 2038
Pittsburgh, PENNSYLVANIA 15230

Dr. Jacques Levy
Directeur-Adjoint - Directeur des
Recherches
Ecole Nationale Superieure
Des Mines de Paris
60, Blvd. Saint-Michel
75272-Paris Cedex 06
Paris, FRANCE

Mr. Armand F. Lewis
Senior Materials Scientist
Lord Corporation
2000 W. Grandview Blvd.
Erie, PENNSYLVANIA

Mr. Kenneth W. Llynarski
Bureau of Mines
3009 Hallmark Drive
Gambrills, MARYLAND

Dr. Victor M. Lozano
Advisor to the Director
General
National Council for
Science and Technology
(CONACYT)
Avenida Insurjentes Sur. 1677
Mexico 20 D.F., MEXICO

Dr. Peter E. Love
Representing the Commission of the
European Communities
Brookhaven National Laboratory
Long Island, NEW YORK 11973

Mr. R. A. Lula
Assistant to the Vice President
Metals Technology
Allegheny Ludlum Steel Corp.
Research Center
Brackenridge, PENNSYLVANIA 15014

Dr. M. P. Makowski
Director, Materials Research
Gould Laboratories, Gould Inc.
540 East 105 Street
Cleveland, OHIO 44108

Mihkel M. Mathiesen
Assistant to the Scientific Counselor
Swedish Embassy
600 New Hampshire Avenue, N.W.
Washington, DC 20037

Dr. Carlos A. Martinez-Vidal, Chief
Technological Development Unit
Department of Scientific Affairs
Organization of American States
Room 1140, 1735 Eye St., N.W.
Washington, DC

Mr. Orlando Martino
Latin American Specialist
U.S. Bureau of Mines
International Data
2401 E Street, N.W.
Washington, DC 20241

Mr. Larry W. Masters
Leader, Building Materials Group
National Bureau of Standards
Building Technology
Washington, DC 20234

Mr. James J. Mattice
Director, AF Manufacturing
Technology Program
Air Force Materials Laboratory
Wright-Patterson Air
Force Base, OHIO

Dr. George Mayer
Director, Metallurgy & Materials
Science Division
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

Dr. Rayner Michael Mayer
University of Cambridge
Cavendish Laboratory
Madingley Road
Cambridge CB30HE, ENGLAND

Professor Hugh J. McQueen
Mechanical Engineering
Concordia University
1455 Blvd. de Maisoneuve W.
Montreal, Quebec, CANADA

Dr. Werner Menden
Science Counselor
Embassy of the Federal
Republic of Germany
4645 Reservoir Road
Washington, DC 20007

Professor Abraham Metzer
Deputy Managing Director-Research
IMI-Institute for R&D
P.O. Box 313
Haifa, ISRAEL

Mr. Cesar A. Rodriquez Milla
Universidad Nacional Autonoma
De Honduras
Universidad Norte BCG Tequcigalpa
Honduras
Tequcigalpa, HONDURAS

Miss Eliane Morin
Scientific Attache
French Embassy
2011 Eye Street, N.W.
Washington, DC 20006

Mr. Robert Morris
Industrial Specialist
Naval Air Systems Command
3238 Regent Street
Kettering, OHIO

David E. Morse
Physical Scientist
U.S. Department of Interior/BuMines
2401 E Street, N.W.
Washington, DC

Mr. Lotfollah Namai
Special Assistant for
International Activities
U.S. Bureau of Mines
2401 E Street, N.W.
Washington, DC

Mr. Leander A. Neumeier
Supervisory Metallurgist
U.S. Bureau of Mines
P.O. Box 280
Rolla, MISSOURI 65401

Mr. Ivan Edgar Newnham
Director, Institute of Earth
Resources
Commonwealth Scientific & Industrial
Research Organization
9, Queens Road
Melbourne, Victoria, AUSTRALIA

Mr. Christopher M. Niemczewski
Economist
Centaur Associates
Suite 465
1120 Connecticut Ave., N.W.
Washington, DC 20036

Mr. Robert Norman Norris
Industrial Development Officer
UNIDO
Lerchenfelderstrasse 1
A-1070 Vienna, AUSTRIA

Mr. Bryan R. Noton
Manager, Design/Manufacturing
Interaction Project Office
Battelle Columbus Laboratories
505 King Avenue
Columbus, OHIO 43201

Mr. I.C.G. Ogle
Assistant Director
Utilization and Materials Energy
Research Program
Canada Center for Materials and
Energy Technology
Department of Energy, Mines and
Resources
555 Booth Street
Ottawa KIA OG1, CANADA

Mr. Thomas E. O'Hare
Consultant
Brookhaven Labs
11 Geiger Place
Upton, NEW YORK 11973

Professor Povl Lebeck Olgaard
Technical University of Denmark
Building 322, DTH
2800 Lyngby, DENMARK

Dr. Meliton U. Ordillas, Jr.
Chairman, Division of Engineering
and Industrial Research
National Research Council of the
Philippines
Bicutan, Taguig, Metro Manila
Metro Manila, PHILIPPINES

Professor Gustaf Ostberg
Lund Institute of Technology
Box 725
220 07 Lund, SWEDEN

Mr. J. K. R. Page
Senior Research Manager
Fulmer Research Inst. Ltd.
Hollybush Hill, Stoke Poges
Slough SL2 4QD, Berks, ENGLAND

Mr. Raoul Pagin
Supervisory Industrial Specialist
Naval Weapons Engineering
Support Activity
Washington Navy Yard
11th and M Streets, S.E.
Washington, DC 20374

Dr. Elio Passaglia
Deputy Director
Center for Materials Science
National Bureau of Standards
Washington, DC 20234

Mr. P. Patrich
Union Carbide
Oak Ridge, TENNESSEE

Mr. William H. Payne
Chief, Engineering & Materials Branch
Smithsonian Science Information
Exchange, Suite 300
1730 M Street, N.W.
Washington, DC 20036

Mr. Roger A. Perkins
Consulting Scientist
Lockheed Palo Alto Research Lab.
0/52-31, B/204
3251 Hanover Street
Palo Alto, CALIFORNIA 94304

Dr. D. Pooley
United Kindgom Atomic Energy
Authority
Harwell, Didcot
Oxfordshire OX110RA, ENGLAND

Dr. William R. Prindle
Executive Director
National Materials Advisory Board
National Research Council
National Academy of Sciences
2101 Constitution Ave., N.W.
Washington, DC 20418

Dr. Nathan E. Promisel
Vice-Chairman
Consultant
12519 Davan Drive
Silver Spring, MARYLAND 20904

Professor Robert N. Pryor
Royal School of Mines
Imperial College
University of London
London, S.W.F., ENGLAND

Dr. S. Victor Radcliffe
Senior Fellow
Resources for the Future
1755 Massachusetts Ave., N.W.
Washington, DC 20036

Dr. I. H. Abdel Rahman
Institute of National Planning
Salah Salem Street
Nasr City - Cairo
EGYPT

Mr. R. Rajaram
M.N. Dastur & Company (P) Ltd.
Consulting Engineers
P-17 Mission Row Extension
Calcutta 700 0133, INDIA

Mr. Carl Rampacek
Director
University of Alabama Mineral
Resources Institute and Mining and
Mineral Resources Research Institute
P.O. Box AY
University, ALABAMA

Dr. Baruch Raz
Director
Center for Technological
Forecasting
Ramat University
Tel Aviv, ISRAEL

Dr. Robert R. Reeber
Program Manager
Department of Energy
20 Massachusetts Ave., N.W.
Washington, DC 20545

Mr. & Mrs. Jorge Richards
Director
Centro de Investigacion de
Materials
UNAM
Mecico 20 D.F., MEXICO

The Lord Ritchie-Calder
House of Lords
1 Randolph Place
Edinburgh, SCOTLAND

Mr. M. A. Flores Rodas
Assistant Director General
Head of Forestry Dept.
Food and Agriculture Organization
of the United Nations
Via delle Terme de Caracalla
00100 - Rome, ITALY

Mr. Maurice Rifkin
Division Staff
The MITRE Corp.
Metrek Division
1820 Dolley Madison Blvd.
McLean, VIRGINIA 22102

Mr. Gregory J. Rosasco
Program Analyst
National Bureau of Standards
Administration A1002
Washington, DC 20234

Mr. Rutger A. Roseen
Studsvik Energiteknik AB
S-611 82 Nykoping, SWEDEN

Ms. Pamela Rowley
Staff Assistant to Professor
Anne Carter
Harvard Institute for
International Development
61 Garfield Street
Cambridge, MASSACHUSETTS 02138

Dr. M. Salamon
Director General of
Research Organization
Chamber of Mines
of South Africa
P.O. Box 809
Johannesburg, 2000
SOUTH AFRICA

Dr. Domingo Salita
Chairman
National Research Council of
the Philippines
Bicutan, Tagig
Metro Manila, PHILIPPINES

Dr. T.R. Santelli
Vice President
Owens Illinois
P.O. Box 1035
Toledo, OHIO 43666

Mr. Z. P. Saperstein
Director of Research
Modine Manufacturing Co.
1500 Dekoven Avenue
Racine, WISCONSIN

Dr. Kyosti Sarkanen
College of Forest Resources
The University of Washington
5744 30th St., N.E.
Seattle, WASHINGTON 98195

Ms. Nancy Schalk
International Economist
Department of State
Washington, DC

Dr. h.c. Erich Schmid
II Physikalisches Institut der
Universität Wien
A-1090 Wien
Strudlhofgasse 4, AUSTRIA

Mr. Murray A. Schwartz
Staff Ceramic Engineer
U.S. Department of the Interior
Bureau of Mines
2401 E Street, N.W.
Washington, DC 20241

Mr. Aly Shabaik
University of California
Los Angeles
6531 B.H. Engineering
Los Angeles, CALIFORNIA 90024

Dr. Robert S. Shane
Principal Consultant
Shane Associates, Inc.
7821 Carrleigh Parkway
Springfield, VIRGINIA 22152

Mr. Donald W. Shannon
Battelle Northwest
Richland, WASHINGTON

Dr. Stanley Shapiro
Director, Research & Development
Center
Revere Copper and Brass Inc.
P.O. Box 151
Rome, NEW YORK 13440

Mr. Chester T. Sims
Manager, Advanced Materials Programs
Gas Turbine Division
General Electric Company
Schenectady, NEW YORK 12345

Shamsher Singh
Chief, Commodities Division
World Bank
Room K3000
1818 H Street, N.W.
Washington, DC 20433

Mr. Richard Smith
Program Manager
Nuclear Systems and
Materials Department
Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CALIFORNIA 94303

Mr. G. Sorell
Engineering Associate
Exxon Research & Engineering Co.
P.O. Box 101
Florham Park, NEW JERSEY 07932

Dr. Richard M. Spriggs
Vice President and Professor
Lehigh University
Alumni Memorial Bldg. 27
Bethlehem, PENNSYLVANIA 18015

Dr. Morris A. Steinberg
Director, Technology Applications
Lockheed Corporation
P.O. Box 551
Burbank, CALIFORNIA 91520

Mr. Bruce Steiner
Special Assistant Director
Center Materials Science
National Bureau of Standards
Washington, DC 20234

Mr. J. H. Stil
Shell International Petroleum
Carel van Bylandtlaan 23
The Hague, HOLLAND

Mr. Robert N. Stone
Research Project Leader
U.S. Forest Products Lab.
P.O. Box 5130
Madison, WISCONSIN 53705

Mr. John Stringer
Project Manager
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CALIFORNIA 94304

Professor E.C. Subbarao
Professor of Metallurgical Engn.
Indian Institute of Technology
I.I.T. P.O.
Kanpur 208016, INDIA

Professor Nam P. Suh
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MASSACHUSETTS 02139

Mr. Pei Sung
Materials Engineer
Bureau of Medical Device
8757 Georgia Avenue
Silver Spring, MARYLAND 20910

Hiroshige Suzuki
Director of Engineering
Tokyo Institute of Technology
2-Ookayama 12-1, Meguro-ku
Tokyo, JAPAN

Mr. William L. Swager
Manager, Mining and Materials Economics Programs
Battelle-Columbus
505 King Avenue
Columbus, OHIO 43201

Dr. Hakan Swahn
Studsvik Energiternik AB
Studsvik
S-61182 Nykoping, SWEDEN

Dr. & Mrs. W. J. McG. Tegart
Member of Executive
Commonwealth Scientific and Industrial Research Organization
Limestone Avenue
Canberra, AUSTRALIA

Dr. Kiyohide Terai
Visiting Professor
Massachusetts Institute of Technology
Room 5-223, Department of
Ocean Engineering
77 Massachusetts Avenue
Cambridge, MASSACHUSETTS 02139

Dr. Thomas E. Tietz
Manager, Metallurgy & Composites Lab.
Lockheed Palo Alto Research Lab.
3251 Hanover Street
Oran. 52-31, Bldg. 204
Palo Alto, CALIFORNIA 94022

Dr. Diego Tinaut
C.S.I.C.
Serrano 121
Madrid 6, SPAIN

Mr. Nils Chr. Tommeraas
Vice President
R&D Corporation Automotive Parts
P.O. Box 2475, Solli
Drammensun 40
Oslo 2, NORWAY

Dr. Gabriel Torres-Villasenor
Centro de Investigacion de Materiales
Apdo P. 70-360
Universidad de Mexico
MEXICO 20, D.F.

Mr. Toshiharu Uchida
General Manager
Environmental Control Department
Nippon Steel Corporation
6-3, Otemachi 2-chrome, Chiyoda-ku
Tokyo, JAPAN

Mr. Werner P. Uhl
Resident Executive Product Development
MAN Corporation
6905 Hutchison Street
Falls Church, VIRGINIA 22043

Mr. P. van Leeuven
Vice President
Oremco, Inc.
261 Madison Ave.
New York, NEW YORK

Mr. Francis Ver Snyder
Manager of Materials Technology
United Technologies Research Center
East Hartford, CONNECTICUT 06108

Professor William A. Vogely
Professor-Mineral Economics
Penn State University
220 Walker Building
University Park, PENNSYLVANIA 16802

Dr. John B. Wachtman, Jr.
Director, Center for Materials Science
National Bureau of Standards
Washington, DC

Dr. Salomon Wald
Principal Administrator
Organization for Economic
Co-Operation & Development (OECD)
2, rue Andre-Pascal
75775 Paris CEDEX 16, FRANCE

Mr. Kung-Lee Wang
Chief, Quantitative Economics
U.S. Bureau of Mines
2401 E Street, N.W., Rm. 833
Washington, DC 20241

Mr. K. P. Wang
Supervisory Physical Scientist
U.S. Bureau of Mines
2401 E Street, N.W.
Washington, DC 20241

Mr. Volker Weiss
Vice President for Research & Graduate Affairs
Syracuse University
304 Administration Building
Syracuse, NEW YORK

Mr. Michael Weisz
Department de Technologie
Service de Recherches
Metallurgiques Appliquees
Centre d'Etudes Nucleaires de Saclay
FRANCE

Dr. James H. Whitten
Counsellor (Scientific)
Embassy of Australia
1601 Massachusetts Ave., N.W.
Washington, DC 20036

Mr. Benjamin A. Wilcox
Program Director
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

Mr. Richard C. Wiley
Head, Metallurgical & Welding
Engineering Department
California Polytechnic State University
San Luis Obispo, CALIFORNIA 93407

Mr. Mark A. Wilkins
First Secretary-Technology
British Embassy
3100 Massachusetts Ave., N.W.
Washington, DC 20008

Dr. F. J. Wobber
Senior Scientist - Materials Group
Office of Technology Assessment
14 Goshen Court
Gaithersburg, MARYLAND 20760

Mr. Ronnie D. Woody
International Economist
Office of International Commodities
Department of State
Washington, DC 20520

Mr. Katsuo Yamasaki
Manager, Special Projects
Nippon Steel USA, Inc.
345 Park Avenue
New York, NEW YORK 10022

Dr. Vladimir Yackovlev
Secretario Ejecutivo, FONINVES
Apartavo 52042
Caracas 105, VENEZUELA

Mr. David W. Yarbrough
Associate Dean of Engineering
for Research
Tennessee Technological University
College of Engineering
Cookeville, TENNESSEE

Dr. Robert L. Youngs
Director
Forest Products Laboratory
P.O. Box 5130
Madison, WISCONSIN 53705

Professor Iraj Zandi
University of Pennsylvania
Philadelphia, PENNSYLVANIA

Professor Bruce Zobel
North Carolina State
University
School of Forestry
Raleigh, NORTH CAROLINA

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