OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

15915 1986

MATERIALS SCIENCE AND TECHNOLOGY INSTITUTIONS FOR DEVELOPING COUNTRIES

by

Pradeep Rohatgi

SUMMARY

In this paper current and future objectives and structure of materials science and technology institutions have been presented; the links of these institutions with industry, their role in policy formulation, assessment, use of local materials and development of new materials are discussed and experiences of USA and India are compared. The concept of materials cycle is represented along with the likely future directions of developments in materials science.

Materials science and technology institutions evolving through titles of applied chemistry, geology, mining, metallurgy, ceramics have made major contributions to materials industry in developed and some advanced developing countries like India. The newly acquired capabilities of tailoring materials at will, should now be applied through Regional, National, International and industry linked institutions and interdisciplinary centers, which have proven effective, to develop materials from abundant, renewable and local resources to meet the basic human needs like food, water, housing and health. Specific directions of materials research should be based on quantitative and normative forecasting and assessment done by Materials Advisory Boards and Commissions, giving due emphasis to materials processing and manufacturing, in addition to materials science. International cooperation in the form of International Institutes of Materials Research, International Materials advisory Boards, Federations of Materials Societies selective involvement of materials manufacturing

320E/2997E

159

multinational, exchange of information including access to data tapes and videotapes, and personnel will go a long way in developing capability for modern materials and alleviating lack of materials as a constraint in development.

TABLE OF CONTENTS

I. INTRODUCTION TO MATERIALS SCIENCE AND TECHNOLOGY

Materials Science and Technology is a recently emerging multidisciplinary activity concerned with the generation and application of knowledge relating the composition, structure and processing of materials to their properties and uses. The total materials cycle which comes under the broader definition of extraction, use and recycling of materials is shown in Figure 1 and the philosophy of research in materials science and technology is shown in Figure 2. Tables 1 through 4 list some of the emerging new materials, markets and problem areas, giving the range of the materials field. Even in developing countries the activity in materials is age old starting from the use of agricultural materials, stone, bronzes, iron and steel, clays and ceramics. It is only in the last twenty years that the bodies of knowledge related to individual materials, namely metallurgy, ceramics, glasses and plastics are merging together in a homogeneous body of knowledge on properties of condensed matter, termed materials science and technology; and the interdisciplinarity of this field will continue to grow in the future. This field covers materials from natural fibers, wood, metals, ceramics and glass to biomaterials, electronic and optical materials, and also the structural elements on the order of a few angstroms to large mile long structures. The materials field is poised for exciting developments similar to what happened in Physics, Energy and Biological Science sometime back. The abundant supply of materials, and the services produced using materials such as food housing and energy, could go a long way in reducing human misery in the developing world. Materials rank with energy and information as a basic resource of mankind, and their equitable and abundant availability at low costs can eliminate international conflicts, cultural conflicts and dehumanizing poverty, especially in the developing world reflected in terms of lack of food, water, housing and health care. For developing countries the linkage between materials and the basic human needs such as food, housing health care, energy availability are more important than the linkage between materials and weapon systems (1-15) and secondary needs. This is why a complimentary view of materials from the developing country perspective is necessary (16-34). In addition to this new view of materials from a total developing world, complimentary views on materials for each nation, and region and each locality are required. The materials field is undergoing a revolution with the emergence of tailor made structures. The developing world should not miss these opportunities to overcome their lack of materials availability. Modern materials science has made possible miniaturization of electronic circuits and enhancement in properties which were heretofore never possible. It is high time that the new knowledge of materials synthesis is applied to solve the problems of food, housing, healthcare, drinking water, energy and associated needs of light and warmth, communication and transport in the developing world. In the words of Professor Cohen, "we are creatures of material. Materials are required to maintain our environment, our food, shelter, transportation, entertainment, recreation... . To belabor the obvious, we may live our lives or fight for metaphysical causes or principals but in the end, we live our lives within a physical-material environment. We tend to guage the metaphysical quality of our lives by the aesthetics and the abundance of our physical and material environment raising the standards of living and reducing deprivations and misery."

II. OBJECTIVES AND GOALS OF MATERIALS SCIENCE AND TECHNOLOGY INSTITUTIONS IN DEVELOPING COUNTRIES:

It is becoming quite apparent that the standard of living in any country is strongly dependent on the availability of materials per capita. The relationship between per capita consumption of major materials like steel and aluminum with per capita GDP has been shown to be linear (35). The per capita demand of materials in developing countries (35). which is very low compared to that in developed countries, is going to increase very rapidly as the standards of living of the large and growing masses of developing world. This is going to bring enormous pressure on the resources for materials as well as environmental problems related to increased exploitation and use of materials; under certain conditions these issues can lead to international conflicts which must be avoided at all costs.

In view of these, the objectives and goals of the materials science and technology institutions in developing countries could be:

a. To engage in research, development and production related to materials to ensure adequate supplies of materials at lowest possible price compatible with other national goals such as security, clean environment and resource conservation.

b. To ensure that the increasing use of materials does not lead to undue pressure on resources for materials and degradation of environment. To attempt to synthesize most materials from the most abundant elements of Earth's crust (Table 5).

c. In the context of developing countries, greater emphasis should be placed on materials related to the more basic of human needs for instance food, water, housing, health care and energy. Normative exercises are needed to derive challenges for modern materials science from these human needs, attempting to meet these needs as far as possible through local resources, local skills and local infrastructure.

d. To maintain standards for materials which are compatible with international standards, and the capability to test locally produced and imported materials.

e. In the context of developing countries, greater emphasis should be placed on materials which can be produced from local resources, specially those which are renewable and abundant, to meet local needs while generating maximum local employment.

f. To train interdisciplinary manpower in Materials science and technology to cater to the emerging needs of the research, development, standardization, testing and production institutions, with special grounding in material problems related to local resources, local needs and local infrastructure.

g. To evolve a national materials policy based on technology forecasting and assessment, to develop a coherent long term strategy for materials, and capability to participate in the evolution of international materials policy. The materials policy could deal with issues of imports and exports of raw materials or finished materials, stockpiling, materials substitution, international trade, research, development, production, distribution, pricing, conservation and recycling of materials. In addition to national materials policy, the objectives should include development of regional and local materials policies to compliment the national and international imperatives in view of regional and local resources and needs.

h. To participate in international research and development efforts, to tackle common problems of resources, standards, environments, materials and legislation dealing with materials, to help develop international materials policy, and international federation of professional societies concerned with materials within the country and worldwide. To set up mechanisms for international exchange of information, experts and technology.

III. LINKS OF INSTITUTIONS OF MATERIALS SCIENCE AND TECHNOLOGY TO INDUSTRY AND THEIR INFLUENCE ON GOVERNMENTS:

It is imperative that the institutions of materials science and technology have links with the industry and the government to influence National Materials Policy through following mechanisms:

1. Institutions of Materials Science and Technology within the industry should be encouraged since they can build bridges much easier with institutions outside the industry.

2. Arrangements for consultancy, sponsored research work, subcontracting, joint appointments, exchange of materials personnel between industry, government and academia should be encouraged.

3. Arrangements should be made to encourage consortiums of industries in a given field to collectively sponsor research in academic institutions and government laboratories.

4. The materials people in industry and academics should help in the formation of National Materials Advisory Boards and other materials policy bodies and serve on these bodies charged with formulating and implementing policies.

5. Academic institutions should offer customized seminars and short courses for personnel in the industry and the government, in addition to teaching regular students. External registration of personnel working in industry and government to a higher degree should be encouraged.

6. Subcontracting of work between the industry and university should be encouraged.

IV. TYPICAL STRUCTURES OF MATERIALS INSTITUTIONS IN DEVELOPING COUNTRIES:

The structure of materials institutions in developing countries is very much dependent on the stage of development of the country. Some of the advanced developing countries like India have world class teaching and research institutions for materials whereas some of the starting countries have only teaching in materials related departments. Generally the institutions have evolved along the following patterns:

1. Establishment of organized production of materials for instance, timber, cement, steel and formation of a testings and quality control institution within the factory followed later by a research section. For instance, in India the Tata Iron and Steel Company started production of steel and had a materials research and development wing soon after.

2. Establishment of teaching of geology, mining, metallurgy, ceramics and materials (in that sequence) in existing colleges in materials related departments. After this initial stage, teaching occurred in departments or even colleges designated by these names. For instance initially teaching of geology followed by mining and metallurgy started in chemistry departments, and this was followed by departments or even colleges of mining, metallurgy, ceramics and recently materials. Degrees in materials science have been offered only very recently in the most advanced of developing countries like India, China and Korea.

3. Some of the materials related departments located in a suitable research environment gradually took on research activity in materials. While some developing countries like India, Korea and China recently, have developed undergraduate teaching comparable to some of the best in the

world, the level of graduate education and postgraduate research in general, is not comparable to the west with a few exceptions.

4. Establishment of government sponsored research, development and testing laboratories related to major materials for instance laboratories related to building materials, cement, jute, metals, ceramics, glass polymers. Some materials related work was also started in government sponsored laboratories established for research in physics, chemistry, aeronautics.

5. Formation of government sponsored institutions of standards and quality control related to materials production.

6. Formation of materials institutions sponsored by associations of industries for instance the Textile Research Institutions in India.

7. Formation of working groups dealings with specific materials in the ministries of the government. For instance Ministries of Mines and Steel in India had groups monitoring and making policies in aluminum and steel. In several countries, including India, the ministerial groups including planning commission make policies related to materials through committees often involving experts from academia, research laboratories and industries.

8. Establishment of regional research laboratories by the government to exploit local resources for local needs. These laboratories have been sometimes very effective in developing new materials using local resources.

V. ROLE OF MATERIALS INSTITUTIONS IN TECHNOLOGY ASSESSMENT, UTILIZATION OF LOCAL MATERIALS, DEVELOPMENT OF NEW MATERIALS, TESTING AND QUALITY CONTROL:

The materials science and technology institutions in developing countries have been involved in technology assessment, utilization of local materials, development of new materials, testing and quality control to varying degrees depending upon the degree of development. In most of the countries the institutions have been reasonably successful in testing and quality control, and to a lesser extent in utilization of local materials. Development of new materials have been few and far between, and technology assessment has been indirectly used while giving licenses for manufacture and import.

These institutions in developing countries must build a capacity first and foremost to do technology assessment to determine which current and future materials technologies are most relevant. They should determine the optimum directions for research, development and production of materials to provide maximum benefits to people in fulfilling basic needs using quantitative technique of technology assessment with local imperatives and impacts in view. The cost of such assessments is quite low compared to the damages due to the wrong directions taken due to adhoc judgements in the absence of technology assessments. The expertise to do technology assessments with local view point can be assembled reasonably easily, and can be supplemented from outside the country. The assessment should not be left to experts in other countries alone who may not do a comprehensive job of assessment from the developing country viewpoint. In fact the lack of such assessments are one of the major reasons that while it has been possible to reproduce research or production in materials done in developed countries after some lag periods in developing countries, frequent development of new materials using local resources for local needs has not taken place. This situation needs to be rectified through objective technology assessment if the materials scientists and technologists are to solve the problems of food, housing, health and energy in the developing world.

The institutions of materials science have played an important role in the utilization of local materials including local minerals, coals, clays, woods and forest products. This is a role that should be intensified in the future, and attempts must be made to apply most modern materials science to local materials to make products developed elsewhere, since this knowhow is not going to be easily available from other countries. The international institutions and corporations have helped in this effort and can be expected to do so in the future.

As mentioned earlier, the development of new materials has been less than adequate by developing country institutions. Some of the reasons include; preoccupation with reproducing what has been done in developed countries, a lack of creativity, a sense of technological colonialism, and lack of initiative in utilizing local resources to meet local needs. If the developing country institutions concentrate on local resources and local needs, as has been done in some national and regional research laboratories, the probability of developing new materials will increase.

As mentioned earlier the most readily feasible role for materials science and technology institutions in developing countries is in testing and quality control. Here testing has been easier but influencing quality improvement has not been readily possible. With growing emphasis on reliability and quality, the modern instrumentation required to test materials is going to be increasingly complex and expensive, and its acquistion, maintenance and continued updating present a challenge to developing countries. It may be necessary to build up the existing infrastructure in teaching and research institutions in terms of national central facilities, for testing of materials.

VI. MATERIALS SCIENCE AND TECHNOLOGY INSTITUTIONS: EXPERIENCE OF INDIA AND USA:

A. India:

In India, early materials science institutions started very much after the British pattern in terms of geological survey, teaching departments of applied chemistry and national test houses. These in time changed to departments and colleges of mining, then to mining and metallurgy, to metallurgy and finally some of the teaching departments are now being named as Materials Science and Engineering following the recent pattern of USA. Materials, in addition to being taught in materials designated departments are also taught in materials related departments like physics, chemistry, mechanical engineering, chemical engineering and civil engineering and aeronautical engineering.

The undergraduate education in metallurgy and materials science at the Indian Institutes of Technology compares with the best in the world. Several universities, regional engineering colleges, and institutes have also started doctoral programs and postdoctoral research programs in the last thirty years. Some of the research programs are quite good, but cannot be compared as a whole with the best in the world as the undergraduate programs. Some of the universities as well as Indian Institutes have started advanced centers in materials science and technology which are quite effective in training students and conducting world class research. The students trained in India have amicably filled the manpower requirements of Indian industry and research institutions; in addition, the students trained in India successfully performed in advanced countries and are reaching to the top of their professions.

In addition to teaching institutions the government established geological survey, Department of Mines and Steel, Forest Research Institute, Jute Research Institute and a series of national and regional research laboratories under the Council of Scientific and Industrial Research including the National Metallurgical Laboratory, Central Glass and Ceramics Research Institute, Regional Research Laboratories at Bhubaneswar, Trivandrum, Bhopal, Jorhet, Jammu and Hyderabad, National Chemical Laboratory and the National Physical Laboratory. The Atomic Energy Commission and the space commissions established very strong materials research and production facilities to meet their materials requirements. More recently the defense research has established Defense Metals Research Laboratory, Defense Materials Laboratory, Solid State Physics Laboratory and several other defense laboratories which do materials related research and development. In addition the, public sector corporations have set up research laboratories like the laboratory of the Steel Authority of India.

In the private sector, one of the first materials laboratories was set up by the Tata Iron and Steel Company. Smaller research laboratories are maintained by other private materials industries like Hindustan Aluminum. However the size and the excellence of private sector laboratories by and large does not compare well with the laboratories in the private sector in developed countries. There is one of the important consequences of import of technology, sellers market and relatively small sizes of industry. There are several industrial associations who have set up sizable laboratories for instance Textile Research Associations and Cement Research Institute which have performed reasonably well but do not compare with similar organizations in the west.

In addition to above, there are several government testing laboratories, standards institutions, departments of industry, ministry of railways which maintain research laboratories in materials.

By and large India has set up an excellent base for undergraduate education, a good base for postgraduate education and research, a few good advanced centers for materials science research, good testing and standards activity and has good infrastructure all over the country for research, development and production. The Indian experience can be very helpful in setting up institutions in other developing countries, and the institutions in India can be the training grounds for materials personnel from other developing countries.

In terms of testing, quality control and utilization of local materials including local minerals, forest products, the materials institutions in India have done quite well. India was one of the first developing countries to do technology forecasting and assessment in materials (16-35), and is considering setting up National Materials Advisory Board. The institutions in India have done research and duplicated production of some of the most modern materials. However the development of new materials has been less than satisfactory. This however will change rapidly as there will be less preoccupation with reproducing advanced materials developed in the west, and greater pride and attention given to developing materials using local raw materials to cater to local basic human needs. Some regional research laboratories have done world class pioneering work in materials science and technology of local materials, for instance developing composites using local natural fibers, forest products and extending the life of local agriculture based materials used for housing.

B. USA:

In USA the teaching and academic research institutions in materials have gone through the cycle of emerging from materials related departments to geology, mining, metallurgy, ceramics, and to materials science and engineering much earlier than India. However, most of the departments of materials science and technology have been so renamed in the last twenty years. The number of teaching and academic research institutions in materials in USA is well over a hundred, and the best ones have very large faculty and several hundred graduate students doing doctoral research. Several of these academic institutions have very large research programs in terms of sponsored research, compared to even the largest laboratories in developing countries. The ties between the academic institutions and industry in terms of consultancy, sponsored research, industrial consortiums, and subcontracting of research and services between industry and university is much better; part of the reason is that the industry is competitive and under pressure from market forces to use the latest developments in materials science and technology. Twenty-eight US universities have materials research centers many of which have been funded as block grants for interdisciplinary activity in materials research and maintaining advanced research equipment. The performance of these materials centers and companies was reviewed recently after twenty-five years of their initiation, and by and large their performance has been very good (10). The model has many useful lessons for setting up materials research institutions in developing countries since several new materials and processes have emerged from these laboratories, the addition to new concepts. A new trend has been to establish materials processing and materials manufacturing centers in the academic and research laboratories in USA which will further increase the coupling with industry.

In addition there are several government laboratories doing materials research including National Bureau of Standards, Argonne National Laboratory, Oakridge, Idaho Falls, Lawrence Livermore Laboratory. The materials research centers in the National Aeronautics and Space Agency and the defense departments are also quite strong and well equipped.

The most unique feature of the US is the presence of materials research institutions in the private industries. This is one of the biggest factors which permits transfer of technology and industrial scale development of technology. Materials research at some of the private industry laboratories like Bell Telepnone, General Electric, Westinghouse, IBM, Owens Corning, DuPont are the best in world in their respective disciplines. A recent survey of the most important breakthroughs in materials has shown that many of them have come from these private sector laboratories (1-4).

In summary, the USA has one of the largest and the best infrastructures for materials research in the world in terms of well developed undergraduate, and graduate teaching and research programs and interdisciplinary materials centers in academic institutions, a few large government laboratories, and most importantly a large number of first rate industrial research laboratories in the private sector. A distribution of the U.S. budget, relating to materials research is given in Table 6.

In addition to the physical infrastructure the USA has mechanisms of assessment to identify the most important areas in materials research. The peer review of research proposals is quite thorough, there is quite a bit of formal and informal forecasting and assessment within and outside the organizations, often using established consulting companies with long-standing record in this area. The National Materials Advisory Board, set up by the National Academy of Science-National Academy of Supervising National Research Council constitutes committees with world class expertise and brings out timely studies on forecasting and assessment of frontier areas in materials. Several of the studies by the National Materials Advisory Board have been very good and have been used in decision making. The four volume studies on "Materials and Mans Needs" by the committee on the survey of materials science and engineering; National Academy of Science (1-4) completed around 1975, is one of the most comprehensive assessments of the materials field. This committee has been reconstructed with Professor M. C. Flemings of M.I.T. as the chairman to update their study from 1986. These studies cover the research imperatives in materials, institutional framework and aspects of materials technology abroad. Recently a review of interdisciplinary materials research centers was completed and the results of this conference when published in 1986 will be very useful (10). A new trend in the U.S. is to establish materials processing and materials manufacturing centers, in addition to materials science centers, and this is of importance to developing countries.

However, despite these efforts the United States government as a whole has no official materials policy as a nation. The 98th congress has authorized the establishment of a national critical materials council. When finally placed into operation by the executive department, this council could be the forum for the evolution of a model materials policy.

At the urging of the materials science and engineering community of the United States, the 98th congress has established the "--National Critical Materials Act of 1983--". In this "Act", congress recognizes that "strategic and critical industrial minerals and materials" are essential for national security, economic well-being, and industrial production.

The Act recognizes the danger to a society that depends too heavily upon sources of materials from politically sensitive regions of the earth. The Act also takes note of the declining industrial capacity in America and the rise of the East and a reasserting Europe.

The Act also states that ...research, development, and technological innovation, especially related to improved materials and new processing technologies, are important factors which affect our long-term capability for economic competitiveness, as well as for adjustment to interruptions in supply of critical minerals and materials. The Act goes on to recognize that ...other nations have developed and implemented specific long-term research and technology programs to develop high-performance materials... and that in the United States, we have no such policy and program.

The Act assuages the national security interest by stating that critical reserves should be a national priority and that the reserve should be well managed.

The stated purposes of the Act are:

I. to authorize the President of the United States to establish a national critical materials council reporting to Executive Office of the President. This executive materials council would have the following tasks:

1. Coordinate a critical materials policy, including all facets of research and technology, among the various agencies and by es-

tablishing responsibilities within the appropriate agencies, to provide for the implementation of such policies.

2. Advise the President, the Congress and the general public on those material concerns, including research and development, which are deemed critical to the economic and strategic health of the nation.

3. Consult with the private sector concerning critical materials, materials research and development, use of materials, and related matters.

II. Establish a national program for advanced materials research and technology, including basic phenomena, through processing and manufacturing technology.

III. Stimulate innovation and technology utilization in basic as well as advanced materials industries.

After more than two years from the passage of the Act, the Executive Department has recently activated the Executive Materials Council.

VII. POSSIBLE INTERNATIONAL COOPERATION IN THE FIELD TO PROMOTE DEVELOPMENT OF MATERIALS SCIENCE AND TECHNOLOGY IN DEVELOPING COUNTRIES:

International cooperation in materials science and technology would go a long way in building capability and increasing materials availability in developing countries. Already international cooperation has resulted in development of materials science and technology in several developing countries including India, China, Korea. A survey should be made of these case studies and recommendations for future collaboration drawn up.

Professor Morris Cohen of MIT indicated that ..."because of the global cradle-to-grave operation now called the materials cycle, we find that the materials enterprise has become a world system which ties people and nations on this planet not only to one another but also to the very substance of nature." Indeed, materials rank with food, energy, and living space as major natural resources of mankind. In his opinion "materials scientists or technologists are in a partnership with nature and it behooves us to guide our sights and our endeavors in ways which will harmonize with nature for the greater good and for the longer term. That perspective can certainly be described as humanistic as well as materialistic in character..."

The following recommendations are made for international cooperation:

a. The developing countries through international bodies, as well as bilateraly, press for greater international cooperation in such matters as setting materials standards, care of environment conservation of resources, materials research of wide varying importance which should be commonly addressed, exchange of materials scientists and engineers and private organizations involved in materials seek more extensive cooperation with their counterparts abroad.

b. The developing countries should seek cooperation from developed as well as sister developing countries to move from the position of mainly raw materials suppliers to more and more value added products and finished products. This may even involve judicious and selective cooperation with multinationals who, with all their drawbacks are able to generate advanced production in developing countries reasonably quickly.

c. The developing countries should request cooperation in evolution of a world materials policy through which a more equitable distribution and availability of materials can be arrived at.

d. A cooperative center of technology forecasting, technology assessment and materials policy should be established in a developing country like India which has the experience in forecasting, assessment, research, development and production of reasonably advanced materials. Such a center should conduct studies related to materials from a developing countries view point and help in building capability to evolve a materials policy in different countries. The center should stimulate education in a materials policy at all levels in all developing countries to sensitize the mind of the young towards the materials policy. This center should examine the materials policy work going on in advanced countries like the USA and UK, and derive information and conclusions relevant to the developing world. It should do normative exercises to derive imperatives to remove the lack of materials as a constraint to development.

e. Cooperation should be sought with developed as well as some relatively advanced developing countries, for setting up interdisciplinary materials science, technology and processing research centers in academic institutions in developing countries, since this model has worked reasonably successfully. However, care should be taken to ensure that the activities of these countries remain strongly responsive to local materials and local needs.

f. Cooperation should be sought for easier exchange of materials scientists and technologists from academic, research and industrial organizations between developed and developing countries, and within developing countries. This is the best mechanism to facilitate transfer of information, knowhow and attitudes.

g. International cooperative research institutes should be set up under the United Nations and other world level bodies to address common problems such as development of materials using the most modern materials science from renewable and abundant resources like biomass, silicon, aluminum, oxygen and iron specifically for basic needs like food, water, housing, health and energy; to increase recycling and prevent degradation of materials; to reduce pollution associated with materials industries; to use renewable resources of energy like solar energy and biomass; to develop standards and testing facilities which can be established even in the least developed countries; to establish national and regional materials research laboratories to respond to local imperatives.

h. Cooperation is required in developing mechanisms for transfer of open information on materials science through international access to computer based data bases, instructing services; exchange of educational video tapes, standards, testing equipment and procedures.

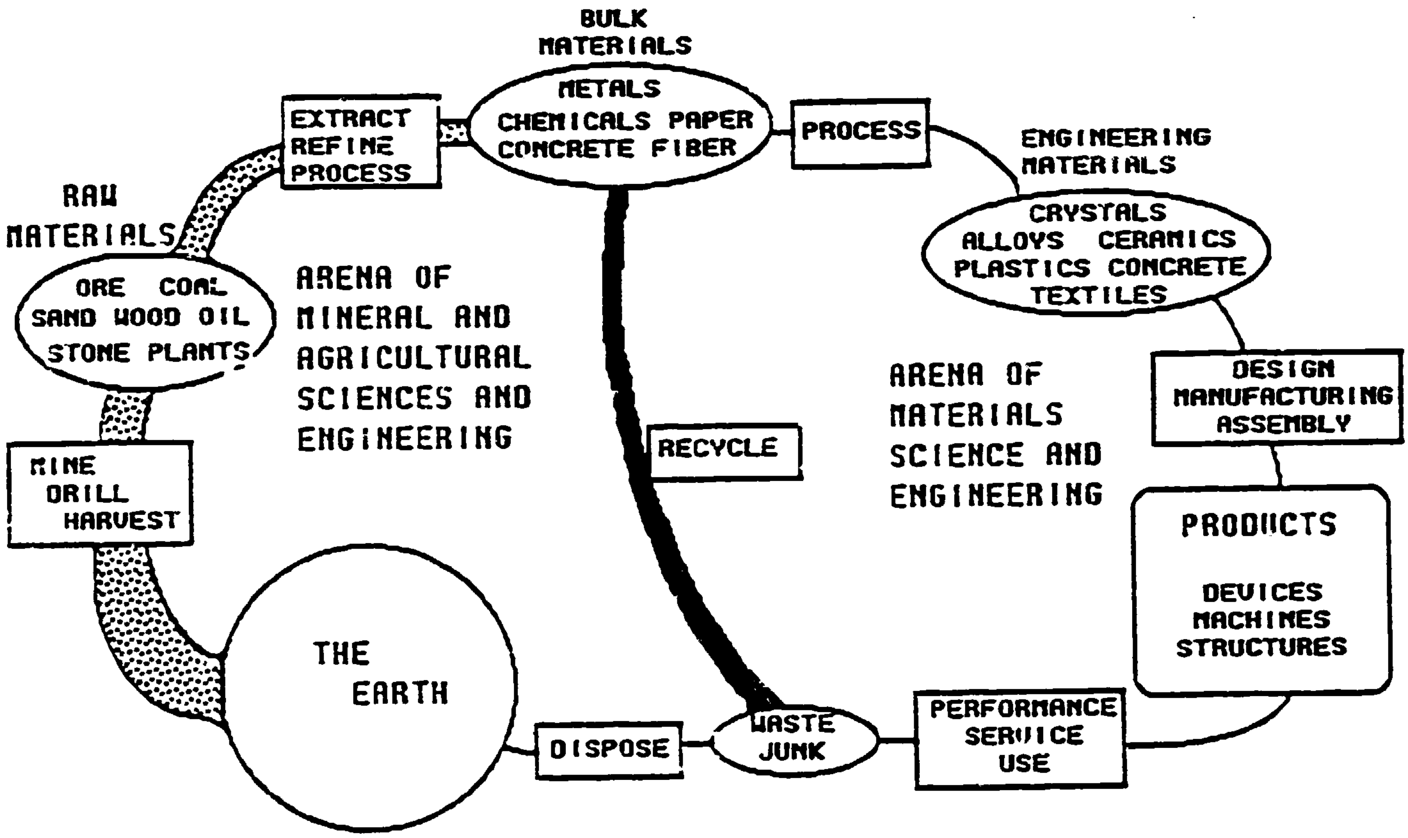

Figure 1. The Total Materials Cycle

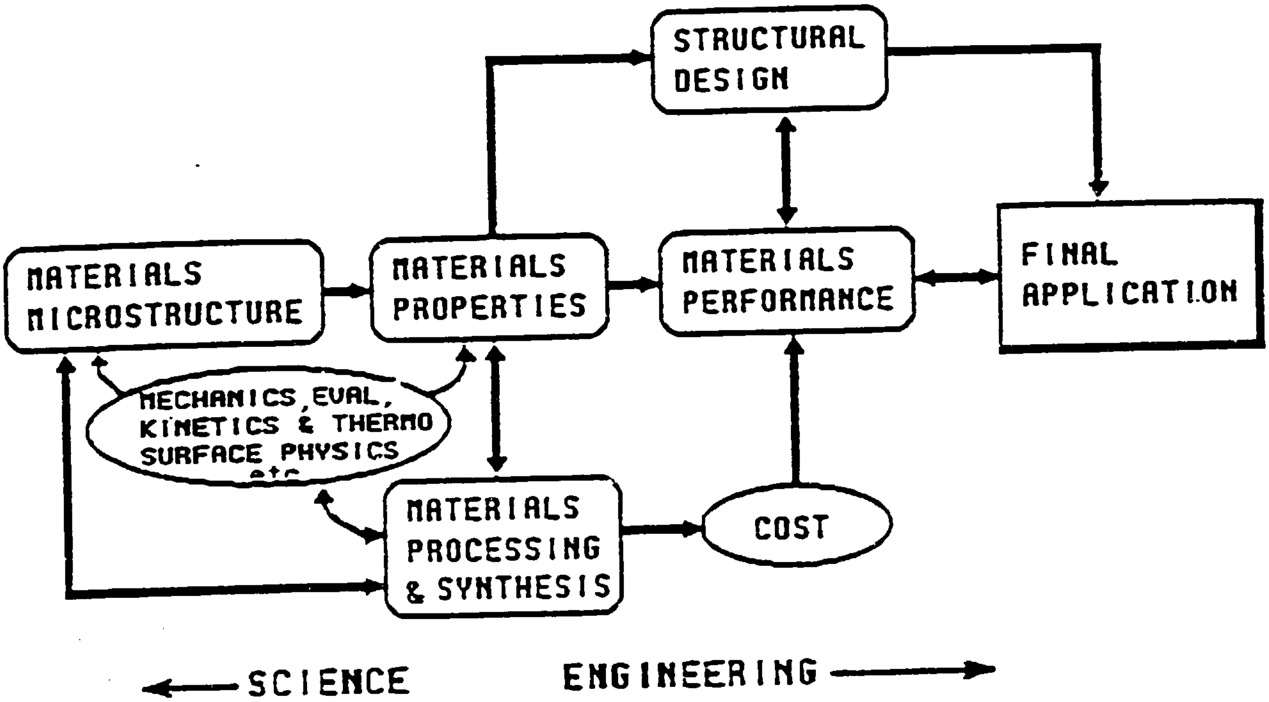

FIGURE 2

PHILOSOPHY OF RESEARCH AND DEVELOPMENT IN MATERIALS SCIENCE AND ENGINEERING

TABLE 1. EXAMPLES OF NEW MATERIALS = TO BE IMPORTANT IN THE FUTURE

- Shape memory alloys
- Coal refuse fibers
- Slag cement
- Metastable and Amorphous materials
- Composite materials (metal matrix, polymer matrix, cermets)
- Intermetallic compounds ordered alloys including aluminides
- Soft/hard magnetic materials
- Superconducting materials
- Structural and superplastic ceramics
- Electronic materials et al. (including ceramics)
- Photovoltaic materials with ultrahigh efficiencies
- Laminates, claddings, surface coatings, surface modification
- High temperature alloys
- Building materials (insulation, cinder blocks, glass)
- Wear materials, hard materials
- High performance materials from renewable resources
- High strength/low density alloys (Al, Ti, etc.)
- High technology cements/concretes
- Conducting polymers
- Glasses
- Low-temperature materials
- Battery materials
- Bio-materials
- Nanostructure materials
- Layered materials

TABLE 2. SOME NEW MATERIALS PROCESSING TECHNOLOGIES

- Molecular beam epitaxy
- Die-casting of high-melting point alloys
- Rapid solidification of bulk components (amorphous sheets to bulk materials, Osprey type spray deposition)
- Superplastic forming
- Plasma melting/spraying/synthesis
- Surface modification (ion implantation, laser, electron beam)
- Coating using melt spraying
- Directional crystal solidification/single crystal growth
- Near net shape processing
- Thin strip casting
- Dynamic powder compacting
- Direct steel making
- Explosive bonding/consolidation
- Laser production of ceramic powders
- Laser glazing
- Sol-gel processing
- Laser machining, electron beam processing
- Water jet machining
- CAD/CAM/Robotized process
- On line sensors with feedback loops to expert systems and artificial intelligence for controls

TABLE 3. EXAMPLE OF MATERIALS APPLICATIONS/MARKETS

- Energy (solar, nuclear, fossil, geothermal, battery, motors, transformers)
- Transportation (of all types)
- Construction (housing, bridges, highways)
- Environmental (chemical waste disposal)
- Agriculture and food processing
- Water (purification systems)
- Medical (implants and healthcare systems)
- Home appliances
- Communications
- Textiles and clothing
- Packaging
- Electronics (computers)
- Automation, robotics
- Shipbuilding
- Aerospace applications
- Mining
- Manufacturing (machine tools, primary metals)
- Catalysts (chemical industry)

TABLE 4. EXAMPLES OF MATERIAL PROBLEM AREAS

- Corrosion
- Wear
- Ductility (hot and cold)
- Formability
- Temperature Resistance
- Toughness
- Joining (welding, etc.)
- Weight Savings (density, modulus)
- Heat Transfer
- Cost (materials, fabrications, life cycle cost)
- Earthquakes
- Pollution (related to processing)
- Producibility
- Availability (strategic materials)
- Appearance (color, surface)
- Optical, Magnetic, Electrical
- Nuclear Waste Disposal
- Garbage (energy conversion, incineration)
- Catalysts
- Weight
- Recyclability

TABLE 5. RELATIVE ABUNDANCE OF ELEMENTS IN THE EARTH'S CRUST

Element	Abundance	Useful Derivative Materials
O	46.6%	Chemicals, ceramics, glasses, resins
Si	27.7	Si, SiO_2, SiC, glasses, resins, ceramics, polymers, silicones, silicates, metcers and cermets
Al	8.1	Al alloys, ceramics, chemicals, metcers and cermets
Fe	5.0	Steel
Ca	3.6	Chemicals, ceramics, glasses
Na	2.8	Chemicals, ceramics, glasses
K	2.6	Chemicals, ceramics, glasses
Mg	2.1	Mg alloys, MgO refractories, ceramics and chemicals
Ti	0.4	Ti alloys, ceramics, glasses, intermetallics, metcers and cermets
C	0.032	Steel, refractory carbides, resins and hydrocarbon chemicals, carbon, graphite, diamond, metcers and cermets

TABLE 6. ITEMS IN THE UNITED STATES BUDGET FOR FISCAL YEAR 1986

DIRECTLY RELATING TO MATERIALS RESEARCH AND DEVELOPMENT

		Millions of Dollars	
Department of Energy			
	Operating, Capital Equipment, Construction	182.9	
	Solar	45.3	
	Fossil Fuel	12.7	
	Energy Conservation		
	Advanced Materials	9.29	
	High Temperature, Materials	3.01	
	Vehicle Propulsion	20.1	
	Multi-Sector Materials	8.8	
	Industrial Process Efficiency and Waste Energy Reduction	11.8	
	Nuclear Energy Materials	63.3	
	Magnetic Fusion Energy Materials	13.5	
	Electrical Energy and Storage	2.9	
	TOTAL		$373.6
National Science Foundation			
	Solid State Physics	12.4	
	Solid State Chemistry	9.1	
	Low Temperature Physics	8.4	
	Condensed Matter Theory	8.9	
	Metallurgy	10.2	
	Ceramics and Electronics	6.8	
	Polymers	7.6	
	Instrumentation	6.6	
	Materials Research Labs	30.0	
	National Facilities	12.0	
	Materials Research Groups	3.7	
	Mechanics, Structures, and Materials	11.0	
	Chemical, Biochemical and Thermal Engineering	3.6	
	Electrical, Communications and Systems Eng'g	7.7	
	Emerging and Critical Engineering Systems	5.6	
	Cross-Disciplinary Research	6.2	
	TOTAL		$149.8

Table 6 (continued)

<u>Department of Commerce</u>		
Materials Science and Engineering	22.6	
Cold Neutron Service	8.0	
TOTAL		$ 30.6
<u>Department of the Interior</u>		
Geological Survey	166.0	
Bureau of Mines, Minerals and Materials Research	24.8	
TOTAL		$190.8
<u>National Aeronautics and Space Administration</u>		
Materials Processing in Space	34.0	
Solid Earth Observations	6.3	
Aeronautics Research and Technology	36.9	
Space Research and Technology	19.3	
TOTAL		$ 96.5
<u>Department of Defense</u> (Basic research only)		
Army	19.3	
Navy	33.2	
Air Force	24.5	
DARPA	20.0	
TOTAL		$ 97.0
GRAND TOTAL		$933.3

<u>Source</u>: "R&D in Materials Science and Engineering"
Federation of Materials Societies
S.V. Margolin (B. Houston, coordinator)

REFERENCES

1. COSMAT Summary Report, National Academy of Sciences (1974) and COSMAT Supplementary Report, National Technical Information Service (1975), USA
   Vol. I: The History, Scope, and Nature of Materials Science and Engineering;
   Vol. II: The Needs, Priorities, and Opportunities for Materials Research;
   Vol. III: The Institutional Framework for Materials Science and Engineering;
   Vol. IV: Materials Technology Abroad

2. M. Cohen, ed., "Materials Science and Engineering, Its Evolution, Practice and Prospects," Materials Science and Engineering, Vol. 37, No. 1 (1979) Elsevier Sequoia S.A.

3. M. Cohen, "Materials and Man's partnership with Nature," Alpha Sigma Mu Lecture, ASM News, July 1979.

4. T. W. Eagar, "Materials Science and Engineering in the United States--Past, Present and Future," Tokyo Management Association Senior Technical Advances in New Materials, July 1985 (Tokyo).

5. "Materials Research Facilities," National Research Council, Commission of Physical Sciences, Mathematics and Resources, 2101 Constitution Avenue, NW, Washington, D.C. 20418 (as reported in Science Vol. 225, p. 704).

6. "Trends and Opportunities in Materials Research," Division of Materials Research, National Science Foundation, Washington, D.C. 20550 (as reported in Journal of Metals, December 1984, p. 53).

7. Congressional Workshop on Advanced Materials Research and Development, Report to the Committee on Science and Technology, U.S. House of Representatives, 1985.

8. Report to Research Brief Panel on Materials, T. H. Geballe, Chairman of Science, Committee on Science, Engineering and Public Policy, National Academy Press (1983).

9. Research Briefings, National Academy Press (1985).

10. United States NAS-NAE Symposium on "Advancing Materials Research," Washington, D.C., October 28-29, 1985.

11. J. B. Wachtman, Jr., "National Materials Policy--Evolution and Prospects," Second Symposium on Industrial Resource Management, Phildelphia, PA, February 17, 1985.

12. The Global 2000 Report to the President: Entering Twenty-First Century, Vol. 1, Council on Environmental Quality and the Department

of State, George O. Barney, Study Director, U.S. Government Printing Office, Washington, D.C., 1980.

13. J. A. Cornie, "Materials Policy in the United States and Advanced Structural Materials—A Global Perspective," Massachusetts Institute of Technology, Cambridge, Mass., USA, Presented to "Ambiente E Risorse," XIII Convegno Nazionale, Bressanove, Itilia, Sede Estivba Universita Di Padova, September 2, 1985.

14. M. C. Flemings, "Materials Science and Engineering—Its Past and its Future," Massachusetts Institute of Technology, Cambridge, Mass., USA, 1985, Presented at Yukawa Memorial Lecture, Iron and Steel Institute of Japan, October 4, 1985.

15. M. C. Flemings and D. R. Sadoway, "Approaches to an Integrated Undergraduate Education in Materials Science and Engineering," Massachusetts Institute of Technology, Cambridge, Mass., USA, Presented to the Symposium on "Frontiers in Materials Education," Materials Research Society, December 3, 1985.

16. A. Lahiri, "Conservation of Mineral Resources in Commerce," (India), Annual Number, 1976.

17. B. Bowonder and P. K. Rohatgi, "Technology Forecasting Social Change," 7 (1975) p. 233.

18. "Objectives and Charter: Use of Technological Forecasting," National Materials Advisory Board, NAS-NAE-NRC, Washington, D.C. 20418, 1972.

19. National materials Advisory Board, NAS-NAE, National Technical Information Service, August 1972.

20. P. K. Rohatgi and B. Bowonder, NML Techn. J., 14 (1972) 141.

21. P. K. Rohatgi and C. Weiss, Technol. Forecast. Soc. Change, 11 (1977) 25.

22. P. K. Rohatgi, B. J. Vyas and B. Bowonder, Indian Fndry. J., 1(2)(1978) 24.

23. Technology Forecast, Surveying 70's Metal Prog., 99(1970) 17, Also January Issue of Metal Progress on Technology Forecast 1973-1986.

24. A. Wittmeser, K. Stainack and R. Hofmann, Br. Foundry., 65(1972) 73.

25. Integrated R&D Plans for Iron and Steel (Hindustan Steel Ltd. Ranchi) March 1976.

26. R. Nagaraj, M. Jose, S. Seshan and P. K. Rohatgi, J. Scient. Ind. Res., 39 (1980).

27. D. Suresh and P. K. Rohatgi, "Potential Applications of Solar Furnaces in Materials Industry," Presented at the Second International, Hamburg, July 1978.

28. D. Suresh, S. Seshan and P. K. Rohatgi, Solar Energy, 23(6)(1979) 553.

29. Tomorrow's Revolution, Microbe Power, edited by Bram Fond (Macdonald and Jane's Publishers Ltd., London) 1976.

30. Bacterial Leaching Seminar Member, NML Tech. J. 15(4)(1973).

31. P. K. Rohatgi, K. Rohatgi and B. Bowonder, "Technology Forecasting: India Towards 21st Century," Teta McGraw Hill, 1979, Republished by Research Reprints, 1865 Trinagar, New Delhi 1100035, India.

32. P. K. Rohatgi, S. Mohan and K. G. Satyanaraya, "Materials Science and Technology in the Future of India," Regional Research Laboratory (Trivandrum), CSIR, Trivandrum, Kerala, India, 1980.

33. P. K. Rohatgi, S. Mohan and K. G. Satyanaraya, "Materials Science and Technolgy in the Future of Kerala," Regional Research Laboratory (Trivandrum), CSIR, Trivandrum, Kerala, India, 1981.

34. P. K. Rohatgi and P. Egbote, "Materials Science and Technology in the Future of Madhya Pradesh," Regional Research Laboratory (Bhopal), CSIR, Bhopal, M.P., India, 1985.

35. P. K. Rohatgi, B. Nagraj and K. Rohatgi, "Future Technologies for Metals and Materials in India," Journal of Scientific and Industrial Research," Vol. 41, June 1982, pp. 351-360.