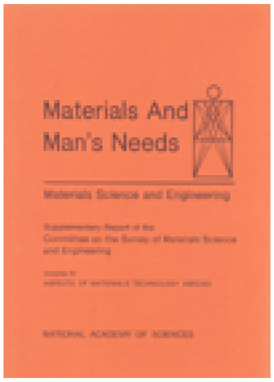

Materials and Man's Needs: Materials Science and Engineering -- Volume IV, Aspects of Materials Technology Abroad

Supplementary Report of the Committee on the Survey of Materials Science and Engineering, National Academy of Sciences

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

MATERIALS AND MAN’S NEEDS

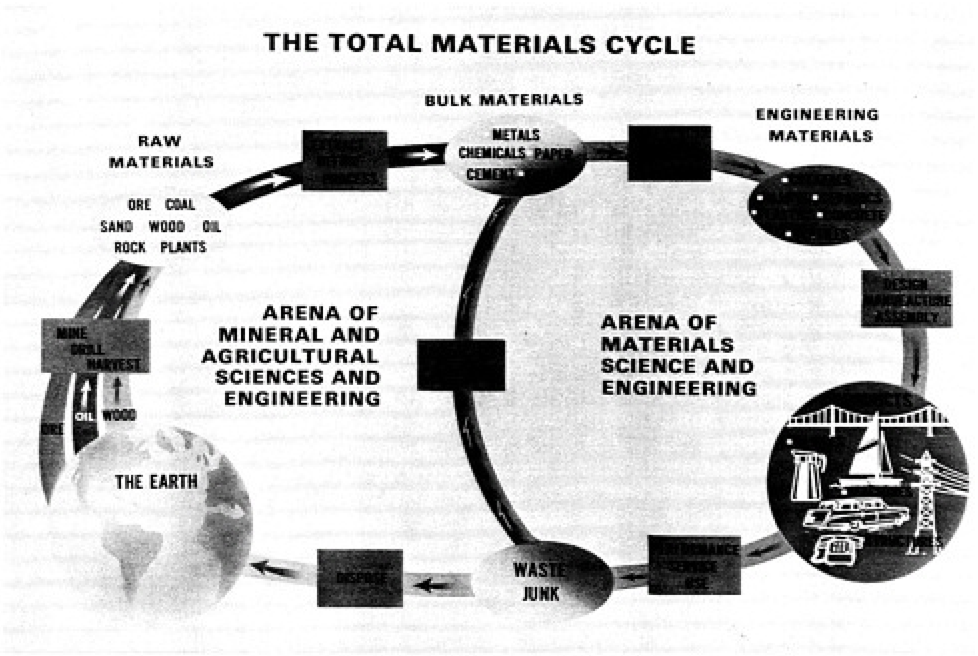
MATERIALS SCIENCE AND ENGINEERING

SUPPLEMENTARY REPORT OF THE COMMITTEE ON THE SURVEY OF MATERIALS SCIENCE AND ENGINEERING

VOLUME IV

ASPECTS OF MATERIALS TECHNOLOGY ABROAD

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1975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METALS
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NOTICE

MATERIALS AND MAN'S NEEDS

SUPPLEMENTARY REPORT OF THE COMMITTEE ON THE SURVEY OF MATERIALS SCIENCE AND ENGINEERING (COSMAT)

The content of this Supplementary Report is part of the basis for the Summary Report of the NAS Committee on the Survey of Materials Science and Engineering. In contrast to the Summary Report, however, the views expressed here are those of the various contributors and do no necessarily represent a consensus of COSMAT.

Frontispiece: A schematic representation of the materials cycle, portraying its global nature and principal stages.

PREFACE

The Summary Report of the Committee on the Survey of Materials Science and Engineering (COSMAT) was published in the Spring of 1974. It was based on informational inputs generated by numerous committees, panels, and individuals. That background information has now been organized into this Supplementary Report, Volumes I to IV.

In assembling this extensive resource, a complete editorial function was not attempted. Thus, occasional redundancies and overlaps as well as some unevenness in style and coverage will be noted. There will also be found views, and perhaps contradictions, that did not make their way into the Summary Report, inasmuch as the latter reflects a consensus of COSMAT. Nevertheless, we believe that it will prove useful to the science and engineering communities, as well as to others concerned with the broader implications of technology, to have available the rich store of information that was collected by COSMAT.

We have organized the present Supplementary Report as follows:

Volume I—The History, Scope, and Nature of Materials Science and Engineering, containing Chapters 1, 2, and 3, is concerned mainly with tracing the history and evolution of materials technology, and of materials science and engineering in particular; also with describing the dimensions of the present role of materials in society; and with a study of the way in which materials science and engineering operates as a multidisciplinary field.

Volume II—The Needs, Priorities, and Opportunities for Materials Research begins, in Chapter 4, with a discussion of how materials research is related to various national goals or “areas of impact.” In Chapter 5, the results of a comprehensive survey of materials research priorities are presented, both for applied research related to these areas of impact and for basic research. Chapter 6 provides a description of several of the more prominent materials research opportunities, again both basic and applied.

Volume III—The Institutional Framework for Materials Science and Engineering (Chapter 7) describes the industrial, governmental, academic, and professional activities in materials science and engineering in the U.S. In the industrial section, emphasis is given to illustrative descriptions of materials technologies and to the roles of materials scientists and engineers in various types of industry. The governmental section describes the ways in which the federal government is involved with the performance and support of materials science and engineering. The academic section contains detailed qualitative and quantitative information on the status and trends in university education and research both in “materials-designated” and “materials-related” departments and in materials research centers. In the professional section, consideration is given to the characteristics and numbers of materials scientists and engineers, as well as to their professional activities and opportunities.

Volume IV—Materials Technology Abroad (Chapter 8) deals with many facets of materials technology, as practiced in other countries. In collecting this information, it was often difficult, or even impossible, to delineate policies and practices specific to the materials field from those pertinent to science and technology in general. In such cases, the broader situation has been reviewed on the assumption that its applicability to the materials sphere is implicit. Volume IV surveys national policies and administrative structures for science and technology, education, R & D, institutions, technology-enhancement programs, technical achievements, and international cooperation. Much of the content revolves around the general theme of technological innovation.

It is surely obvious from the magnitude of this Supplementary Report that COSMAT is enormously indebted to a wide diversity of committees and individual contributors, whose inputs and insights have proved so valuable. The COSMAT Panels, Committees, and Consultants are listed in the Summary Report. They and other individual contributors are also referred to in this Supplementary Report.

COSMAT is deeply grateful to Marguerite Meyer, Beverly Masaitis, and Judy Trimble for their indefatigable efforts in the typing and assembling of these four volumes; theirs was a prodigious task, indeed. We are also most indebted to Amahl Shakhashiri for her careful editing of these volumes.

And once again, COSMAT wishes to acknowledge the support of the National Science Foundation and the Advanced Research Projects Agency in this undertaking, carried out under the aegis of the Committee on Science and Public Policy of the National Academy of Sciences.

Morris Cohen, Chairman
William O.Baker, Vice Chairman
Committee on the Survey of Materials Science and Engineering
September 1975

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MATERIALS AND MAN'S NEEDS

Supplementary Report of the Committee on the Survey of Materials Science and Engineering

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CHAPTER 8. ASPECTS OF MATERIALS TECHNOLOGY ABROAD

CHAPTER 8

ASPECTS OF MATERIALS TECHNOLOGY ABROAD*

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*This chapter, prepared by A.G.Chynoweth, also draws on the work of COSMAT Panel IV. Helpful inputs were received from several individuals overseas, including: (Denmark) N.Meyer; (Finland) E.Suoninen; (France) C.Dugas, J.-C.Poree and M.Servant; (Italy) U.Colombo; (Japan) E.Nagasawa, S.Onogi, I.Sakurada, and I.Shuhara; (United Kingdom) Sir Kenneth Berrill, Sir Brian Flowers, C.Freeman, A.B.Hammond, and W.Marshall; (West Germany) G.W. Becker, H.Queisser, E.Kirste, and Graf Schwerin Krosigk.

CHAPTER 8

ASPECTS OF MATERIALS TECHNOLOGY ABROAD

INTRODUCTION

On Making International Comparisons

Until recently the United States regarded itself as the world leader in almost all phases of technology. This leadership was also recognized outside the U.S. as signified by the concern expressed by other countries in the 1960's over "The Technology Gap"; concern that the U.S. had perhaps achieved so commanding a lead in technology that it could not be overtaken. This lead was particularly marked in the high-technology, science-intensive areas such as aerospace, nuclear energy, defense technology, electronics and computers.

Yet within a few short years, the U.S. has come to feel that its leadership has narrowed in most areas of technology, and has perhaps even reversed in some cases. While the U.S. position is still quite strong in aerospace, defense hardware and large computers, there is the suspicion that other countries have taken over the leadership in various other areas and particularly in sectors that until now have been regarded as low technologies. Prominent among these are several of the basic materials industries.

The question naturally arises, how did these countries catch up or take over the leadership? Why does the U.S. lag behind other countries in certain industrial fields? Have other countries found a successful formula that the U.S. should emulate?

There is no simple answer to these questions. Indeed, it is not even clear that they are the right ones to be asking. Trying to establish definitely whether, taking a reasonably long-term view, there are actual leads or lags between the U.S. and other advanced countries in various industrial sectors can prove an extremely frustrating exercise and one which often leads to inconclusive results. The whole subject is so enmeshed with widely disparate parameters such as geography, cultural heritages, living styles, political systems, national objectives, and natural resources, that hard, critical comparisons of the means adopted by different countries to enhance their technologies are extremely difficult to make.

Nevertheless, it is obvious that some countries have had notable successes at advancing certain kinds of technology and it is therefore useful to consider whether this is because of deliberate national policies or priorities, or the establishment of particular institutional mechanisms.

Naively one might approach this task by examining the policies and practices of other countries over the last 25 years, say, delineating what seems to have been the most successful elements and then judging whether these should be adopted by the U.S. But while this is a feasible approach, it has its dangers—the danger of assuming that the future will be a simple extension of the past. This cannot be so now. The rapidly-growing, worldwide concerns over population growth, food, oil, raw-material supplies, and pollution of the environment is leading to vast changes in perceived national priorities. Standards of living and trading patterns are changing rapidly. The ways in which wealth and economic resources are being redistributed among nations make it obvious that the conditions of the 70’s, 80’s and beyond cannot be simple extensions of the 50’s and 60’s.

It is generally recognized nowadays that materials consumption cannot go on increasing exponentially, that it has to level off and perhaps even decline in the long run. The shape of the consumption curve is more sigmoidal (sometimes bell-shaped) than exponential, but different countries are at different points along their curves at any given instant. The industrially more mature countries are generally further along toward their plateaus than the developing nations and the upper limits will vary from country to country depending on geographical, resource, and social factors. It can be very misleading, therefore, to make direct comparisons between the state of a technology in one country versus that in another without taking into account the relative positions of these countries on their growth curves. The priorities and tactics adopted by a country during the early stages, characterized by increasing growth rates, are likely to be very different from those of a country in the later stages which are characterized by decreasing growth rates.

With these cautions in mind, we will endeavour to review some of the approaches taken by various countries to enhance technology, an aim that has been common to most industrially-advanced nations since World War II. Some major elements in determining technological prowess are: education; investment and activity in research and development; investment in industrial scale-up; legislative, administrative and institutional measures; and public attitudes. While the principal focus in this chapter is on materials science and engineering, it is difficult to keep this focus in making international comparisons. Instead, the broad approaches taken by various countries towards enhancing technology will be reviewed with the expectation that these will often determine success or failure in enhancing the materials technology sector.

Some Historical Perspectives

With the advantages of hindsight, it is now well recognized world-wide that the U.S. emerged from World War II in an unusually, perhaps unnaturally, strong technological position and that, wisely or otherwise, some other countries felt they had to pattern their technological efforts after the U.S.

model if they were to take advantage of the advancing frontiers of scientific and technical knowledge and achievement. The U.K. and, later, France mounted major efforts in much the same set of technological areas pursued by the U.S., including heavy commitments to defense technology. By putting extremely heavy emphasis on defense compared to the civilian sectors, the USSR succeeded in competing technologically, perhaps both in quantity and quality, with U.S. technical achievements in the defense sphere. Germany and Japan, relieved of the need to devote large efforts to the defense sector, were able to concentrate on rebuilding their basic industries and to develop civilian-oriented technologies. In these spheres they were able to establish themselves at least as competitors and often as leaders in the technologies they chose to emphasize. The smaller but technologically quite advanced countries of Western Europe recognized they could not compete with the larger countries in all areas of technology simultaneously and that they had to concentrate carefully on areas in which they had some basic assets.

Thus, by the mid-fifties we find: the U.S. and the USSR concentrating on the so-called “big science” sectors of defense, space, nuclear energy and, particularly in the U.S., electronic systems; the U.K. and France pursuing a mix of big and little science, struggling to keep up with the U.S. in the defense sphere; Germany and Japan focusing on a carefully-chosen set of civilian-oriented technologies; and the smaller industrial countries emphasizing technology in areas related to their individual basic resources, material and intellectual. It is perhaps not unreasonable to compare technical activities in the civilian sectors of the U.S. economy during this period with the “little science” activities of countries in Western Europe and in Japan. It could be, therefore, that the U.S. has, on the whole, more to learn from the approaches taken, not by the USSR, U.K., and France, but from the countries not so heavily involved in defense expenditures, such as West Germany, Japan, Netherlands, Switzerland and Scandinavia.

Elements common to the technological approaches of many smaller countries include: a) a concentration on.the more basic, low-technology, civilian-oriented industries; b) a high degree of cooperation between government, industry, and universities; c) a high degree of willingness on the part of the universities to undertake applied research; and d) recognition of the advantages of industrial size and economies of scale in order to compete with other countries.

Time Factors in the Diffusion of Technology

An invention occurring in a given country is usually (but not always) exploited in that country. At the same time, industries in other countries, if they are alert to such inventions, move to exploit them as well. Exploitation, both in the originating country and the copying countries, takes time. The time varies considerably, depending on a complex mix of factors including: corporate technical alertness and capability, the climate for capital investment, consumer attitudes, and government actions. But in spite of the complexity, it has been found that the diffusion patterns for technology in various countries display remarkably similar behavior, although with varying time spans, for highly diverse products, materials, and processes.

Fisher and Pry[1] have shown that data describing the substitution of a new product or process for an old one can generally be fitted extremely well by a sigmoidal curve of simple mathematical form. The model is based on three assumptions:

a) In many instances, a technological advance can be considered as a competitive substitution of one method of satisfying a need for another.
b) If a substitution has progressed as far as a few percent (capture of the market), it will proceed to completion.
c) The fractional rate of substitution of new for old is proportional to the remaining amount of the old left to be substituted.

From the above analysis, it can be concluded that the time required for the new product or service to grow and diffuse through technology and society has not shortened in any discernible way over the last 60 or 70 years. The substitution time does seem to vary from product to product depending on the breadth of impact of the product, the capital needed, social changes required, and marketing and distribution patterns, as well as product superiority or other technically-related factors, but not with the specific time-period of the substitution.

Some results of the Fisher-Pry studies of particular interest to materials industries are given in Table 8.1. They emphasize the often considerable time-spans for substitutions to be fully implemented and hence the lack of credibility that must be attached to most of the subjective impressions of relative leads and lags-by relatively uninformed individuals.

The analyses of the substitutions of the basic oxygen furnace for open hearth in steelmaking in various countries are particularly pertinent. Quoting Pry: “Since Japan had relatively little (steel) capacity in 1960, but a real commitment to increase production, its (substitution) curve could be considered to be an experimental determination of the rate at which capacity could be installed in an advanced country; limited only by construction constraints and industry learning curves.”

“By using Japan as a base, one might say that the U.S. and West Germany, whose behavior was and is nearly identical, demonstrate the effect of the delay in technology diffusion caused by heavy investment in an existing technology and a slightly more conservative investment policy.”

“Knowing very little about the underlying facts in the recent advances in the USSR steel industry, one can only speculate about the significant time delay in the USSR substitution. Could it be that a lack of first-hand knowledge of the technical operating characteristics of BOF plants delayed the substitution for five to ten years?”

In another study of the international diffusion of technology, Cooper[2] has compiled the average imitation lags for various countries following important innovations (see Table 8.2). Differences between the response times appear relatively small for countries at comparable stages of development.

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[1] J.C.Fisher and R.H.Pry, Tech. Forecasting and Social Change, Vol. 3, 75–88, 1971

[2] Richard N.Cooper, “Technology and U.S. Trade: An Historical Review;” Proc. of Symposium under the auspices of the Natl. Acad. of Eng., Technology and International Trade, Washington, 1971.

TABLE 8.1 Take-Over Times (?T) and Substitution Mid-Points, Toa

SUBSTITUTION				
	OF	BY	?T[b] (YEARS)	T_o
I.	PLASTICS			
	Natural rubber	Synthetic	58	1955
	Natural fibers	Synthetic	58	1969
	Natural leather	Synthetic	57	1957
	Hardwood residence floors	Plastic	25	1966
	Various boat hulls	Plastic	20	1966
	Natural tire fibers	Synthetic	17.5	1948
	Metal car bodies	Plastic	16	1981
II.	STEEL PROCESSES			
	Bessemer	Open hearth	42	1907
	Open hearth	Electric arc	47	1947
	Open hearth	Basic oxygen furnace		
		a) Japan	9	1963
		b) Germany	12	1969
		c) USA	12	1969
		d) USSR	14	1975

[a] R.H.Pry, General Electric Corporation, Corporate Research and Development, Schenectady, New York, Report No. 73CRD220, July 1973.

[b] ?T is the time between 19% and 90% take-over.

TABLE 8.2 Average Imitation Lags Following Important Innovations

	Average Number of Years Between First Production in Innovating Country and Subsequent Production in Imitating Country				
Industry Where Innovations Occurred	United States	France	Germany	Japan	United Kingdom
Synthetic rubber and synthetic fibers					
1897–1949 (15 innovations)	8.8	10.3	7.4	14.7	8.3
Plastics					
1870–1957 (20 innovations)	5.2	8.7	6.1	14.0	8.7
Semiconductors					
1951–1957 (8 innovations)	1.0	3.0	2.4	3.9	2.6
1958–1963 (5 innovations)	[a]	2.6	1.2	2.6	1.6

[a] All these innovations were in the United States

Sources: G.C.Hufbauer, Synthetic Materials and the Theory of International Trade (Gerald Duckworth, London, 1966), pp. 131–132.

John E. Tilton, The Semi-Conductor Industry (The Brookings Institution, mimeo., 1970), Table 3.1.

However, the evidence in the case of the semiconductor innovations is that the innovating country holds a definite advantage over its imitators.

NATIONAL POLICIES FOR SCIENCE AND THEIR IMPLICATIONS FOR MATERIALS TECHNOLOGY

Introduction

Every living organism or institution must accommodate itself to change in order to survive. The first law of every living organism or institution is its own self-preservation. Change results from stresses that can be generated either internally or externally, or some combination of both.

- What present stresses, internal and external, on the United States are involved with materials? What additional actions would be appropriate in delaing with them?
- What future stresses involving materials can be foreseen? What actions can be taken now to prevent such foreseen future stresses from developing or to make them tolerable when they occur?
- What posture and what organizational arrangements can be adopted to increase the effectiveness and flexibility of response to unforeseen and unforeseeable stresses?

Thousands of years ago, man made the unconscious decision to employ technology. This decision, which has turned out to be progressive and irreversible, has set in motion an enormous series of consequences. Man lives today in a world which he has largely shaped by the use of technology. From the time of man's first use of technology, and progressively thereafter, experience has shown that by rational expedients using either trial-and-error or cause-and-effect reasoning, man could improve his compatibility with, his environment.

The main purpose of technology is to improve the compatibility of man's relationship with his environment. The purpose of applied research, then, is to develop ways of further improving this compatibility. Social organization is a form of technology and shares its general purpose. It has three important characteristics: (1) it attempts to specify the relationships among its components, which is why it is called a "system"; (2) it enables the concerted achievement of tasks beyond the capacity of its individual human components; and (3) its lifetime is independent of the life span of its human components.

All human institutions, like biological organisms, experience aging. Unlike biological organisms, however, social organisms are capable of being rejuvenated. Rejuvenation is measured by the improved viability of such institutions—whether governments, churches, businesses, universities, or families—in tolerating, reducing, or overcoming internal and external stresses. Stresses cause changes in the environment and in the compatibility of the organism (or institution) with it. Adaptability to change is the hallmark of viability.

One distinguishing characteristic of man is that he consciously employs technology to improve his environmental compatibility, more often than not by the use of institutions organized for this purpose. The most highly-developed method for achieving the desired compatibility is by the conversion or consumption of materials to produce articles, like clothes and houses, or effects, like warmth and light. Without the institutions that provide and process materials, the present structure of society could not endure. Most institutions would collapse. Most men would perish.

The elaborate structure of present day society, not only in the United States but worldwide, rests ultimately on a materials base and on the institutions that employ materials. Whether or not this condition is a “good thing” is irrelevant; it is a fact, the result of an irreversible process, and mankind must make the best of it.

Every nation can be considered to have a strategy for the materials field. It may be to develop a rigid and comprehensive five-year plan, or it may be to ignore the issue and let events take their natural course, or somewhere in between. Either way, consciously or by default, a strategy has been chosen.

Some might believe that national strategies in the materials field are carefully thought out as sectors in the broader strategies for science and engineering as a whole and that these, in turn, are logically related to generally-agreed national goals or policies. It is much more likely, though, that where materials strategies exist, they have been only loosely related to broader science policies, if at all.

That the world is involved in a period of accelerating change and competition—in economics, politics, art, philosophy, management, science and engineering, technology assessment, etc. —few will question. And the exigencies of change and competition are forcing the delineation of national policies for science and engineering either deliberately and directly, or inadvertently and indirectly. Likewise, policies for the materials field are emerging.

In this section we attempt to indicate how strategies in the materials field may vary among different countries, reflecting differences in national goals and conditioning influences.

National Goals

A pluralistic society rarely has consensual goals except in reaction to some external threat (e.g., war, trade competition, waning national influence) or some internal danger (e.g., depression, insurrection, environmental degradation). Lacking such challenges, each man tends to go his own way.

However, in an increasingly crowded and turbulent world, possessing weapons of great destructive power, increasingly reliant on technologies of ever greater potency, consuming more materials and energy and generating more products, with more and more interactions among nations and peoples, the question arises as to whether the United States can safely enjoy in the future the luxury of an unplanned strategy for materials.

Before one can begin to think about a national strategy for materials, there needs to be a clear statement of broader national aspirations, both as to internal conditions and as to the nation’s role in the world of nations. With regard to the first, there should be a concept—or at least some reasonable assumptions—concerning the standard of living, the philosophy of industrial growth, the optimal level of population, and the relative importance of all these as compared with environmental quality and its preservation (or restoration). There should be an assumption as to the desired rate of change in technology, bearing in mind the current attempts to evaluate new technology before adopting it. As to the second, questions need to be resolved as to the nation's determination to influence global diplomacy, to effect changes in the economies of developing countries, to achieve specific patterns of international trade, to respond to the economic and technological prospects of the principal competing nations, to advance the United States at the expense of other nations or as a part of a general program of international advance, to aim at universal superiority in science, technology, and industrial achievement or to choose areas in which our superiority in resources gives us an automatic precedence, leaving other nations to surpass us in field where they are potentially stronger. Is it politically feasible to make these decisions? Is it economically feasible not to do so? What will the other nations be doing in the meantime?

Thus, a nation's science or materials strategy is not formed in a vacuum, but is always a derivative—intended to advance some more fundamental national purpose (such as the items in Table 8.3). A statement of national purposes is never complete because there are always additional things for somebody to want. It is never good for all time because (a) external stresses generate new aims, (b) new things become possible, and (c) new people with different desires get to be in charge. The most durable goals are those fixed by geography (England's desire to be "mistress of the seas"), or deep-seated human traits (reduce taxes, improve health standards), or persistent enthusiasms (historically, nationalism has been one of these), or economics (reduce unemployment), or compelled by historical evolution (eliminate racial discrimination), cultural (renew blighted urban areas), behavioral (reduce crime), convenience (improve highways), or even esthetic (eliminate advertising signs along the highways).

In the implementation of a national strategy or achievement of a national goal, size of country has much to do with effectiveness. Japan has demonstrated this repeatedly, in achieving optimal use of land, birth control, and rate of new capital formation. Denmark, when the U.K. turned to New Zealand for beef and cattle, converted to the production of bacon, eggs and milk in a remarkably short time. Switzerland has shown a fine ability to maintain high standards of quality of exports.

The degree of authoritarianism exercised by a country may be important in goal management. In Nazi Germany, a high level of efficiency was observable in the classification of household wastes at the source. In the USSR, in the 1920's, new capital formation in basic industries proceeded rapidly, while needed wheat was exported to earn foreign exchange.

Some salient national goals, as they appear to us for various countries are indicated in Table 8.3. In relating national strategies for materials to these national goals there are several "conditioning variables" that have to be taken into account: first and foremost, the national geography, including the pattern of available natural and human resources; second, the

TABLE 8.3 Some Salient National Goals (1950–1970)

National Goals	Chile	France	Germany	India	Japan	Netherlands	Union of Soviet Socialist Republics	United Kingdom	United States
General Science and Technology Preeminence							x		x
Science Preeminence							x	x	x
Technology Preeminence			x		x		x		x
Economic Growth	x		x	x	x	x	x	x	x
Exclude Economic Influence of Some Other Nations	x x			x	?		x		
Increase Diplomatic Influence							x	x	x
Enlarge Military Strength							x		x
Catch Up Technologically With An Adversary				x	?		x		x
Environment Quality			x		x	x		x	x
Improve Terms of Trade				x	x	x		x	x
Raise Living Standards	x			x		x	x	x	
Reduce Unemployment				x				x	x
Control Inflation	x		x		x	x		x	x
Reduce Extent of Government Intervention									x
Increase Extent of Government Intervention	x			x					
Improve Internal Economic Balance	x			x			x	x	

economic system; third, the historical evolution of the societal patterns; fourth, the general educational level of the population, including its level of scientific and technological sophistication; fifth, the availability of investment capital, and accompanying propensity to invest in relevant technologies for research and development, and for the production and fabrication of materials; sixth, the extent and character of restraints and encouragements imposed by the national government; and seventh, the propensity for war-making of the nation.

Perhaps no positive and definite national goal or strategy would be acceptable to the United States for materials (or any other aspect of national culture) except in reaction to some internal or external stress. However, the emergence of such a stress often cannot be predicted. The viability of any nation depends on its adaptability to conditions of stress. Accordingly, a guide-line for U.S. strategy might be to strive toward a general condition of flexibility so that when stresses appear they can be tolerated or overcome.

National Strategies and Tactics in the Materials Field

In the United States, no agency appears to have responsibility for the total job of formulating materials policy or goals for the materials field. Thus, it is not surprising that there is no well-formed strategy for achieving national goals in the materials field, including materials science and engineering. Bits and pieces of materials strategy are done in many places but always aimed at limited, partial, or even conflicting objectives.

The purpose of a strategy is to provide guidelines for fulfilling of a purpose, for achieving a goal, for concentrating national energies to some end. A strategy signifies first, a determination of present posture; second, a definition of an ideal or preferred future posture; and third, a broad design of how to progress from the present to the future posture. With respect to MSE there has been expressed no purpose, no goal, no end, and therefore no setting of priorities among the components of strategy. Consequently, one can expect to find a variety of strategies and tactics in operation. One can also expect to find a variety of strategies among various countries according to the role of materials in their respective economies, as exemplified in Table 8.4.

That the formulating of a materials strategy involves a highly complex set of policy issues can be gauged by the following examples of questions that might have to be resolved first.

1. What is to be the time span of the planning?
2. How is policy planning to be coupled with implementation?
3. How can we best combine incrementalism with the “5-year plan” approach?
4. Is it possible to decide in advance whether to employ the principle versus the case law approach?
5. How salient is the problem of materials to political decisionmakers?
6. If the United States is in competition with other nations, what should be the terms of the competition? Should we compete across the board, or selectively?

TABLE 8.4 Definition of the Role of Materials, by Countries

	Raw Materials Production	Manufacturing Usage of Materials	Export of Raw Materials	Export of Fabricated Materials	Import of Raw Materials	Industrial Style	Style of Export Trade	National Materials Attitude
Chile	Much	Low	Much	Negligible	Minor	Labor intensive	To earn exchange	Sell
France	Some basic, but not diverse	High	Little	Some	Much	Capital & labor intensive	Mfd. products worldwide	Fabricate
Germany	Considerable basic, but not diverse	High	Little	Much	Considerable	Labor & Capital intensive	High value added	Conserve
India	Much	Low	Much	Negligible except cloth	Minor	Small (labor intensive)	To earn exchange	Sell
Japan	Little	High	Little	Much	Much	Capital & labor intensive	High value added	Secure

	Raw Materials Production	Manufacturing Usage of Materials	Export of Raw Materials	Export of Fabricated Materials	Import of Raw Materials	Industrial Style	Style of Export Trade	National Materials Attitude
Netherlands	Little	Some	Little	Considerable to Common Market countries	Considerable	Capital & labor intensive	Agric. & high value added	Conserve
U.K.	Little	High	Little	Much	Much	Capital & labor intensive	Mfd. products worldwide	Fabricate
U.S.A.	Much (but far from sufficient in quantity)	High	Some	Much	Much	Materials & Capital intensive	Balanced	Use
U.S.S.R.	Considerable basic, wide diversity	High	Moderate (Cr/Mn especially)	Much to Comecon countries	Small	High output	1) instrument of foreign policy 2) cash for surplus	Use

7. In our reliance on R&D, what should be the allocation of effort among industry, Government, the Universities, and Government support of other?
8. What is the role of the Government in ensuring the coupling of research with the commercial exploitation of research results?
9. How formally should needs and goals of materials R&D be defined?
10. What mechanisms are needed to ensure specific programs toward goals?
11. How can adequate trained manpower be assured for all materials programs? —And for all functions, such as data management, planning, research design, project evaluation, performance of research, development of research products, industrial materials management, and education for all of these?
12. How can a reasonable degree of stability be achieved (and is it desirable?) in the placement of manpower in materials functions?
13. Aside from problems of stability of manpower, and expeditious support of promising new lines of inquiry, how important is level of funding (e.g., in relation to GNP or some such standards?
14. Is balanced research (including stimulation of lagging areas) more important than total level of effort?
15. When broad national objectives are decided on that involve some improvement in materials technology, should the emphasis be on total research and development coverage of all approaches to the problem, or on careful selection of high probability pay-off, or on short- versus long-range solutions?
16. What degree of effort should be applied to securing solutions abroad, or reinventing the wheel at home?
17. How can flexibility of response to changing environment (e.g., materials availabilities and costs, new kinds of hardware, problems of disposal and recycling, etc.), be preserved in the face of high capital investment in obsoleting technologies, large corporate organizations, and elaborating regulations of Government?
18. If dollars are the constraint, should research—especially applied research—be aimed at maximum return in areas yielding dollar profits, or correcting areas of greatest weakness at least cost in dollars for R&D?
19. Has the U.S. been wasteful of research resources by concentrating on the “exotic” aerospace and related research efforts yielding a high-cost, high-reliability, low-production product?
20. How important for strategy planning is the forecasting of technology— determining what is technically feasible, economically practicable, socially desirable, and environmentally tolerable?
21. Is it necessary to ask: What are we giving up in order to preserve whatever it is that we’re preserving? What are the opportunities for trying something quite new, and what would that require us to give up?

Techniques or tactics employed to implement a national materials strategy are virtually infinite in scope. To begin with, the strategies themselves— and variations of them—are innumerable. They might include such as—

A posture of materials in preparation for national defense emergency;
A national program of materials conservation in peacetime;
A strategy of concentration on high-technology materials;

A strategy of abundant materials for rapid economic expansion;
A strategy of low-cost, high-level production of goods for export;
A strategy of national simplification in materials usage; (Etc.)

Then, within any single strategy, the tactical implementation could take countless forms, either in parallel or as alternative options. For example, a nation adopting a strategy of preparedness for war might:

Stockpile reserves of imported materials;
Stockpile materials in semifinished form (e.g., aluminum ingot);
Devise patterns of materials substitution;
Write conservation orders;
Establish a system of priorities and allocations;
Formulate a controlled materials plan;
Set up salvage depots;
Construct specialized metals-recovery plants;
Adjust tax policies to enable accelerated plant amortization;
Establish overseas purchasing missions;
Review mining activities to optimize output in the short run;
Stimulate private corporate materials-conservation plans; (Etc.)

A strategy of peacetime conservation of materials could involve such tactical options as:

Government action (tariff, etc.) to overprice materials;
Subsidy to minimize tailings losses;
Household scrap segregation;
Government pilotplanting of conservation practices and waste recycling systems;
Encouragement of use of renewable resources;
Research in utilization of most abundant materials;
Tax imposed on “wasteful practices;”
Subsidy to encourage marginal salvage operations;
Federal quality standards for consumer goods;
Increased emphasis on sound maintenance practice in consumer durables; (Etc.)

Some types of tactics and their perceived status in various countries are indicated in Table 8.5.

Before concluding these general introductory remarks, it should be noted that just as every different kind of materials strategy implies a different set of implementing tactics, so too each set of implementing tactics implies a different set of ad hoc organizational arrangements. To begin with, there are many conceptual approaches to the management process. For example:

Voluntarism
Incentive approach
Legal authority
Confiscation
Government operation
Corporate-government consortium
Legally-backed industry codes Etc.

TABLE 8.5 Techniques for Implementing National Goals for Materials (Subjective Views)

	Chile	France	Germany	India	Japan	Netherlands	UK	USA	USSR
I. Education									
A. Broadly based		x	x				x	x	x
B. Decentralized				x				x	
C. Elitist		x			x		x		x
D. Centralized		x				x			x
E. Content emphasizes phys. sci.					x			x	x
F. Import teachers									
G. Export teachers							x	x	
H. Planned academic cohorts to meet forecast requirements					x				x
I. Industry-subsidized training to meet requirements								x	
J. Other (specify), etc.									
II. Science									
A. High level of effort in the national budget		x					x	x	x
B. Expanded effort, year by year			x		x				x
C. Rely on imports of information from outside	x			x	x				
D. Exploit international consortia			x		x		x		
E. Freedom of science		x	x		x		x	x	
F. Total excellence		x	x					x	x
G. Emphasis on areas of expected high early pay-off					x	x		x	
H. Selected areas in relation to highest professional competence			x		x		x		x
I. Emphasis on fields involved in international competition								x	x
J. Other (specify), etc.									

	Chile	France	Germany	India	Japan	Netherlands	UK	USA	USSR
III. Technology									
A. Buy technology from other countries			x	x	x	x			x
B. Government investment in technology		x	x	x			x	x	x
C. Reliance on private industry			x		x		x	x	
D. Emphasis on basic industry improvement			x		x	x			x
E. Emphasis on improvement of "prestige" fields of technology		x						x	x
F. Emphasis on military potency		x						x	x
G. Emphasis on fields involving local comparative advantage	x		x		x				
H. Emphasis on fields of high international economic competition			x		x		x	x	
I. Other (specify), etc.									
IV. Materials Acquisition									
A. Seek new sources abroad			x		x	x	x	x	
B. Rely on established markets			x			x	x	x	
C. Develop domestic sources	x			x				x	x
D. Resort to conservation measures			x		x				
E. Other (specify), etc.									

	Chile	France	Germany	India	Japan	Netherlands	UK	USA	USSR
V. Materials Flow									
A. Maximize value added		x	x		x	x	x	x	
B. Maximize through-put								x	x
C. Accept environmental limits on production							x	x	
D. Emphasize high technology		x	x		x	x	x	x	
E. Large variety of slightly-differing product forms			x		x			x	
F. Standardize on few varieties									x
G. Emphasize product durability			x			x			
H. Emphasize production for domestic use		x	x	x	x			x	x
I. Emphasize product for export			x		x	x	x		
J. Other (specify), etc.									
VI. Materials Salvage									
A. Reliance on free market economy		x	x		x	x	x	x	
B. Careful segregation to preserve material values, as result of economic pressures			x	x	x	x			
C. Regulation requiring recycling									
D. Speedy recycling to save space					x		x		
E. Product design for efficiency of salvage and recycling									
F. Regulation to prevent environmental pollution by throw-away and wastes			x		x			x	
G. Priority to consumer convenience		x			x			x	
H. Priority to producer convenience					x				x
I. Priority to manpower over materials in efficiency of utilization								x	x
J. Priority to materials over manpower in efficiency of utilization				x	x	x	x		
K. Other (specify), etc.									

Then, there are numerous standard organizational requirements that would need to be adapted to whatever approach and whatever goal and strategy had been selected. These include:

Formulation of strategy
Tactics of scientific research
Tactics of engineering development
Fiscal management
Legal management
Control program management
Tactical studies
Public relations
Education and training

Whatever the form of management, there are a certain range of general policies that are likely to be applicable under most circumstances. These might be expanded considerably, but the following are indicative:

- Identify the limiting factor(s) to achievement of the desired purpose and maximize for it;
- Identify the long lead time item in the array of processes or systems contributing to the objective and schedule all programs around it;
- Allocate dollar resources and human effort to emphasize high pay-off programs and minimize effort on programs yielding minor results;
- Consider alternative uses for the organizations and people committed to specific programs, otherwise they will keep on doing their thing when the need is past—when “their thing” might be counterproductive.

Some Examples of National Policies in Science and Engineering

There are, according to Robert Gilpin,[3] three alternative national strategies for science and technology: (1) to support scientific and technological development across the broadest front possible; (2) scientific and technological specialization; and (3) the importation of foreign technology. The United States and the Soviet Union have followed the first strategy; Great Britain attempted to follow this strategy also in the years immediately following World War II but, along with other countries such as France, has had to adjust to the second strategy, a strategy which has traditionally been followed by countries with limited resources such as Sweden, Netherlands, etc. Japan and West Germany followed the third strategy at first but have now largely changed to the second. Although the U.S. strategy has been relatively successful, particularly in fields of high technology like space and the computer, it has begun to show defects. In the first place, even America does not have the economic and technical resources to support all projects of importance; it, too, must choose. Second, a high proportion of the limited resources has gone to military and military-related projects, while pressing social and economic needs of the nation have not been met.

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[3] Robert Gilpin, “Technological Strategies and National Purpose,” Science, 169, 441, 1971.

Third, the devastating consequences of technological advance on the environment have recently emerged as a major national concern. As a result, Gilpin concludes with a prediction that:

> "…To a degree perhaps unparalleled in the past, economic and technological considerations will shape the ways in which political interests and conflicts seek their expression and work themselves out. In a world where nuclear weaponry has inhibited the use of military power and where social and economic demands play an inordinate role in political life, the choice, success, or failure of a nation's technological strategy will influence in large measure its place in the international pecking order and its capacity to solve its domestic problems.

Until recently, the U.S. has shaped its national policies in science and technology largely as a reflex to military threats, real or imagined. Thus, this country has concentrated its efforts on technologies seemingly remote from everyday experience. It has supported the laser but not the science of processing garbage. There are lags in the technological levels of a number of industries in the U.S.; such lags may impair the credibility of this nation's posture in world technological leadership. Which older technologies, such as the railroads, glass and ceramics, coal, lumber and textiles, might be revitalized by an infusion of fresh technological effort? And what would be the international consequences of a vigorous technological effort in one, several, or all of these fields?

It has been shown repeatedly in the recent past that enormous outlays of public funds by the U.S. to support a new field of research have brought only a short-lived technological advantage which quickly disappeared. Other nations came into the act and duplicated the U.S. successes while avoiding the failures and blind alleys that are an inescapable part of pioneering. Clearly, there are added costs as well as benefits in the hard-earned role of technological leadership. The various fields of science and technology may lead to certain natural advantages such that specialization may be of mutual benefit within the community of nations. But to choose this course would require a conscious decision to abjure overall leadership in favor of an international partnership in technological progress.

Strategies based on an over-simplified objective are likely to be selfdefeating. Attention is called to the French effort to free themselves from reliance on U.S. enriched uranium by development of nuclear reactors using natural uranium fuel, to their effort to develop an independent large computer industry, and to the Anglo-French program to develop commercially-successful civilian supersonic airliners. No notable success has been achieved in any of these directions.

United Kingdom

The course taken by the United Kingdom is instructive. In many senses, the U.K. is ahead of the United States. The Industrial Revolution of the nineteenth century gave Great Britain technological supremacy in the world; this in turn was the main underlying source of the commercial, diplomatic and military strength that the U.K. enjoyed well into the 20th Century. But the Industrial Revolution also brought in its wake a host of social problems which led to the necessity of many social reforms concerning labor laws, unemployment benefits, old-age pensions, national health schemes, preservation of the environment, and the like.

While it takes the hard but exciting and inspiring work of pioneers to establish leadership for a nation, it proves to be even harder for that nation to maintain its position of leadership. History is replete with examples of the rise and subsequent decline of empires. Once a nation has established itself as a leader its methods are studied by other countries who are determined to find a way to go one better. At the same time, the first nation has a tendency to remain with its old methods in the belief that what worked before will work again; and besides, it has much investment tied up in its factories and equipment. The British started facing reality in the late 1950's. They realized they could no longer compete with every other nation in every branch of technology. The slow process of rationalization and the making of painful choices set in.

There seems to be an uncanny similarity between the position the U.S. now finds itself in and that which the U.K. has had to face somewhat earlier. The achievements of science and engineering over the last 30 years in the U.S. put this country in a dominant technological, commercial, diplomatic, and military position. But erosion of this position has been occurring very noticeably over the last decade. At the same time, social problems have come to the fore. And again, we see national realization that even the U.S. does not have the resources to compete successfully with the rest of the world in all phases of human activity. The process of making painful choices has arrived.

It is difficult to discern any long-term fixed national policy for science and engineering in the U.K. other than that they are regarded as important components of national economic health and that, therefore, they should be supported at an adequate level. But as each new government is elected, there is generally a review of policy for science and engineering which, in turn, usually leads to adjustments to the organizational and administrative framework and to some change in emphasis in the funding patterns. In the decade after World War II, national priority was placed on government research establishments in activities judged vital for technological as well as national survival, e.g. the atomic energy and the defense establishments. Later, recognizing the need for more and better trained technical manpower, a considerable expansion and upgrading of the universities was undertaken. Since 1965 steady effort has been made by the government to promote industrial R&D and, whenever possible, to deploy the government R&D establishments on to civilian technologies. As a result of all these steps, there is now a more or less broad-based scientific and engineering capability in Great Britain, and current efforts are now concentrated more at optimizing its operation. However, the British have often been somewhat embarrassed by their apparent inability to optimize the coupling of development and engineering to their strong basic research programs. It is almost as if, to every attempt by the government to push or pull technology and thereby improve the international trade balance and the standard of living, there is a reaction in the opposite direction by the British people that tends to negate the governmental efforts. Perhaps the people feel that in order to raise the (materialistic) standard of living a price may have to be paid in the quality of life (intangibles).

Nevertheless, there is a continuous demand for better public services without adequate recognition that industrial strength is needed to pay for them. It is curious though, that the U.K., with all its years of experience, has not put more emphasis than it has on providing commercial services to the rest of the world—trade facilities, insurance, banking, transportation, etc. — in order to ease the balance of payments.

France

Various factors contribute to present trends in France's science and technology policy. During the de Gaulle period there was heavy build-up of research effort and also considerable university expansion. Now France is experiencing consequences similar to those experienced earlier by Britain and the U.S.—an oversupply of science graduates and an undersupply of funds. Defense support, emphasized heavily during de Gaulle's tenure, has levelled off and in some sectors is being cut back. French industry has not really taken up the slack in R&D and surplus manpower. Thus, the proportion of the GNP which goes into R&D has dropped from 2.4% in 1968 to 1.8% in 1971. (France's VIth economic plan calls for 2.45% in 1975.)

Under de Gaulle, France tried to "go it alone" in high technology, but now it is cutting out certain programs, e.g. the costly, uneconomic program to develop natural uranium power reactors. Also, a proposal to detach the computer division from the French Atomic Energy Commission and move it into the private sector is being discussed. As regards basic research, there is a growing tendency to seek international arrangements. Also, the VIth plan (covering 1970–1975) includes a variety of encouragements for industry-oriented research. France is mindful of the importance of research in the trade competition of high technology, yet it is faced by the failure of its large investments in R&D to pay off up to now. In the industrial research sector, there still seems to be a technology gap.

U.S.S.R.[4]

The rise of Soviet science and technology has taken place in an institutional framework quite different from that of the United States. Ever since the revolution of 1917 the deliberate fostering of advanced technology has formed a central feature of Soviet governmental policy. During the late 1920's and 1930's, the U.S.S.R. Academy of Sciences was transformed into a coordinating center for most fundamental research and much applied research, with an extensive network of research establishments employing a large scientific staff. The position of the Academy at the heart of the Soviet scientific effort was consolidated during the second World War.

Most of the nation's R&D resources were devoted, however, to the establishment of centralized R&D facilities in the major industries; national

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[4] See Science Policy in the U.S.S.R., OECD, Paris, 1969.

research and design organizations in each industry created or adapted advanced technology and channeled it to the Soviet factories. The number of scientists employed in such R&D was always far greater than the number employed by the Academy system.

Another element in the U.S.S.R. science system, as it emerged during the 1930's, was the network of higher educational institution, 817 of them by 1940 which, with a few exceptions, did not feature significant research, but were responsible for the mass training of engineers and others to man the expanding industries.

The rise of the complex structure of the Academy and industrial R&D, and the attempt to "plan science," made the Soviet Union a pioneer country in the history of science policy. In the post-war period, with the impact of the "research revolution," the Soviet government has been faced with a number of major problems in endeavouring to devise a comprehensive national science policy along with the instruments to put such policy into effect.

In some important respects, the U.S.S.R. is technologically one of the two world super-powers. Largely as a result of the size and quality of her defense and aerospace industries, she is the only serious rival to the U.S. both as a military power and as a competitor in the space race. In certain other industries, such as iron and steel and machine-tools, the U.S.S.R. also commands a high level of technical performance. These achievements have been supported by successful R&D in modern weapons, including ICBM's and military aircraft, in space technology, in nuclear energy, and in various branches of engineering. In all these cases, planning, a priorities system, and a high degree of centralization of R&D have facilitated coordination and concentration of effort and thus enabled the deliberate translation of research findings into production.

The Soviet Union has, however, been able to reach this high technical level only in a few priority fields. In the computer and chemical industries, and in almost all consumer products, the U.S.S.R. is well behind the U.S., and in some major sectors she is less advanced than the industrial countries of Western Europe.

Two main groups of factors appear to have contributed to the relatively poor application of the results of research in the U.S.S.R. The first stems from the traditional system of economic planning. By the late 1950's, the central planning arrangements which emerged 30 years earlier to facilitate the rapid introduction of advanced technology were tending to restrict further innovation. Planning was production-oriented. The success of both factories and ministries was primarily judged by their ability to carry out their set production plans, within cost constraints. This led ministries to skimp on the resources allocated for experimental work; if these could be squeezed, more would be available for extending basic production facilities. Similarly, factory managements tended to resist innovations proposed by research establishments, because any major change in the pattern of output would disrupt the flow of production, and so the diffusion of existing innovations were slowed down.

The second group of factors inhibiting innovation lay in the very strong organizational barriers between the different phases of the research-production sequence. These operated at several levels:

(1) Planning of research, development, pre-production and production of a new product, outside the priority projects, are not adequately integrated;
(2) The research institutes of the Academies of Sciences which are responsible for most fundamental research, are organizationally quite separate from industrial R&D, and the system is tilted so as to give the latter preference and priority;
(3) The strong barriers between military and civilian R&D are not conducive to "spin-offs ;"
(4) Industrial R&D is divided among a number of ministries between which administrative barriers prevent easy communication;
(5) Within each ministry, the administrative separation from the factories of the large research institute and its attendant design bureaus inhibit the introduction of new products and processes.

Some further insights into the problem of technology transfer from the basic-science institutes to the R&D institutes within the industrial ministries in the U.S.S.R. are provided by the following statements published in Pravda:

Science and the Acceleration of Technical Progress Pravda, March 31, 1970, p. 6

A single question was put by the editors of Pravda to a group of physicists from a number of different cities in the country: "What, in your opinion, should be done to increase the contribution of Soviet science to accelerated scientific and technical progress?" The replies of the participants of this informal round table are given below.

The Scope of Research

I.N.Frantsevich, Director of the Institute of Problems of the Science of Materials, Member of the Academy of Sciences of the Ukrainian SSR. "The primary stimulus to scientific and technical progress is to be found in the kind of long-range, fundamental scientific research, the practical significance of which may at first not appear particularly evident. Let us cite a typical example. About 40 years ago the dislocation theory was developed. The prevailing view, during the initial states of its refinement, held that it was extremely unlikely that this theory would ever contribute significantly to a solution of the essential problems of materials science. In fact, the very existence of the dislocation itself was regarded with considerable skepticism. Today this theory is at the very heart of solutions to a wide range of practical tasks.

"No less important is the ability to guide successful concrete ideas through to their large-scale practical implementation. An instructive example of this kind of follow-through can be seen in the work of the outstanding Ukrainian scientist Ye.O.Paton and his associates in their development of the automatic flux welding method into a full-fledged scientific methodology.

“The departmental breakdown of work projects into the twin categories of long-term and applied-engineering should not be absolute. It is not administrative association with a particular branch or department, but personnel that is the determining factor in an organization’s creativity. It is very important that, wherever expedient, every institute have the resources to see its theoretical scientific developments through to practical fruition. To this end it is necessary, in our opinion, that organizations involved in scientific research be able to call upon its theoretical scientific developments through to practical fruition. To this end it is necessary, in our opinion, that organizations involved in scientific research be able to call upon well-equipped design offices, prototype production facilitites, and—if its staff is working on some radically-new technical innovation—an adequate team of instructors capable of giving on-the-spot production assistance at plants and factories.

“The main thing, in our view, is that the theoretical as well as the practical people become as involved as possible and play a more active role in the solution of these engineering and physical problems.”

Avoid Lost Time

V.M.Tuchkevich, Director of the Physical-Technical Institute, Corresponding Member of the Soviet Academy of Sciences. “According to our system, the implementation of any new scientific idea passes through a number of successive stages: the laboratory—the branch institute—the plant. And quite often the idea runs into obstacles at each stage.

“If the concept originated in the laboratory of an academic institute or higher institute of learning, it is by no means always possible to demonstrate its appropriateness or practical feasibility in a reasonably short time. This is because not every laboratory has the equipment necessary to this end.

“Regarding the second stage, at the Scientific Research Institute, it may happen that the technical people there are not interested in developing an ‘outside-originated’ idea. Often it is a matter of months before both sides can reach an agreement on all aspects of the technology and design.

“Finally, there is the terminal stage, the plant. Here, based on the equipment and tooling presently available at the plant, the engineering staff will occasionally revise the technology and, in some cases, even the design. The result, still further delay.

“It does not follow that even series production of a new item necessarily means practical acceptance of that item. In fact, simply because it has been produced, a component or instrument does not automatically become useful to a customer if the equipment for which it has been designed is not yet in production. This was the case, to cite one example, of the high-power semiconductor tubes developed at our institute. For two years the plant manufacturing these tubes was working, you might say, for the ‘shelf.’ The situation changed only with the appearance of the rectifier units for electrolysis and electric trains. In a word, lack of coordination and guidance in the efforts of numerous research agencies, branch institutes, and production facilities poses a major obstacle to the practical implementation of many scientific achievements.

“It would appear that in many instances important national economic problems might best be solved by abandoning this step-by-step processing of new ideas. In our opinion, task forces might be set up, which would continue their work only until the completion of a specific project. These task forces should include representatives from all interested organizations and agencies, from the Academy of Sciences to the plant level.

“Quite instructive, in this regard, is the experience we gained in the development of the semiconductor current-frequency converter. To meet this task, we established a task force which included staff workers from our institute and from the Power Institute, along with plant-level technical personnel. The entire work, from the conceptual stage to production of a pilot model, was accomplished in a very short time.”

In Cooperation with Engineers

E.D.Andronikashvili, Director of the Institute of Physics, Member of the Academy of Sciences of the Georgian SSR. “The rate of scientific-technical progress is affected by a variety of factors. One of the principal deficiencies in many scientific establishments is insufficient attention to the development of new experimental methodologies for the discovery and analysis of natural phenomena.

“At our institute we developed spark chambers, of the streamer and wide-gap type, which are now used with all accelerators. Another kind of instrument was designed for work in the area of high-energy physics—a discharge-condensation chamber, capable of competing, in a number of applications, even with the familiar hydrogen bubble chamber. We have proposed original methods for studying the strength characteristics of metals and alloys at low temperatures and have built sensitive microcalorimeters to permit the formulation and solution of utterly new problems in the area of biomacromolecular physics.

“Unfortunately, the instrument-manufacturing industry has shown little interest in the production of these new devices. To cite a specific case, our institute worked on the development of an apparatus which, based on the behavior of a radioactive signal throughout a production cycle, would signal the manganese concentration in the raw material, in the concentrates, and in the ferroalloys. What was the result? Far less time was required for the R&D phase of the project than for the introduction of a prototype model at one of the Chiatura concentrating mills.

“It often happens that the practical implementation of scientific developments is left to scientists who do not understand the production aspects of the problem, or to engineers who are not familiar with the principles underlying the new machine or equipment. We have already submitted a proposal to the effect that in such cases mixed teams of alternating membership should be formed, to include scientific personnel and production-oriented engineers. As the work proceeds, the number of scientists in the group should decrease, while the number of production engineers, well acquainted with the prospective environmental conditions of the equipment under development increases. It is our belief that an approach of this kind would do much to meet the requirements of satisfactory scientific and technical progress."

From Department to Shop

I.N.Pustynskiy, Department Chairman of the Tomsk Institute of Radio Electronics and Electronic Engineering. "Here is a letter we recently received: 'In line with technical assistance procedures, we request that you send operating instructions for the PTU-8G "Teleglaz" industrial television system, as well as information regarding its cost, the manufacturing plant, and the enterprises at which it is presently in use.' The inquiry came to us from the Kuznetsk Metallurgical Combine.

"Our reply was a factual one. Portable television systems which can be used to view the inside of pipes and various containers do exist. The PTU-8G is one such system; the letter "G" in the designation stands for "gornaya" ["mining"] (Translator's Note: The remaining letters "PTU" in the same designation are the initial letters of the Russian words for "portable television system"). This 'Teleglaz' ['Tele-Eye'] can be inserted into a shaft 100 millimeters in diameter.

"This system (it was shown at the VDNKh (Translator's Note: VDNKh— Exhibit of National Economic Achievements)) was developed by us on an order from, and with the assistance of, the Institute of Mining of the Siberian Branch of the Soviet Academy of Sciences. Other similar devices have been used at aircraft factories, at chemical plants, and at the I.V.Kurchatov Atomic Energy Institute. This last 'Tele-Eye' of ours, the tenth of the series, is the smallest. Its pick-up camera is designed in the form of a metal cylinder 25 millimeters in diameter. The entire unit, with cable and remote receiver, will fit in a briefcase. It plugs into a normal power outlet and in the field is fed by a 12-volt storage battery.

"With regard to the second part of the question, about the manufacturing plant, thus far there is, regrettably, no manufacturing plant, although our own in-house production facilities are limited and unable to satisfy even the internal demand.

"What should be done? A system clearly delineating the various areas of responsibility should be set up; who is to propose new ideas, who is to carry out the research and development work, and who is to see to series production. All these activities must be subordinated to a single coordinated plan, with common incentives provided for everyone involved in the projected new item. And while in the case of the branch institutes these problems are solved in accordance with the economic reform program—as indicated by the experience of the electrotechnical industry—effective lines of communication must also be sought for vuz-centered research organizations.

"Today, in our opinion, the process of bringing a new item from the institute laboratory into actual production must still involve an intermediate step—an organization or firm capable of assigning and remunerating the work at its various stages of completion. We consider the establishment of such financially self-sustaining firms to promote the purposes of scientific and technical progress to be a measure of great timeliness."

Japan

Smaller than California with a useful area of only 30%, prostrated by total war just 30 years ago, Japan now challenges the world for supremacy in high-technology goods and services. So far, this challenge is economic—but if their industrial power continues to grow, it is hard to see how they can avoid leadership in cultural, political and perhaps even military roles as well.

Their economy is now third largest—ahead of West Germany, France, Britain, and China. Even more remarkable is the GNP growth that they sustained for 20 years up to the impact of the "energy crisis." From their destitute drop due to World War II they grew in real terms annually at 9% in the fifties; more than 10% in the early sixties; and 12–14% in the late sixties. They rank first in shipbuilding, commercial vehicles, optics, and most consumer electronics—they are a fast-growing second in computers, passenger cars, bulk steel, aluminum, copper, textile fibers, and petrochemicals.

Japan is poor in natural resources—but with long low coastal areas, efficient shipping, and vigorous trading conglomerates, they command lowcost access to the raw materials of the world. They have been very active in forming congenial partnerships with developing countries to produce the materials needed by Japanese industry.

Japan's success is not a recent phenomenon; the Meiji reformation began it a century ago. It is not just cheap labor; with their permanent security, housing, bonuses, education, and 10% annual-wage increase, they are passing some of the West Europeans. It is not just high exports; Japan exports less than 12% of its production—only half that of Britain and Germany. Rather, Japan's success may be attributed to the efficient functioning of a special social system, all of whose parts act together for the common purpose of economic advancement.

Perhaps "Japan, Inc". best describes their unique system. The goals of government, management, and labor are the same—to become the leaders in world productivity. In this system, the government sets overall goals, plans and coordinates long-term strategy, and controls major investment. But the nation's corporations retain great tactical operational autonomy for achieving national goals, and they compete vigorously for profits with one another within Japan. To a remarkable extent, the entire system operates by consensus—a sort of national participative management.

An elaborate, generalized technology strategy was adopted by the Japanese, ideally conceived to exploit that nation's energy, cultural skills, and basic scientific resources, while overcoming the obstacles posed by geographical remoteness, dearth of home natural resources, and limited space. The strategy called for:

- Vigorous expansion in basic industries (e.g. surpassing U.S. in steel capacity by 1975 or so);
- Vigorous lining up of overseas mineral supplies (copper, chromium, etc.);
- Establishing shipbuilding and shipping for transporting these supplies;
- Concentration on small-volume, high-value products (optics, solidstate devices, small vehicles);
- Importing rather than inventing technology;
- Highly selective, long-range basic research;
- Heavy emphasis on engineering education;
- Seeking out areas of high growth potential suited to their culture (such as marine resource recovery).

Although the Japanese program has had astonishing success, the future is somewhat clouded by the polluting effect of all this progress on the environment and by the nation's lack of primary energy sources.

Global Technological Policy of Japan Japan provides the most sophisticated example of a national technological policy. Yet, Japan has no Ministry of Technology, not because technological policy is unimportant, but because it is probably too important to be entrusted to any particular body. One of its most vital and best-known agencies (and often initiator of technological policy) is MITI (Ministry of International Trade and Industry), whose jurisdiction extends over a large number of industrial sectors. Other agents are the Ministry of Transportation (which includes shipbuilding), the Ministry of Public Health, the Science and Technology Agency (which plays a major role in the imports and exports of technology), and the Foreign Investment Council. Thus, overall or global technological policy transcends both sectoral policies and departmental responsibilities. The originality of Japan is that there are such sectoral policies for almost all industries, whereas in other countries the number of sectoral policies is markedly smaller and more limited in scope; in fact, these policies in other countries are the exception rather than the rule and tend to address themselves essentially to the science-based industries. In Japan, technological policy covers not only the newer sectors such as computers and integrated circuits, but also the well-established industries such as petrochemicals, steel, heavy machinery, and automobiles.

National technological policy seeks to assess and improve the overall level of technological sophistication of a country viewed in its totality. Components of the policy include international trade, imports and exports of technology, level of education, degree of technological independence, and the country's role in the world techno-economic system. Until recently, such policy in Japan has focussed primarily on the problem of catching up, technologically and economically, with the most advanced countries. Now that Japan has essentially caught up, fresh objectives are (a) to maintain that which has been achieved, i.e., to push forward at a pace at least commensurate with that of other countries and (b) to try to solve social and technological problems which arise as a result of rapid technological development.

Japan has developed a number of technological indicators which are similar in many respects to economic indicators upon which economic policies are built. Among the most important are: the balance of technological payments, the patterns of direct international investment, the directions of foreign trade, the volume of industrial production made on the basis of foreign technologies, the average size of industrial firms, and the productivity of industry. (By contrast, in most other countries, such data tend to be less refined, less reliable and comprehensive, and not available over sufficiently long periods. Likewise with science policy; while relatively good data exist on inputs into the science system—e.g. R&D expenditures and manpower—relatively little data exist on the outputs of these systems. Hence, it is then virtually impossible to measure the effectiveness of national science policies).

The implementation of Japan's technological policies has relied essentially upon two tools, one external, the other internal. The external tool is the system of control of the access to enter national markets: imports of technology, licensing agreements between Japanese and foreign firms; direct investment by foreign companies and all foreign payments are tightly controlled by the government. The internal tool is the peculiar, and probably unique, partnership between private industry and government. This partnership reflects a congruence between the objectives of the government and those of private industry, a congruence synthesized in a common understanding of the national interest. Another feature of the Japanese system is the nature of the decision-making process—a good decision is the one upon which all participants have agreed and not the one in which one point of view has gained the upper hand over the other.

Some Particular Aspects of National Technological Policy

A. The Concept of "Key Industries" —In the U.S. and Europe, the science-based industries such as electronics, aerospace and nuclear power, have generally been regarded as key industries. In Japan, industries which are usually considered as highly traditional can also be regarded as key industries. Thus, shipbuilding in Japan has been a major stimulus to the steel industry, the electronics industry (fully automated tankers), and the machine tool industry. This suggests that virtually any large industry can come to play the role of a key industry in a technological policy.

B. Critical Size of Markets—Western countries, particularly European, have tended to opt out of certain technologies which require large investments primarily because their vision of the potential market was too narrow, often being limited to the purely national market. It is increasingly clear that technological progress can be achieved only if markets are defined in worldwide terms. The Japanese experience suggests that the traditional definitions of critical size of market or investment rely too heavily on the data and experiences of the U.S.

C. Investments in Fundamental Research—Compared with other highly industrialized countries, Japan has until quite recently been spending relatively much less on fundamental research. (Japan has obtained only two Nobel prizes in science.) Yet, the successes of Japanese technology suggest that at a certain stage of its development (which Japan has probably just passed) a country can save on its fundamental research effort without endangering its technological and industrial strength.

D. Balance Between Original Innovation and Imported Innovation—Most national science policies tend to concentrate upon the creation and diffusion of original innovation i.e., generated within the country itself. Scant attention is given to the fact that the overall process of innovation draws very heavily upon imported innovations, brought into the country through foreign firms, licensing agreements, transfer of scientists, personal contacts, and imitation. Japan is probably the only country where imported innovation is treated as a major dimension of technological policy. However, this poses some problems: How can imported innovation be made to stimulate rather than thwart the indigenous innovative efforts? How can a smooth transition be achieved from imported technology to indigenous technology? What are the most effective and cheapest means for bringing new technology into the country?

E. Spin-off from Military Research—In the last 30 years a number of major technologies in the West have found their origin in military research. Japan has been spending little on military research but this does not seem to have affected, negatively, the competitiveness of its industries and the sophistication of its technology.

F. Importance of Sociological Factors—The Japanese model suggests that if a technological policy is to be successful it must fit into the country's social and psychological patterns, a point that seems to have been largely overlooked or ignored in other countries. For example, European countries, in the belief that greater mobility of scientists and engineers would help diminish the technology gap, have tried to stimulate such mobility. The Japanese model shows, however, that a very low rate of mobility is no real impediment to innovation. It suggests that a technological policy should consider such factors as mobility or nonmobility as a specific national characteristic and, rather than try to modify it, seek to use it in a positive way, or at worst to accept it as one of the societal constraints on policy.

Japan's Science Policy for the Seventies The Science and Technology Agency of the Prime Minister's Office has indicated the broad outlines of Japanese science policy for the 1970's. Five major influences are recognized: (1) the growing awareness of the adverse side effects of technology on environmental quality; (2) the problems of an expanding, information-oriented economy and rising standard of living while dependent on overseas sources for raw materials; (3) the need for more mission-oriented R&D in concert with the promotion of basic science; (4) the need for more interdisciplinary cooperation in order to solve society's increasingly-complex problems; and (5) the need for increased international cooperation in science and technology, if the economy is to continue expanding, with both, developed and developing countries.

A science policy is being developed in response to these influences. In contrast to earlier policies which aimed primarily at raising the technical level of industry and the economic level of the country, science policy for the 70's will be concerned with the betterment of human wellbeing. The following factors are being considered:

(1) There must be more respect for man and his welfare.
(2) Problems facing science have become exceedingly complex and call for collaboration among many disciplines and the interdisciplinary approach.
(3) Basic science and applied technology must develop in harmonious collaboration.
(4) Highly-original technology must be cultivated to meet changing situations at home and abroad and to meet social and economic needs—particularly new technologies to be used in exchange for technologies from other advanced countries and new technologies (to ease Japan's high-density population problem) which are not readily available elsewhere.
(5) To give due consideration to the relationships between science policy and other national policies.
(6) To clarify and define the state's role in promoting science and technology so that the state can play its role effectively—e.g. accelerating R&D, promoting the spread of scientific and technical information, supporting scientific and technical talent, aiding developing nations. On the other hand the private sector is now more able to carry the R&D load in some sectors previously carried by the state.
(7) To attach greater importance to international cooperation in science and technology to raise Japan's status—particularly aid to developing nations and exchanges with other advanced nations.
(8) To foster greater capacities and flexibilities for information processing to give faster response to social, economic, and technical changes.
(9) To emphasize the view that the earth's material resources are finite.

In line with the above guidelines, the following tactics for science and technology have been proposed:

(1) To improve the quality of life:

(a) Improve medical care.
(b) Improve living conditions—food, diet, housing, etc.

(2) To consolidate social and economic foundations and preserve the environment:

(a) Increase transport capacity—e.g. 3D traffic systems.
(b) Facilitate information processing and communications.
(c) Secure and use more effectively sources of energy and materials.
(d) Preserve the quality of the environment (control of pollution, etc.)
(e) Prevent natural and man-made disasters and/or consequences.

(3) To develop the economy efficiently:

(a) Modernize agriculture, forestry, fisheries.
(b) Modernize and rationalize manufacturing industry and foster new industry. Develop automation and emphasize brain-intensive Industries.

(4) To fulfill international obligations:

(a) Assist developing nations.
(b) Exchanges with advanced nations.
(c) Participate in international agencies.

(5) To develop the foundations of technology:

(a) Support applied science both when the eventual applications are clear and when they are still hidden.

(6) To promote basic science:

(a) Cultivate the ground for later development of technology and to engage in the search for truth.

The Implications of National Goals for Research Strategies

Much of the post-war growth in research in countries such as France, Germany, and the U.K. seems to have stemmed from a conviction that there is a causal relation between investment in research and economic and social prosperity. Nations expanded their scientific resources and coupled them to more and more national programs as needs arose. Science policy, such as it was, developed as a superposition of these programs which were expected to have a stimulating national effect. Such a build-up was inevitably piecemeal and haphazard—it lacked a systems approach. It is now increasingly evident that there has to be enhanced coordination among the departments and sectors responsible for conducting a nation's scientific and technological progress, but that coordination is not the same as central control. In relating scientific policies to national goals, there has to be a continuing dialogue between the scientific community and society at large. Out of this dialogue should come broad agreements as to allocation of resources among various programs and between basic and applied research. Instead of, for example, the government simply supporting basic research in the hope that corresponding support for applied research and technology will be taken care of in some vague manner by industry, a systems approach could lead to a more balanced distribution of resources.

If the post-war period saw some over-emphasis on the support of basic research in various countries, there is now a danger of over-reaction: that relative to applied research, basic research will be supported too little. This danger becomes more acute in the face of changing national goals, multiplying national needs, and social pressures which are impinging on the scientific community in more ways than ever before. In this climate, the scientific community has to become increasingly adaptable and flexible. In addition, while national technological priorities may change with time, it is vital that a policy be maintained which gives the scientific community adequate opportunity for spontaneity in basic research. Compared with other scientific fields, the materials field is relatively fortunate in that important links can readily be perceived between basic research and applications. On the other hand, the fruitfulness of the basic research may be significantly reduced if it is required to shape itself too strictly according to national priorities. Again, the overview or systems approach is called for on a national scale.

> In conclusion; "At a time when the necessary or possible objectives are particularly shifting and elusive, research policy cannot apportion fundamental research to a number of precise orientations; for lack of simple goals, the national demand for research cannot be defined in detail. In the last analysis, the quality and relevance of research

> can depend only on the quality and relevance of a demand for research which can be precisely and flexibly formulated only by those directly concerned. The orientation of scientific effort is for this reason becoming a matter more of mechanisms than of objectives."[5]

NATIONAL ADMINISTRATIVE STRUCTURES FOR RESEARCH

Materials science and technology throws into sharp relief, more than many fields of science alone, the critical importance of the form of national administrative structures for research. Since materials science and engineering (MSE) depends so heavily on close relationships between all parts of the spectrum, from basic research to industrial applications, it is a field of activity which cuts across what are traditionally departmental boundaries in the administrative structure. Thus, wherever such boundaries pose problems in technology transfer, there is hope that MSE will provide a robust vehicle for surmounting them. This section reviews some of the research administrative structures that have been developed in various countries, and draws implications for the administration of materials research in the U.S.

General Outlines of Administrative Structures

The typical approach for federal conduct of R&D in the U.S. is for mission-oriented departments and agencies, such as DOD, AEC, and NASA, to have the authority for deploying their resources for research between inhouse and outside laboratories, granting R and/or D contracts to industries, nonprofit laboratories and universities, and supporting a mix of basic and applied research. In addition, NSF has traditionally concerned itself with the health of the nation's science by supporting high-quality academic research. This administrative system seems relatively unique to the U.S. For the most part, other countries appear to have administrative systems which lead to a more clear-cut delineation between organizations responsible for supporting basic research on the one hand and the mission-oriented organizations supporting applied work on the other.

In Western Europe, the governments of France, Germany, and the United Kingdom shoulder the main responsibility for formulating and coordinating science policy but none of the three has brought all scientific and technological activities into a single ministry, though the degree of centralization varies in the different countries. Similarly in Japan, and even Russia, where national technological planning has perhaps figured more conspicuously than in other countries, there is no one body responsible for the whole of technology.

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[5] The Research System; OECD, p. 55, 1972.

United Kingdom

In the United Kingdom, responsibility is shared between the Department of Education and Science (DES—mainly basic research) and the Department of Trade and Industry (DTI—primarily applied and mission-oriented research) but with considerable freedom for maneuver left to the private sector. Reporting to the Cabinet is a Central Advisory Council for Science and Technology (whose current chairman is a well-known metallurgist), the function of which is to advise on the most effective national strategy for the use and development of the country's scientific and technical resources.

The DES is responsible, among other things, for governmental policy regarding the universities and for promoting civil science throughout the U.K. The Departments' relations with the universities are conducted through the University Grants Committee (UGC); and its responsibilities for basic and applied civil science are discharged mainly through the five research councils: Science, Medical, Agricultural, Natural Environment, and Social Science. The Department is also responsible for some aspects of international scientific relations and for governmental policy regarding libraries and information systems. To advise the head of the Department (Secretary of State for E and S) in the exercise of his responsibilities for formulating and executing scientific policy, there is a Council for Scientific Policy (CSP). Among the issues with which the CSP is concerned is the balance of scientific effort in those areas within the purview of the DES.

The DTI has as its main objective the assistance of British industry and commerce to improve their economic and technological strength and competitiveness by establishing a general framework of requirements, incentives, and restraints within which firms can operate to their own individual advantage. The DTI, among other things, is responsible for the Atomic Energy Authority, the National Research and Development Corporation, and six industrial research establishments including the National Engineering Laboratory, the National Physical Laboratory, and the Warren Spring Laboratory (primarily chemical engineering). Besides R&D for industry, these establishments are engaged in the application of techniques and discoveries to design, production, quality control, and distribution. The DTI also sponsors research in autonomous industrial research associations as well as in industry and universities.

A third agency is the Department of the Environment (DE). The DE has responsibility for the range of functions affecting the physical environment in which people live and work. These include: Housing and Construction, Transport, and Environmental Pollution, each of which engages in some research.

Germany

In Europe, decentralization is most marked in Germany (where, for example, the Länder retain considerable autonomy in education) —the system appears to have achieved a high degree of social, political and economic pluralism; here the initiatives and contributions of the different institutions of the public and private sectors cross-fertilize each other, but each of the partners retains a large measure of autonomy. Support of basic research is mainly in the hands of private organizations—the Deutscheforschungsgemainschaft (DFG) and the Max-Planck-Gesellschaft (MPG), with the federal government primarily involved with applied and missionoriented research administered through the “Ministry für Bildung und Wissenschaft.” There is good cooperation between the ministry and other agencies, especially DFG, to bring about contacts and joint efforts between industry and universities. This reflects recognition of the serious communications gap that has persisted between the academic and the industrial establishments in Germany where the tradition of the autocratic, independent, securely tenured, professorships still has a firm hold. Materials research has played a particularly important role in bringing about more collaboration both within universities and between universities and industry. Furthermore, the materials disciplines, including solid-state physics, are receiving much more attention in all respects than they did five to ten years ago when nuclear physics dominated science policy.

France

In France, the interministerial structure of the Délégation Générale a la Recherche Scientifique et Technique indicates an effort to centralize and coordinate decisions, while executive responsibility is assigned in particular to the Ministry of Education and the Ministry for Industrial and Scientific Development. The Centre National de la Recherche Scientifique (CNRS) is the mainspring of the French system of financing and performing basic research. It combines the roles performed by the DFG and MPG in Germany.

Each of the above countries seems to have recognized the impracticality of detailed planning of fundamental research while feeling the need to ensure the balanced use of available resources. It has proved difficult to reconcile the accomplishment of sector missions with the undifferentiated financing of basic research. But research policies are becoming more inseparable from national planning policies; they are explicitly included, for example, in the “national five-year plans” that have been practiced for several decades in France and, of course, the U.S.S.R.

U.S.S.R.

In Russia, the prestigious Academy of Sciences has long exercised a central responsibility for the nation’s research programs carried out in its own institutes and in the universities, while applied research and development of a mission-oriented nature is the responsibility of the various industrial ministries. Effort to achieve overall coordination has centered mainly in the Academy of Sciences, but “departmental barriers” between different research sectors are considerable, and have been overcome in the case of major scientific projects only by means of special arrangements. In the case of the atomic bomb project, this was achieved by the setting-up of special government agencies, supported by the defense departments, which cut across existing barriers, involving both the Academy of Sciences and industry plus a massive authority to exercise priorities for resources. More recently the trend has been for applied R&D to be consolidated under the appropriate technical ministries.

Before about 1930, the Academy had been firmly oriented towards theoretical research or "pure science." During the early 1930's, however, in an effort to associate the Academy, and "pure science" generally, closely with the industrialization drive, a number of leading engineers and technologists were elected as Academicians; technological research institutes were established under the Academy; and in 1935, a separate Division of Technical Sciences was formed.

Between 1959 and 1963, the role of the Academy in the technological sciences was strongly called into question. It was argued that the large technological research establishments within the Academy system did not have sufficiently-close connections with industry; moreover, because the efforts of the Academy were overextended, it did not devote enough attention to leadership in the natural and social sciences. Subsequently, a substantial number of institutes concerned with applied R&D were transferred from the Academies to the industries concerned.

Czechoslovakia

The Eastern European countries which came under U.S.S.R. influence after World War II offer unique opportunities to observe what happens when a country's scientific establishment is reorganized completely along Soviet lines. The case of Czechoslovakia is particularly interesting since this country was technologically the most advanced of the countries in question when Russia took over in 1948.

Paralleling national policy in the U.S.S.R. the Communist government in Czechoslovakia gave science top priority. At first, a research bureau was set up to direct all basic and applied research, but in 1952 the Soviet model of an Academy of Sciences was adopted for coordinating all basic research. That this was done reflected the high prestige and power of the Soviet Academy of Sciences. Thus, like the Academy in the Soviet Union, the Czechoslovakian Academy became relatively disconnected from industry.

Within a few years, the following became the principal features of science organization in Czechoslovakia:

(a) The Academy was responsible to the government for all basic research in the natural sciences, mathematics, social sciences, and humanities, both within its own institutes and the small amount carried on in the universities;
(b) The universities were restricted very much to teaching, receiving only very limited support for research;
(c) A relatively large number of applied research institutes under various Ministries were created with responsibilities for applied research and development for industry.

The "Basic Research Plan" of the country is divided into many "Problems" such as nuclear physics, elementary particles, solid-state physics, plasma physics, analysis, topology. Every Problem is divided into "Sub-problems," such as solid-state physics into semiconductor physics, physics of metals, physics of ionic crystals, structure of solids, ferroelectrics, etc. Each Sub-problem contains actual topics of research such as, for semiconductors, "theoretical determination of band structure," "experimental determination of band structure," "amorphous semiconductors," and so on. These topics usually denote the actual work done by various groups headed by Candidates of Science. The division of research into Problems and Sub-problems was fixed in the late fifties and provided a formal, almost permanent structure for the administration of planning.

Each year, every research group in every institute of the Academy suggests the plan of work for the following year; this is discussed in the Council of the Director of the Institute and then sent to the "Coordinators for Sub-problems" in the Planning Department of the Academy. After consultations with all concerned, the Coordinator lists the topics for each Subproblem, the responsible investigator, the date of termination of various phases of the research, and the estimated amount of money required.

The plan assembled in this way has to be approved first by the various bodies in the Academy. The members of the Academy are divided into Collegia, such as Collegium of Physics, Collegium of Nuclear Energy, Collegium of Mathematics, etc. For reviewing the research plan the Collegia are augmented by others, such as directors of large institutes, a few professors of the University and a few outstanding scientists from the institutes of the Academy. One or more members study the proposed problems submitted to the Collegium for approval and report their findings to the Collegium. Approval, perhaps with a few suggested changes, is given in principle by voting; usually the decisions are unanimous.

The Planning Department then assembles all the approved Problems and presents them at the beginning of the year to the government for the formality of final approval.

The Coordinator follows the progress of the research effort during the year. If some work does not proceed as planned, modifications to the plan are discussed between the Coordinator and the investigator. At the end of the year a brief performance report is submitted for approval by the appropriate Collegium. In turn, the Planning Department submits a final report on the fulfillment of the plan to the General Assembly of the Academy which, after discussion, approves it by voting, and transmits it to the Government for the formal final approval.

If taken literally, the Central Planning procedures are exceedingly tedious and frustrating and call for commitments of research programs towards well-defined, practical objectives. However, as is not unknown in the West, ways are found for wording proposals that are politically expedient and yet leave the scientists relatively free to pursue their work in the way they judge best.

Funding is not tied directly to each annual proposal in the Plan but is more in the form of a block grant to the institute. Equipment purchasing is time-consuming—large items, such as an electron microscope, have to be planned for at least two years ahead, while even small equipment (such as voltmeters) requires a year's advance notice. Restrictions on equipment imported from the West may cause severe delays.

Attempts at coordinating the work of Academies in various Eastern Bloc countries have been of only limited success—limited mainly to exchanges of scientists, the organization of conferences and summer schools, and exchange of information about research programs. Joint programs have not developed, in spite of goodwill among the scientists, mainly because of bureaucratic difficulties.

As far as advantages and disadvantages are concerned:

(a) The system provides a fair degree of protection for the scientists since their research programs are officially approved by the government. As a result, research in natural sciences enjoys relatively free development.
(b) The planning procedures do not actually make heavy demands on the time of the scientists and yet they are assured of relatively long-term support. (As a result, in Czechoslovakia remarkable progress was made in chemistry, physics, and biology (compared to the situation before the War).
(c) The detailed planning results in some program inflexibility. It is difficult to terminate existing programs in order to provide resources to start new ones. Thus research programs tend to be perpetuated well beyond the point of obsolescence.
(d) It is difficult to impose research programs from above principally because such programs seldom appeal to the scientists who prefer to continue working on what they choose even if the financial support is somewhat less.
(e) In spite of all the central planning, science as a whole is poorly coordinated, principally because research plans from different institutes can be differently worded even if the work is much the same. (The best form of coordination arises through personal contacts and direct information exchange at conferences.)
(f) The planning largely fails in the task for which it is primarily created— to provide a link between basic research and industrial research (see below).
(g) The planning system is inefficient for promoting interdisciplinary research involving different institutes. Instead, if a physics institute needs the cooperation of chemists, it generally has to have them on its own staff rather than try to arrange collaboration with a chemistry institute.

In the fifties, many scientists in Czechoslovakia were sympathetic to the notion that most research should have a practical pay-off, but the way in which industry was organized and operated tended to frustrate effective cooperation between the Academy scientists and the industrial engineers. There seemed to be strong indications of the “Not Invented Here” syndrome in industry which had set up its own development or technological institutes. But also, industrial planning was much more specific and tied to clear-cut objectives. If these objectives were met, there were bonuses. On the other hand, the bonus could still be obtained despite failure to meet the objective if the failure could be attributed to bad advice or information from the Academy scientists.

Another negative feature of the bonus system in industry was that individual workers were encouraged in this way to make suggestions that would lead primarily to cost savings in production. The result was often a decrease in the quality of the product. Such a system worked against introducing potentially more costly, even if better, ideas stemming from research. The fact that the customers had virtually no product choice also gave little incentive for product quality.

Thus, in ways such as these the Academies became the whipping-boys for industry. And in every dispute with industry the politicians tended to side with industry.

As an example, when engineers in the electronics industry became interested in solid-state devices they initially obtained information from Academy scientists. This information was then declared "useless," the industrial institute claimed it had to make many "technology improvements," and thereby earned its bonus. Nevertheless, Academy scientists did see some of their work being applied in industry and this led, in turn, to useful informal contacts at the working level. However, for obvious reasons these were generally frowned upon by upper management, especially in industry, and the scientists had to spend much effort to defend themselves against various accusations. They noticed, however, after a time, that such difficulties did not arise when their work had no practical applications. Thus, the Academy work tended to become more fundamental and more detached from industrial application. Some institutes acquired a high reputation for their research and when this was noted by influential Academicians in the U.S.S.R. it came as a surprise to the government which had heard nothing but complaints about the Academy from industry. So, in due course, a modus vivendi or co-existence with relatively little interaction developed between the Academy, the research institutes, and industry.

Japan

Japan uses separate organizations for supporting basic and applied research—principally the Ministry of Education for the former and the Ministry of International Trade and Industry (MITI) and other technical ministries for the latter. The Prime Minister is advised in scientific matters by two committees: the Council for Science and Technology, an arm of the central Science and Technology Agency which links the various Ministries and Agencies and is comprised of various key ministers and external "men of learning;" and the Science Council of Japan which is a representative organization of Japanese scientists.

The role of MITI in implementing national science and technology policy is worth reviewing. MITI generates an overall plan for the direction in which technology is to develop in Japan, determines the subsidy or funding which is to be provided, and determines which organizations are to undertake the initial development and then the subsequent steps. MITI administers 16 laboratories with a staff of 2600 researchers. The following are some examples of recent actions taken by MITI:

(a) In 1968 MITI held talks with representatives of various Japanese electric and electronic manufacturers to consider the future course of integrated circuit (IC) production, as well as current problems. The Ministry was particularly concerned over the fact that more than ten firms were producing IC's on a small scale, whereas mass production was considered to have many benefits. As a result of these talks, an Integrated Circuit Council was established by nine of the manufacturers with a view to advancing the IC industry through closer cooperation among manufacturers as well as backup from the government. The next step was the standardization of IC's into a modest number of types with the aim of mass producing this smaller quantity at lower cost. Subsequently, some of the restrictions on the kinds of IC's that could be undertaken were eased as the industry gained strength.

(b) MITI undertook the same general pattern in the computer industry where, under its guidance, six computer manufacturers agreed to concentrate production on certain standard types of computers and output devices on a division-of-labor basis. It was agreed which of these manufacturers would produce which units.

(c) MITI undertook to regulate the equipment investment by 57 companies in the electronics industry during fiscal 1969. The program called specifically for increased investment in the manufacture of electronic computers, for the volume production of integrated circuits, for increased production of color TV sets and related parts, and for increased output of electronic desk-top calculators and tape recorders.

(d) Another project undertaken by MITI was the development of electric automobiles. As might be expected, the initial effort was to concentrate on high-power batteries which could be used to run such a car. The electric automobile program now is being carried out under six phases. The first is the development of five types of experimental vehicles by five separate companies; second, the development of a reinforced plastic body; the third, development of batteries by three firms; fourth, the development of motor controls by three firms; fifth and sixth are research on battery-charging systems and research on utility systems.

(e) MITI has formed plans to integrate some 20 oil development enterprises in the country into groups of three or four firms in order to promote effective operations for overseas oil resources. It appears that they have been dissatisfied with the previous effort of one company which did not have the resources itself to carry on a program of this magnitude.

(f) MITI is now establishing a basic policy for setting up a special enterprise for the development of Japan’s next civil air transport plane. It is said that this will be undertaken jointly with some foreign aircraft firm, possibly Boeing.

(g) MITI has formed a plan to control the steelmaking capacity of the country by reducing the number of blast furnaces in operation, as larger and more modern blast furnaces are put into service. The pattern for the control of the capacity is based on a long-range projection of the nation’s steel supplies and demands. It is recognized that there could be ill-effects not only domestically because of overproduction, but also in international relations because of the drive to export as a consequence of such excess capacity.

(h) MITI recently placed extra emphasis on modernization of the polyvinylchloride industry. This move was undertaken because that industry was suffering seriously from falling profits in the Japanese petrochemical industrial sector. The modernization would include establishment of a joint export company and the formation of a joint government-industry organization to regulate the expansion of facilities.

(i) MITI has worked out a “stockpile system” to help assure a stable supply of important basic materials like oil and nonferrous metals. The aims are to avoid emergency supply shortages caused by disasters or accidents and the encountering of sharp increases in market prices, as well as to strengthen Japan’s bargaining powers in negotiating purchases from overseas sources.

Other Countries

It is interesting that in some smaller, but technically advanced, countries, such as Belgium and Sweden, responsibility for science rests with the Prime Minister and is not delegated.

Centralized or Decentralized Administration?

This question has been discussed by Brooks[6] in a broader framework but it is particularly pertinent to the administration of MSE.

The aims of science policy in the future will be more diversified, but also more coherent, and will be designed to produce innovations comprising important nontechnological components.

Research policy during the next few years will, therefore, include an increasing variety of circumscribed and even highly-specific programs. It may be thought that such a situation requires flexible agencies endowed with wide autonomy, capable of reacting quickly to events without deviating from the missions assigned to them. A careful selection and integration of a wide range of changing and sometimes conflicting options, however, seems to call for some central decision-making mechanism.

It is not surprising that the proper balance between the pluralistic and the centralized systems is a matter of continuing debate. In practice, there is no national system of science policy that follows either model in its simplest form. Any viable system of science policy must involve some blend of the two idealized approaches. Each tends, with time, to develop its own rigidities and limitations, and some shift in the mix from time to time may actually be beneficial.

Many national systems that recently approximated the centralized model are now moving towards a more pluralistic or sectoral approach. There appears to be a convergence of all systems of national science policy towards arrangements that embody elements of both idealized models.

The mixed scheme fairly closely resembles that of most large science-based firms. Such companies often have research arms attached to each of their operations or product divisions, in addition to a corporate laboratory responsible for long-range research aimed at developing new products and operations, and providing a general technical background for all the firm's activities and decisions.

To summarize more specifically, experience in various countries indicates that a certain proportion of the total R&D funds should be allocated centrally by a scientific agency concerned mainly with, longer-term research, while another part of the R&D funds should be allocated by those responsible for individual sectors. There should be sufficient overlap between the research supported in the two different ways so that there is a continuous two-way flow of information and personnel between the scientific and operating areas.

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[6] H.Brooks, Science, Growth and Society, OECD, Paris, 1971.

There is an additional problem of coordination, where goal planning involves the intersection of various sectors, both technical and nontechnical. Science is then only one resource included in the planning and, under such circumstances, the planning function may have to develop in a single type of staff agency—an agency with projection, forecasting and analysis functions rather than just a coordinating agency for science and technology. Some of the principal features of the pluralistic and centralized model, are summarized in Table 8.6.

Discussion of Administrative Structures in the U.S.S.R. and the U.K.

Further insight may be gained concerning the effects of various administrative structures by examining such structures in the U.S.S.R., generally regarded as a centralized model, and the U.K., generally regarded as closer to the pluralistic model. These remarks are based on information given in "National Science Policies in Europe," UNESCO, Paris, 1970; "Science Policy in the USSR," OECD, Paris, 1969; and "A Framework for Government Research and Development," Her Majesty's Stationery Office, London, 1971 (the "Rothschild-Dainton Debate").

U.S.S.R.

The main organizations administering science policy in the U.S.S.R. are the Academy of Sciences for basic research and the various ministries for applied research. All are subordinate to the Council of Ministers (Cabinet). Many of the ministries possess their own substantial R&D networks, controlled from the center. Likewise, the Academy of Sciences exercises central control over research in natural and social sciences in many Soviet institutions. Thus, in principle, the degree of central control of all science is very high. Prior to 1965, the Academy was also responsible for numerous applied research institutes, but in 1965 these were transferred to appropriate technical ministries. At the same time the Academy's responsibilities for the natural and social sciences were increased. The Soviet Academy is now responsible for managing the research of its own establishments and for planning and supervising all research in the natural and social sciences, whether carried out at its own establishments, in the Union-Republican Academies of Sciences, or in Higher Educational Establishments. How far the planning and coordinating powers of the Academy are effective is not clear. Within the Academy itself, complaints abound that research plans are simply bureaucratic compilations of independent projects, and that science councils are often mere talking-groups which lack the powers to enforce their decisions. It is also difficult to assess how far the Soviet Academy influences the activities of Republican Academies and of Higher Educational Establishments.

The available evidence reflects a rather complicated process in which attempts at central planning of fundamental research, often somewhat bureaucratic, have been coupled with a situation in which much of the direction of research is determined by individual scientists rather than by

Table 8.6 Comparison of Pluralistic and Centralized Model of Research Programming

	PLURALISTIC MODEL	CENTRALIZED MODEL
STRUCTURE	Resources assigned to each policy sector as a whole— e.g. defense, health, transport, etc.	All resources for R&D given to a single agency for allocation among sectors.
ADVANTAGES	1) R&D is well coupled to the operational needs of various social goals and is more responsive to these needs. 2) New technological opportunities and scientific knowledge likely to be brought quickly to attention of relevant sector.	1) Facilitates more effective use of limited technical resources—manpower, facilities and money. 2) Encourages development of overall coherent policy for technical activity that avoids disruption of scientific establishment caused by sudden policy shifts. 3) Can have high flexibility and adaptability.
DISADVANTAGES	1) Places long-term and shortterm needs of the sector in direct competition with each other. 2) Definition of scientific and technological goals in the sector tend to become static. 3) Sector becomes less alert to new technical stimuli from elsewhere.	1) Likely to be less responsive to the operational needs of the various sectors. 2) Results of research can more easily be ignored or overlooked in sectoral planning. 3) May result in some rigidity or excessive conservatism in the operational aims of the various sectors.
USES	When sectoral goals are fairly constant and the total resources available to the sector are growing.	Situation of limited resources and uncertain or rapidly-shifting social goals.

the central authorities. In the post-war period, the problem of coordinating all R&D activities was acute. While each industrial ministry possessed substantial powers over its own R&D network, the authorities responsible for coordinating the work of the separate research networks (the U.S.S.R. Academy in the case of fundamental research, the U.S.S.R. Gosplan in the case of new technologies) lacked sufficient power to influence the activities of the major ministries.

The first real attempt to achieve such overall coordination was made in 1961, with the creation of the State Committee for the Coordination of Scientific Research (since 1965, the State Committee for Science and Technology).

The new Committee received powers to create new scientific establishments, to approve the list of lead institutes, to decide priorities, to discontinue research, and to allocate research projects to particular institutes. It soon became evident, however, that these powers were insufficient to achieve effective coordination. The Academy of Sciences, which remained independent of the new Committee, became in effect a “ministry” for the natural and social sciences. The various central authorities which administered research organizations between 1957 and 1965 often proved strong enough to resist the attempts of the new State Committee for Coordination of Scientific Research to control their research. More generally, its work was undoubtedly hindered by some hostility to the unified planned management of the development of science.

After 1965 the conception of overall administrative coordination of science was no longer maintained. Attention shifted to increasing the efficiency of scientific organizations, ways to accelerate the use of scientific and technical discoveries in the national economy, and to longrange (10 to 15 years) scientific and technological forecasting upon which to base the selection of directions for technical progress and developing the national economy.

The new instruments and agencies for planning and coordinating R&D still tend to reflect the administrative gap between the different phases of the research-to-production cycle. At the center, the State Committee for Science and Technology is apparently responsible for only R&D per se, up to and including the prototype stage; production, including the first industrial batch of a new product, is handled by Gosplan. At the same time, the U.S.S.R. Academy of Sciences continues to bear the main responsibility for research in the natural and social sciences, and its plan for these sciences does not form part of the annual Plan for Scientific Research and New Technology.

It seems that the centralized planning system in its present form imposes definite limits on the efficiency of Soviet R&D and that the problem of generally increasing R&D efficiency depends on the successful modification of the planning system as a whole. Key questions here are the proposed decentralization of decision-making; the introduction of noncompulsory, financial and economic instruments of plan implementation; and the use of consumer’s preferences and market equilibrium as major functions in setting planned targets.

U.K.—The Rothschild-Dainton Debate

The present framework for government R&D has been reviewed recently by two committees. The first, chaired by Lord Rothschild, Head of the Government's Central Policy Review Staff, was concerned with the overall organization and management of government R&D, and mainly applied R&D. The second, undertaken by the Council for Science Policy within the Department for Education and Science, concerns the future of the research council system.

The Rothschild (R) Report "is based on the principle that applied R&D… must be done on a customer-contractor basis. The customer says what he wants; the contractor does it (if he can); and the customer pays." Pointing specifically at the Research Councils, R notes that the latter, particularly the Medical, Agricultural and Natural Environment Research Councils, claim that much of their work is "applied." "But this work had and has no customer to commission and approve it. This is wrong. However, distinguished, intelligent and practical scientists may be, they cannot be so well qualified to decide what the needs of the nation are, and their priorities, as those responsible for ensuring that those needs are met. This is why applied R&D must have a customer."

R also declares that "it is sometimes said, for example, that development should be done by different people, in a different place, and with a different administrative system from research. The reverse is the case, whenever possible." Regarding the technological importance of chance observations in basic research, "the country's needs are not so trivial as to be left to the mercies of a form of scientific roulette." As for the often argued fuzziness in the distinction between pure and applied research, R does not accept this.

R notes that virtually all applied R&D laboratories sooner or later indulge in some research not directly related to customer-commissioned programs and amounting, on the average, to an expenditure of about 10% of these programs. This expenditure should be regarded as a surcharge on the applied work and covers research done for the following reasons:

(a) To engage in basic research in a field relevant to the applied tasks of the laboratory, but which is not being done elsewhere.
(b) To test out new, way-out, or unprogrammed ideas of the scientists and engineers.
(c) To maintain expertise, e.g. to recruit and keep a spectroscopist who will not join the laboratory unless he can spend part of his time on his own research.
(d) To facilitate the transition of researchers from academic life to that in an applied R&D organization.

[N.B. This seems like an incomplete view of the role of research within organizations whose primary responsibility is applied work. Other values of basic research that might be listed are:

(e) To establish or enhance the reputation of the laboratory within the general scientific community.
(f) To facilitate Communication between the laboratory and the general scientific community by having people with relevant interests and common language, a communication link that is important for obtaining advance notice of important developments elsewhere.

(g) To help set the tone and generate confidence within the laboratory by having scientists who, by digging deeply, show that science does work.]

R states that it is important to accept the concept of multifunctional laboratories and institutes which can serve several customers from different departments.

To implement the establishment of the customer-contractor principle, R recommends that £27.7 million out of £109.5 million now devoted to the Research Councils by the DES should be transferred to the various other governmental ministries and departments concerned, that all other work performed by the Councils on behalf of other departments should be paid for by the latter.

As is to be expected, the views expressed in the Dainton (D) Report are somewhat different. Stirred by the above writing on the wall, D rises to the defense of science, emphasizing particularly the importance of obtaining knowledge and the benefits to mankind that result from such endeavors. In contrast to R, D argues that "the adjectives, 'pure' and 'applied' imply a division where none should exist and their use can be harmful. In the course of his work the engineer or technologist makes use of experiment and theory in just the same way as the 'pure' scientist, and at least as great demands are likely to be put upon his intelligence, judgment and imagination." Again: "The historical boundaries of scientific disciplines are becoming increasingly blurred. Multi- and interdisciplinary studies grow apace and as a result old boundaries dissolve and the links between seemingly disparate parts grow stronger. This internal cohesion of science is one of its most characteristic features and will surely increase rather than diminish."

Rather than categorize science into "pure" and "applied," D finds it useful to identify the following three categories:

"(a) Tactical science—the science and its application and development needed by department of state and by industry to further their immediate executive or commercial functions. The extent and nature of this activity may vary widely according to the functions served and to the degree that they involve science. At one extreme it may contain a significant element of sophisticated research over a long period, while at the other extreme it amounts to little more than a modest intelligence and advisory activity.

(b) Strategic science—the broad spread of more general scientific effort which is needed as a foundation for this tactical science. It is no less relevant in terms of practical objective…but more wide ranging. For this 'strategic' work to be successful, it is necessary to maintain the vigor of the underlying scientific disciplines and to deploy these disciplines with due regard to national goals.

(c) Basic science—research and training which have no specific application in view but which are necessary to insure the advance of scientific knowledge and the maintenance of a corps of able scientists, upon which depends the future ability of the country to use science."

D emphasizes that the distinctions between these categories are fuzzy and that the "users" of scientific knowledge and of scientific personnel also need to have close connections with basic and strategic science as well as with tactical science.

The purpose of the Research Councils is broadly to foster research and training. To do so they operate flexibly, in many ways including the following:

(a) Provide grants to support research in universities.
(b) Provide awards to support students proceeding to higher degrees.
(c) Establish research units, usually at universities, staffed by employees of the Research Councils.
(d) Provide special experimental facilities for universities.
(e) Provide grants to independent research agencies.
(f) Carry out their own research programs in their own research institutions.
(g) Participate in international scientific projects providing facilities for researchers from the U.K.

A large element in the policy of the Research Councils has been and will continue to be to support projects on scientific merit in terms of timeliness and promise. The Councils also choose for particular support areas they judge to be of national importance. Additionally, they often find it necessary to encourage the concentration of activity and resources.

The Research Councils interact with a wide range of ministries and departments. For example, the Science Research Council (which is the one most relevant for MSE) has major links with:

British Broadcasting Corporation
Central Electricity Generating Board
Department of the Environment
Department of Trade and Industry
Independent Television Authority
Ministry of Aviation Supply
Ministry of Defense
Post Office
United Kingdom Atomic Energy Authority, in addition to many links with industrial firms and organizations.

In considering the Research Councils, D believes the most important general points to keep in mind are: the pervasiveness of the consequences of science, the diversity of its users, the complexity of the connections between basic research and related economic benefits, the close relationships between different scientific disciplines, and the unifying importance of training in the methods of research. But in addition D recognizes that:

“(a) There is now some public disillusion with science and some of its technological consequences so that one cannot assume there will be general assent to the proposition that more science will make the nation wiser and richer.
(b) Because of the pressure of other demands on resources, we are now probably past the point of maximum growth rate of resources for science. (Note that, to some extent, the increasing cost of experimentation to produce the same ‘amount’ of good science can be partially offset by international collaboration and by selectivity in the support of science).
(c) Particularly because of these increasing social and financial pressures, it is imperative that those responsible for determining scientific priorities should be fully informed of, and should pay due regard to, governmental policy and national needs.”

(d) There is growing realization that we can no longer expect to improve existing technologies or introduce new developments by simple application of knowledge based on the physical and biological sciences. Increasingly, we need to know more about ways in which such new knowledge can be used in harmony with the economic and human needs of the situation. And this calls for a much closer integration between the natural sciences and the social sciences, not only in research but also in the broader training of able people so that we may deploy our knowledge in ways which will give optimal benefit to the community.

D is clearly struck by the growing interaction and erosion of boundaries between the scientific disciplines, "by the great extent of multi- and interdisciplinary work and by the rapidly increasing tendency for the interactions between the disciplines to grow stronger. The interactions are facilitated by having productive and imaginative scientists in day-to-day contact with colleagues working on related scientific projects with whom they can collaborate directly in new research. An interaction of this sort is quite unpredictable both in its nature and in the nature and extent of its consequences which may be the emergence of an entirely new area of scientific activity or the application of a particular scientific technique to an entirely different field of science. To maintain therefore strong and flexible linkages between scientists working in these fields it is important that they should be within the same organization, administered by people who recognize the benefit of these interactions, and should not be dispersed to executive (i.e., functional) departments. For the same reason it is necessary to have a coherent policy for the whole of this scientific activity, especially during a period when costs are likely to grow more rapidly than resources."

The above argument is used to defend the organization of the Research Councils and their strong links with many departments; fragmentation of the Councils among these departments is held not to be the answer. By way of an example, "the applied psychology work which, is undertaken by the Medical Research Council is of very considerable value to the Post Office, the Ministry of Defense, to the Department of Trade and Industry, and to industry generally. To allocate an activity of this kind to a particular government department would create difficulties for the other interested departments and would involve fragmentation of existing teams of scientists making their work much less effective than it otherwise would be." Moreover, an additional complex of linkages and coordinating committees would be needed. Under the present arrangement, the Research Councils act as a relatively simple focal point for all these interactions.

D finds it illogical, on the one hand, to assert the unity of science and the fluidity of its internal boundaries, and on the other hand, to approve a system of completely independent Research Councils, each of which can only operate within relatively rigid boundaries set by its individual charter. D is then led to propose only a slight modification of the current arrangement, namely, that a Board should be appointed to coordinate and administer the activities of the five Research Councils and that this Board would replace the (advisory) Council for Science Policy. The Board would consist of a Chairman, the scientific heads of the Research Councils, members from the most relevant governmental organizations, and various others from outside the government.

To sum up, Dainton is arguing in favor of retaining the management of the nation's science primarily in the hands of scientists, but he considers that they should pay more attention than they have done in the past to societal needs and pressures. He proposes some organizational changes aimed at making the management of the Research Councils by the scientists more efficient and responsive. Rothschild, on the other hand, would give the customer more control over what the scientists do, especially in applied R&D, but would allow a surcharge in the applied R&D contracts to cover longer-range pure research. Moreover, he would transfer at least parts of the Research Councils to the primary customer departments.

Publication of the Rothschild and Dainton Reports aroused strong reaction in the scientific community, much of it reflecting nervousness among basic research scientists over the application of Rothschild's customer-contractor principle. Nevertheless, fairly widespread acceptance of this principle eventually emerged: the Institute of Physics (London), for example, stated, "In relation to national needs where departments of state have statutory duties, the discharge of which involves the need for scientific research, we agree that the Rothschild customer-contractor principle is appropriate."

Another point that received much emphasis was that, if the governmental departments were going to take on more of a role in contracting out research to the Research Councils and elsewhere, they needed to have the intellectual resources to administer such activities; the customer-contractor principle would work only if governmental departments were properly equipped to ask intelligent questions of their potential contractors.

Brooks (Nature, Feb. 11, 1972) has given a U.S. view of the debate. He is struck by the mildness of the Rothschild proposals when compared with American reality which has operated largely on the customer-contractor principle since World War II and, until recently, fairly comfortably. Nevertheless, Brooks is concerned by Rothschild's "apparent obliviousness to some of the evident weaknesses and dangers of the American system: the instability in funding, the effective lack of concern with the integrity and viability of scientific institutions—especially the universities—the wasteful competition for control over glamorous or spectacular technical programs, the confusion of technological virtuosity with scientific achievement, the increasing obsession with narrowly conceived 'social relevance,' sometimes to the detriment of scientific quality, the exacerbation of competitiveness, 'grantsmanship,' and political maneuvering in the scientific community."

Much depends on how the customer-contractor principle is applied in practice. It works best when the relationship between client and supplier is a negotiated one between competent scientists rather than dictated by the client. Its success depends on persons and attitudes as much as on institutional forms.

Brooks notes that the Rothschild concept "of multi-purpose applied laboratories within government has been poorly developed in the U.S. The so-called "national laboratories" are largely the captive of single agencies and offer their services to broader national missions at considerable political risk…It will be very valuable if Britain can successfully develop and implement this concept of the broad-spectrum multi-purpose laboratory, with which many ministries and the private sector may contract for technical work."

Predictably, the British government proceeded to adopt many of Rothschild's main proposals—the customer-contractor principle, the need to hold ministers responsible for seeing that departmental objectives are properly backed by research and development, and that there are effective partnerships between departmental customers and research and development contractors. The government also declared, in passing, that it cannot accept the notion that there should be a Minister for Research and Development. Applied research and development are a necessary part of government and cannot be separated from the responsibilities of all ministers.

For the coming years, the effect of the Rothschild plan will be to encourage more mission-oriented research in a system that has traditionally emphasized the freedom of the scientist to go wherever his curiosity takes him.

CONCLUSIONS AND IMPLICATIONS FOR THE ADMINISTRATION OF MATERIALS RESEARCH IN THE U.S.

The thrust of the discussions in this section appears to be that there is no one permanent solution or ideal administrative structure for allocating and managing resources for basic and applied research. However, extremes are to be avoided, either in which one organization is responsible for all basic and applied research, or the other where these are the uncoordinated responsibilities of separate, poorly-interacting organizations. The line between basic and applied research remains extremely fuzzy and dynamic, and often so in the activities of an individual scientist let alone in departments and larger organizations. What seems to make most sense is that the "centers of gravity" of some organizations will be in basic research while those of others will be in applied research. Clearly there will be some overlap between the two sets of organizations. This overlap may outwardly seem like wasteful duplication, but this is not necessarily so. It should be recognized as vital for information and technology transfer between the two communities of scientists. It also introduces some healthy competition.

As societal priorities fluctuate so will, to some extent, the balance between basic and applied research. A heavy responsibility falls on those whose job it is to allocate resources among the various basic and applied research proposals. Whether at the administrative or working level, a special kind of wisdom is called for—one that recognizes and understands the different motivations often operating within these two sectors, that can appreciate the intellectual excitements, challenges, and satisfactions of basic research as well as those of the technical and economic objectives of applied research. The practical approach as far as policy is concerned is to appoint a suitably representative advisory committee that reports to the highest levels of government.

In the U.S. the administration and coordination of basic research has traditionally been the province of the National Science Foundation. It has only recently become involved in the administration and support of some applied science in the private sector through the Research Applied to National Needs (RANN) Program and the Experimental Technolocy Incentives

Program. The Interagency Council for Materials has for some time provided a coordinating role for materials R&D programs among the various governmental departments and agencies.

The main bodies concerned with coordination of U.S. science policy and the federal support of R&D, particularly in the materials field, can be summarized as follows:

Coordination of national science policy with other national policies.	Cabinet; Counsellors
Advice on broad distribution among sectors of federally-supported basic and applied research	The (former) Office of Science and Technology; now the President's Science Adviser, the NSF
Coordination of materials research carried on in various sectors.	Interagency Council for Materials
Federal support of basic research in the private sector.	NSF
Federal support of generic applied research	NSF—RANN Dept. of Commerce—NBS— Technology Incentives Program

At the highest level differences of opinion exist among various countries as to whether the coordination should be associated with—or even subordinated to—a particular field of national activity (the economy, industry, education, etc.) or whether, on the contrary, such an association might not have the effect of restricting to a single type of research, or a single area of application, the interest and support which should be accorded by the government to the national R&D system as a whole.

The (former) Office of Science and Technology, in principle, performed an essential and central role in advising on the distribution of federal resources for R&D among the various sectors competing for funds. It has its counterpart in almost every other major country. While the U.S. Office of Management and Budget has the final say in the disposition of funds, there seems to be a clear need for effective scientific and technological advice of the sort that could be expected from a properly constituted and staffed Office of Science and Technology.

The Interagency Council for Materials performs useful liaison and coordination in materials R&D among the various technical departments and agencies of the federal government. It has no funds of its own, however, for supporting R&D, nor does it have any substantial authority.

The NSF has traditionally been a main supporting agency for long-range and basic research in the academic community. It is divided into various operating divisions, one of these being the Materials Research Division (which embraces a mix of disciplines and subdisciplines very similar to those defined by COSMAT as within the field of MSE). More recently, NSF has engaged in the support of applied research through its RANN Program although its resources, administrative as well as financial, for this program may not be at all commensurate with the needs. An additional avenue for the support of applied research is the Commerce Department's Technology Incentives Program, administered through the NBS, but its resources are also very limited.

EDUCATION

Statistical Information on Scientists and Engineers

Table 8.7 summarizes some data, drawn principally from OECD sources, on the levels of effort being put into higher education in several advanced countries in the mid-sixties. To facilitate comparisons, the second part of the table shows the data normalized to a figure of 100 for the U.S. Perhaps the most striking feature of these data is the completely different emphasis placed by Japan (and the Soviet Union) on the distribution of resources between the educating of scientists and engineers. Compared with the U.S. in the mid-sixties, Japan was educating proportionally far fewer science students and far more engineering students at the first degree level. The ratio of science to engineering students in Japan was about one-tenth of that in the U.S. while, in proportion to the population of the labor force, the total number of Japanese students (all disciplines) was about one-third of the U.S. total. At the doctorate level, Japan also was producing far fewer science and engineering graduates than the United States.

While there are differences among the educational patterns of Canada, France, Germany and the U.K., none is so different from the U.S. picture as is Japan. Nevertheless, it should be observed that all other countries, and especially the U.K., were devoting a greater proportion of their higher education effort to science and engineering than to other disciplines.

By comparing 1955 with 1965 data (Figure 8.1), trends in emphasis on science (S) vs. engineering (E) enrollments for university-level education can also be discerned; these are summarized as follows:

Country	Emphasis in 1955	Emphasis by 1965
Canada	S—?	S—?
	E—Average	E—Had dropped considerably
France	S—Very high	S—Increased even higher
	E—?	E—?
Germany	S—Average	S—Held constant
	E—Slightly above average	E—Dropped slightly to average

Table 8.7 Educational Data

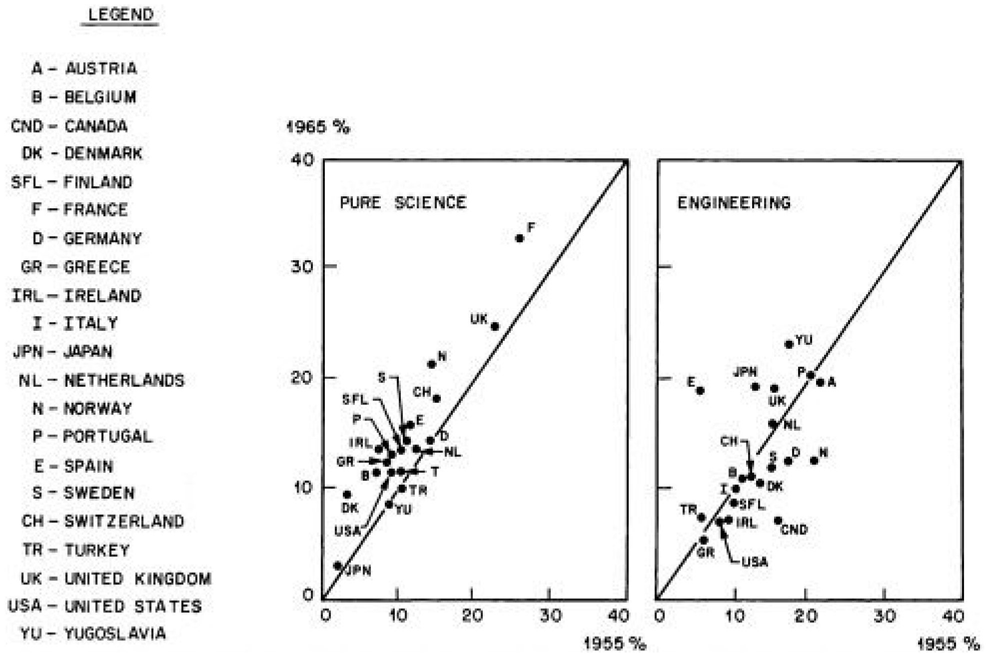
		Canada	France	Germany	Japan	U.K.	U.S.A.	U.S.S.R.
1)	Ratio of total enrollment in higher education between 1965–66 and 1955–56	3.27	2.43	2.10	1.78	2.12	2.08	
2)	Number of students/1000 inhabitants (1965)	16.6	10.3	7.2	11.1	7.9	28.6	
3)	Number of students/1000 labor force (1965)	45.4	24.9	15.5	22.7	16.6	72.2	
4)	Proportion of students in pure science (1965)	13.1	32.7	14.2	3.0	24.7	11.4	
5)	Proportion of students in engineering (1965)	8.8		13.5	19.5	19.2	7.1	39.0*
6)	S/E ratio	1.49	–	1.05	0.15	1.29	1.51	
7)	Ratio of all higher degrees to all lower degrees (1965)	0.16	0.36	0.29	0.06	0.45	0.29	
8)	Percent of age group— all first degrees	13.93	4.19	2.16	9.68	5.28	21.80	14.10
9)	Percent of age group— pure science	1.32	1.08	0.19	0.29	1.42	2.45	0.37
10)	Percent of age group— technology	0.8	–	0.34	1.84	0.96	1.52	5.35
11)	Rates of doctorate degrees— Percent of year group (All)	0.29	0.48	0.66	0.22	0.58	0.78	
12)	Rates of doctorate degrees— science & engineering	0.22	0.34	0.23	0.06	0.36	0.39	

*From Science Policy in the U.S.S.R., OECD, Paris, 1970.

		Canada	France	Germany	Japan	U.K.	U.S.A.	U.S.S.R.
		Data normalized to U.S.=100						
1)	Ratio of total enrollment in higher education between 1965–66 and 1955–56	157	117	101	86	102	100	
2)	Number of students/1000 inhabitants (1965)	58	36	25	39	28	100	
3)	Number of students/1000 labor force (1965)	63	34	21	31	23	100	
4)	Proportion of students in pure science (1965)	115	287	125	26	217	100	
5)	Proportion of students in engineering (1965)	124	–	190	275	270	100	550*
6)	S/E ratio	99	–	70	100	85	100	
7)	Ratio of all higher degrees to all lower degrees (1965)	55	124	100	21	155	100	
8)	Percent of age group— all first degrees	64	19	99	44	24	100	65
9)	Percent of age group— pure science	54	44	8	12	58	100	15
10)	Percent of age group— technology	53	–	22	121	63	100	352
11)	Rates of doctorate degrees— Percent of year group (All)	37	62	85	28	74	100	
12)	Rates of doctorate degrees— science & engineering	56	87	59	15	92	100	

*From Science Policy in the U.S.S.R., OECD, Paris, 1970.

FIGURE 8.1
DISTRIBUTION OF UNIVERSITY-LEVEL EDUCATION ENROLLMENTS BY FIELD OF STUDY IN 1955 AND 1965



Country	Emphasis in 1955	Emphasis by 1965
Japan	S—Very low	S—Still very low
	E—Average	E—High
U.K.	S—High	S—Still high
	E—Above average	E—High
U.S.A.	S—Average	S—Below average
	E—Low	E—Dropped lower

These data strongly confirm the view that at a time when Japan was relatively early on its sigmoidal curve compared with other advanced countries, it chose a policy of emphasizing engineering rather than science in order to “catch-up” technologically. If what seems to be the national scenario can be applied more narrowly to an industrial sector, then part of the Japanese prescription for a lagging industry is to increase the national effort in the relevant applied science and engineering education.

Now that Japan has caught up in many ways, it is of interest to see whether the same formula will move Japan forward to establish an overall technological lead or whether its investment mix in science and engineering education will move closer to those of the other countries. It is noticeable, for instance, that up till now Japan has lagged considerably behind the western countries in Nobel Prizes for science, imperfect indicator though this may be of national scientific leadership. (1–2/3 physics; 0 chemistry; out of 73 awards in each field).

Curricula and Interdisciplinary Education for the Materials Field

The U.S. appears to have led the way in establishing interdisciplinary materials science centers for working towards advanced degrees at universities. In other countries, education for the materials field still seems to follow mainly along traditional departmental lines—physics, chemistry, metallurgy—though a few of the newer universities, for example in the U.K. (see below), are developing interdisciplinary undergraduate curricula somewhat similar to the broader approach common in U.S. colleges. It is difficult to make meaningful comparisons of the curricula for science and engineering students among various countries let alone assess the quality of the education vis-a-vis that of the U.S.

An Interdisciplinary University[7]

In England, the University of Sussex, founded in 1961, was designed from the start to operate with an innovatory curriculum and with a new form of internal organization. The unit of university development was to be not the

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[7] From Interdisciplinarity, OECD, Paris, 1972.

single-discipline department but a multidiscipline school, with interdisciplinary courses in each school. The schools included Mathematical and Physical Sciences, Molecular Sciences, Biological Sciences, and Applied Sciences.

Undergraduate education was to combine specialization in one discipline with common work in clusters of disciplines. The plan also entailed replacing the department with a professorial head by a school with a dean, part of whose responsibility would be to encourage multidisciplinary and interdisciplinary work.

In the sciences, a common introductory course was developed on “The Structure and Properties of Matter,” to be taken by all science undergraduates and stressing concepts cutting across traditional disciplines. At a later stage in the undergraduate program, courses were designed linking Biological and Physical Sciences and other scientific disciplines. The School of Applied Sciences abandoned the old professional distinctions between Mechanical, Electrical and Civil Engineering, and introduced new common courses on subjects like Control Engineering and Materials Science.

Some tentative conclusions about the Sussex experience can now be drawn:

(a) There seems little danger of any revision into “departmentalism.”
(b) It has been necessary and valuable to retain some “subject” organization alongside interdisciplinary work.
(c) Success depends on attracting good faculty with genuine interdisciplinary interests.
(d) With the right kind of faculty, new “unplanned” interdisciplinary activities nucleate and grow e.g., a Medical Research Group came into existence even in the absence of a Medical School. It included biochemists, engineers, sociologists, and educationists and established close contact with hospitals.
(e) New schools, with new combinations of courses are now being canvassed, some of which focus attention on problem areas of great practical importance as well as of intellectual stimulus. It is to be expected that such schools will help counter the trend in undergraduate enrollment from the science to the arts.
(f) The Sussex system has emerged within the framework of national educational policy; it has had no privileged position in relation to cost, capital provision, or staff/student ratios.
(g) It has involved much effort on the part of the faculty in planning new courses, etc.
(h) Educational technology is being explored, such as television and programmed learning,
(i) Only a minority of graduate students are engaged in interdisciplinary work,
(j) There are also 18 units, Centers and Institutes at the University, most of which are interdisciplinary in purpose and staff, e.g., the Science Policy Research Unit.

United Kingdom

Capital requirements of universities and the support of undergraduate education in the U.K. are largely the responsibility of the University Grants Committee (UGC) of the Department of Education and Science. The UGC has recently assessed educational needs in the field of "Materials Studies," covering mainly metallurgy, ceramics and glass technology, polymers, and electronic materials. The UGC found that the emphasis of materials studies varies from university to university, ranging from heavy concentration on the engineering use of materials, and sometimes on their preparation, to emphasis on the structure and behavior of the material per se, usually involving close links with departments of applied chemistry and applied physics. They conclude that there is no single block of work that can be labelled materials studies and treated as a comprehensive discipline.

Comparison is made with the USA where they note that the traditional patterns of departmental structures have been modified in favor of the growth of interdisciplinary organizations such as materials science centers, and this has stimulated the treatment of neglected but important areas of materials research. "Over the years, however, the tendency has been for the centers to become divorced from the teaching functions of the original departments. The centers have also been criticised for lack of technological motivation or interest and failure to build up their contacts and interrelationship with industry to the degree that had at one time been hoped."

In the U.K. the following forms of organization occur: Undergraduate level

(a) 3- or 4-year courses, including sandwich (or cooperative) courses, recruiting directly from school or industry, in which the student normally continues in the same discipline throughout the course. Courses in metallurgy are an example.
(b) 3- or 4-year courses combining specific disciplines, and therefore entailing a streamlining of "traditional" content so as to fit the studies into the period of the course. An example of this is a course in engineering metallurgy.
(c) 3- or 4-year course in which the first part is common to several disciplines, usually of the "pure science" or "applied science" type. The second part comprises various options in materials as well as other subjects. These courses are often located in wellestablished schools where there is administrative oversight of a wide range of courses bearing on materials and related scientific disciplines.

Graduate level

(d) The taught courses vary in length from short postexperience ones intended mainly for graduates from industry to those open to 1-year MSc and 3-year Phd students. Their organization generally follows the pattern adopted by the individual university concerned, but there are examples where there is a loose connection between departments even though a postgraduate "core course" is run.
(e) Sometimes the research takes place within a school of materials technology or science. This can be a closely knit organization where there is sponsorship of interdisciplinary groups of

> researchers tackling different facets of a common problem; but more usually it is a much looser organization of research activities that is in practice no more than oversight by an interdepartmental committee.

Interdisciplinary graduate courses centered on metallurgy are usually successful in attracting high quality students if they are organized in close collaboration with industry. The tendency for research in metallurgy is for it to broaden across disciplinary lines, leading university research workers to think more in interdisciplinary terms just as industry has to. For historical reasons, large research schools in metallurgy are often located in centers of the metallurgical industry, thereby enhancing the opportunities for university-industry coupling, although questions are being raised whether there is some overlap and redundancy in the overall metallurgical effort which might be rationalized. One of the problems encountered in regard to university-industry coupling is that where a large proportion of undergraduates are industrially based, as they are in the technological universities, it is very difficult to build up a strong research school. The research has, therefore, tended to be shorter-term, much of it on a contract-basis for industry.

There are two principal schools for ceramics and glass science and technology—Leeds and Sheffield. The total output of graduates per annum for these and other schools is about 40. There is an uncertain demand for such graduates at present and in consequence, the addition of any more ceramics or glass schools is not being encouraged.

Polymer science and technology is finding its way into an increasing number of academic syllabuses, often as a specialized option in the latter years of metallurgical courses. However, polymer science as such is not regarded as a suitable subject for a complete first degree course in the present stage of development, but more as a graduate course based on a sound undergraduate foundation in physics and chemistry. At the graduate research level, much progress has been made at implementing the interdisciplinary approach but more needs to be done to equip polymer scientists for work in industry.

The study of electronic materials at universities has generally grown up in departments of electronics, electrical engineering, and applied physics, and is likely to continue so. The strongest departments appear to be those in which teaching and research are closely integrated and, in particular, where the materials research is aimed specifically at device applications. However, collaboration with departments of physics, chemistry, etc. can be fostered by the sharing of common facilities such as electron microscopes, X-ray equipment, etc. This seems to be preferred to the establishment of materials centers where the motivation of technological application is often absent.

Many universities appear unwilling to appraise critically the quality of their work in materials studies relative to their resources and abilities. Some research programs are superficial, others are poorly supported.

This leads to the question of universities establishing research centers in "materials science." The general idea of universities interested in centers is that they would concentrate mainly on contract work for industry or government, and as such would be particularly fitted to conduct medium-term research and to attract postdoctoral fellows. One center has not been a success apparently because it failed to gain sufficient moral and financial support from the contributing departments. This is liable to happen unless the departments concerned are convinced that it is in their long-term interests to give up a proportion of the research they would otherwise undertake, together with the limitation of research opportunities this is bound to cause for their own staff. The UGC suggests therefore that universities should approach the idea of a research center with caution. Their present attitude is to discourage the development of additional centers until more experience is gained from the operation of existing ones in Britain.

As regards the administration of Materials Studies, where the oversight is vested in a Council, or Board of Studies, or Faculty Board, the general arrangement is for the main departments involved to be represented on the Council or Board, although the arrangements for the chairing of such a body vary a good deal. A conscious and sustained effort is required of university staffs to maintain the vitality and advantages of such interdepartmental organizations and to prevent them from recrystallizing into a collection of individual departments with little concern for each other's activities in Materials Studies.

There has been a decline in the undergraduate enrollment for metallurgy and materials science courses of 18% over the period 1965–1970, although within this total decline, the enrollment for materials courses has increased fourfold while that for metallurgy alone has declined by 35%. This is attributed to the increasingly favorable image of materials science, and to the desire of students to keep their options open as long as possible. As a result, it is felt in the U.K. that an increasing proportion of students of only moderate ability are entering metallurgy courses and, in consequence, no more university departments of metallurgy should be established in the near future. There has also been a tendency recently to emphasize physical metallurgy at the expense of chemical metallurgy; however, extractive metallurgy has begun to feature more prominently in some university syllabuses. The signs are that the latter subjects collect the somewhat less able students who are destined for careers in production rather than research.

The breadth of materials science courses makes it more difficult to cover production technology than in metallurgical courses. Another disadvantage of the broad approach is that many companies to which students subsequently go are specialized into certain classes of materials—metals, ceramics, polymers or electronic materials. Thus, advantages are seen in materials courses which start out broadly but then give an opportunity to specialize in the final year. But universities should be wary of giving broad courses to weak students. There is some danger that a first degree in materials science (or materials technology), dealing with so many topics that none can be studied in depth, will produce a man who cannot be said to have professional training for a career in any particular field. Universities should embark on such programs only if they are confident that they will attract high quality students. A first degree course in one of the older established disciplines, followed by a graduate course in a more specialized aspect of materials, is seen as a good way for training materials scientists.

In conclusion, the UGC finds that in the U.K. the concept of a materials studies school is not in every case as successful as claimed by the university concerned; collaboration between departments in the school can sometimes be more on paper than in practice. Whatever the local arrangements may be, a conscious and sustained effort is required of university staffs to maintain the vitality and advantages of such interdepartmental organizations and to prevent them from recrystallizing into a collection of individual departments.

UGC has also concluded that the development of additional materials science centers should be discouraged until experience is gained from the operation of the few existing ones in Britain. Also, universities should persevere with arrangements which make possible the transfer of undergraduates to metallurgy or materials science courses after the first or second year of a science course in another field.

Materials studies should be a proper, fully integrated and continuing part of any engineering course, whatever the specialist engineering discipline, and not simply regarded as a first year topic to be “got out of the way.”

Universities wishing to provide courses covering new topics and founded on new integrating principles should do this only if they are confident that they can obtain enough students of high calibre; and they should be ready to suppress these courses if the good students fail to appear in sufficient numbers.

In these circumstances, universities might experiment by first providing the broader courses at graduate level following on from a first degree in one of the older established disciplines. Only a university which had made successful provision along these lines should then contemplate provision also of a first degree course in materials science for able students.

There are advantages in operating materials courses with a broad introduction to all materials, provided there is the opportunity to take a specialist option in the final year.

Japan

The most important of the National Universities of Japan are the seven former Imperial Universities. These receive a large share of their financial support directly from the Japanese government, attract the best students, and do most of the nation’s academic research. The University of Tokyo is considered the most prestigious and its graduates succeed to many of the important positions in government, education and industry. In close succession follow the Universities of Kyoto and Osaka, and the other four (Tohoku, Nagoya, Hokkaido, and Kyushu) in less definite order. Career prospects for graduates seem to be pegged accordingly.

The larger universities are divided into several campuses, each accommodating one of the major divisions of the university, e.g., faculty of medicine, faculty of arts and sciences, etc. The faculty of science may comprise physics, chemistry, biology, etc., each with its own chairman. The role of chairman is not quite as strong as in the U.S. since individual professors within a department enjoy a semi-autonomous position as heads of their respective research units, each of which has its own permanent budget granted directly by the Ministry of Education.

Often associated with a National University are one or more National Institutes, somewhat like the Lincoln Laboratory associated with M.I.T. Thus, the Institute for Solid State Physics is managed by a board of physics professors from the Institute itself and from the University of Tokyo. Each National Institute is devoted to a specific technical field usually restricted in scope but pursued at considerable depth. Some Institutes accept graduate students who do thesis work under a professor permanently assigned to the Institute, but more frequently the best graduate students are retained by the parent university.

The Ministry of Education, with its power to determine budgets for research and education, exercises extraordinary power over the academic and intellectual community throughout Japan. Participation by prominent professors in the decisions of the Ministry helps to make it partly responsive to local requirements.

Examinations for university entrance are the sole admissions criterion, each university designing its own examination. The four-year undergraduate curriculum is divided into 1–1/2 or 2 junior years and 2–1/2 or 2 senior years. In general, the senior course is highly specialized with emphasis on deep knowledge within a given field. Graduate school consists of a 2-year “Master” course and a 3-year (or more) “Doctor” course of research, the two separated by a stiff examination. Upon graduation, arrangements for a position for the graduate as an assistant in some university, or in industry, are usually made through personal contacts by his thesis professor. The American practice of postdoctoral fellowships is not generally followed. After 5 years or so as an assistant, he may be promoted to assistant professor at some university. At this level he then enjoys considerable independence. The final promotional step is to professor, a position in which he has much freedom and prestige.

A typical research organization at a university is organized rather differently from that of the American university department. Each research unit, called a koza, consists of one professor, one assistant professor, and one or two assistants, and it is funded directly by the Ministry of Education. Several graduate students are connected with the koza as well as one or more technicians and a secretary. There is usually a close-knit family air about a koza with considerable deference being paid to the professor. However, the traditional koza system is more strongly upheld by older professors than by younger ones, and the competing advantages of less formal arrangements are being felt in many Japanese laboratories. For example, instances can be noted of cooperation between professors in several adjacent koza, grouping and regrouping informally as the scientific occasion may demand. Likewise, at the National Institutes less importance is attached to the koza tradition and the atmosphere may be more like that prevalent in the U.S.

Research style is rather different in Japan compared to the U.S. In the U.S. most scientists discover new ideas partly by contemplation and partly by informal discussions with colleagues. Ideas are then tried out by exploratory experiments, the results of which lead to further rounds of informal discussion, and so on. In Japan, such informal preliminary discussions are rarely held. It is customary for a research worker to spend a very long time in private thought before advancing his ideas to the rest of his koza at a formal research seminar where he is naturally more likely to strive for accuracy than to be speculative. Furthermore, intellectual aggresiveness is not admired in Japan and criticisms in seminars tend to be gentle.

Education in Materials Science and Engineering

Japanese education in MSE is generally organized along disciplinary rather than interdisciplinary lines. While some Metallurgy Departments have broadened their title to include Materials Science, this generally means adding such topics as the physics of metals and does not necessarily indicate a broadening of the scope into inorganic and electronic materials or polymers and plastics. In the following, therefore, the educational picture will be described according to its material components. Metallurgy, Metallurgical Engineering, and Materials Science:

The demand for metallurgy and materials science graduates in Japan is high and even increasing. For example, at Tohoku University the number of offers made in 1970 to 168 graduates was 548.

An interesting sociological sidelight is that members of the faculty act as intermediaries in arranging jobs for graduates with various companies; the students and the companies are not allowed to make direct contact with each other. In addition, there appears to be a gentlemen's agreement between the head of the department and various companies aimed at avoiding wasteful competition between companies for the graduates.

The graduate production in 1970 is listed for all universities in Table 8.8.

One of the best known schools in the materials field is at Tohoku University, comprising the Departments of Metallurgy, Materials Science, and Metal Processing. This school is indicative of the nature and quality of Japanese education in this field.

The Department of Metallurgy was established in 1923. The Department of Materials Science was founded in 1960. The Department of Metal Processing was started in 1965 and became fully operational in 1968. At present, the three departments are administered as a single unit with professors belonging to different departments participating in teaching throughout the unit. All students take the same course for the first three years, specializing in one of the departments for their fourth year.

Also associated with Tohoku University is the Research Institute for Iron, Steel and Other Metals and the Research Institute for Mineral Dressing and Metallurgy. Professors associated with these Institutes also participate in the graduate work of the University.

Following the four-year undergraduate course students may go on for a Master's degree (minimum 2 years) or a Doctor's degree (minimum 3 years).

There are six professorial chairs in each of the three departments. These are: Department of Metallurgy—Chemical Metallurgy and Chemical Engineering Group—Ferrous Metallurgy; Nonferrous Metallurgy; Electrometallurgy; Corrosion and Protection of Metals and Alloys; Metallurgical Engineering; Chemical Metallurgy. Department of Materials Science— Physical Metallurgy and Materials Science Group—Structural Metals and

Table 8.8 Number of Advanced Degrees per Year in Departments of Metallurgy, Metallurgical Engineering, and Materials Science in Japan (1970)

Name of University	Location	Number of Students per Academic Year	Number of Master's Degree's per Year	Number of Doctor's Degree's per Year
Hokkaido University*	Sapporo	40		
Metallurgy			12	6
Tohoku University	Sendai	115		
Metallurgy			20	15
Materials Science			19	13
Metal Processing			14	none
University of Tokyo*	Tokyo	80		
Metallurgy			30	18
Tokyo Institute of Technology	Tokyo	25		
Metallurgical Engineering			13	6
Nagoya University*	Nagoya	85		
Metallurgy			12	6
Iron and Steel Engineering			12	6
Kyoto University*	Kyoto	75		
Metallurgy			13	7
Metal Science			12	6
Osaka University	Osaka	180		
Metallurgy			26	6
Materials Science+			12	6

*Former Imperial University
+Belongs to School of Engineering Science

Name of University	Location	Number of Students per Academic Year	Number of Master's Degree's per Year	Number of Doctor's Degree's per Year
Kyushu University[*]	Fukuoka	60		
Metallurgy			8	4
Iron and Steel Metallurgy			12	6
University of Osaka Prefecture[+]	Sakai	50		
Metallurgical Engineering			12	5
Waseda University[#]	Tokyo	90		
Mining and Metallurgy			20	5
Kansai University[#]	Suita	80		
Metallurgical Engineering			6	3
All other universities		1100	109	

*Former Imperial University
+Public
#Private

Alloys; Special Purpose Materials; Physical Metallurgy; Strength of Metals and Alloys; Chemistry of Metals; Metal Physics. Department of Metal Processing—Metal Processing and Mechanical Metallurgy Group—Foundry Engineering; Welding Engineering; Powder Metallurgy; Mechanical Metallurgy; Plastic Working of Metals; Interface Science of Metals.

Solid-State Physics in Japan

Solid-state physics is part of the normal curriculum for undergraduates in most, if not all, of the physics departments in Japan, and most of these departments possess one or more koza in solid-state physics for graduate work. Those universities which are particularly strong in solid-state physics are Tokyo, Osaka, Nagoya, and Kyushu.

At Osaka University, solid-state physics is carried on in the Physics Department proper, the Department of Engineering Science (Materials Science), the Faculty of Engineering, and in the Institute for Scientific and Industrial Research.

The University of Tokyo became dominant in the field of solid-state physics in Japan with the creation of the Institute for Solid State Physics in 1957 upon the recommendation of the Science Council of Japan with the concurrence of the Science and Technology Agency and the Ministry of Education. The major purpose of the Institute is to carry on basic research in solid-state physics, thereby promoting rapid development in the field, a field “which has many applications for improving industrial technology.” The Institute is perhaps the finest and best-equipped laboratory of its kind in Japan and has already earned world-wide renown. However, although an express purpose is to offer opportunities, when appropriate, for joint programs and to provide facilities for visiting scientists from other institutions, a strong koza system operates.

France

Higher education in the materials field is generally carried out in the “grandes écoles.” These are engineering schools into which candidates enter after highly competitive examinations. Typically the emphasis in these schools is towards a broad, theoretical training, leaving the question of practical experience to subsequent employment.

There are 140 such schools, 30 of which are concerned with military, broad engineering, or general scientific studies. The remaining 110 schools specialize in various sectors of engineering—see Table 8.9.

U.S.S.R.

It appears that metallurgical education in the Soviet Union is concentrated in relatively few institutions, some of which are enormous by Western standards (thousands of students). Contact with industry is often

Table 8.9 Fields of Specialization in Higher Education in France

Field of Specialization	Number of Schools	Students/Year
Physics and Chemistry	28	1,381
Mechanical Engineering & Metallurgy	14	1,386
Electrical Engineering— Computer Science	20	1,903
Aeronautical Engineering	3	140
Civil Engineering	8	643
Textile	6	128
Agriculture & Agricultural Products Engineering	25	1,259
Others	7	152

close and industrial equipment is frequently used in the research activities of the universities and institutes. Most institutes are mainly single-disciplined in their staffing but the Institute of Metal Physics recruits staff from various disciplines. Young people, especially solid-state physicists and physical chemists, are preferred though they need “seasoning” by exposure to metallurgists.

Students, either directly from secondary school (at age 18) or from industry (up to age 35), go to teaching institutes which are rather similar to the German “Technische Hochschule.” There, they study for the Diploma (5–1/2–6 years of undergraduate study), Candidate (3 years of graduate study) and Doctor’s degrees. Included in the training for the Diploma is considerable practical experience, making the students qualified engineers on graduation. However, the practical experience may be dispensed with in institutes where the emphasis is on science. In the final year or so of study, the students specialize, working in smaller classes with a fair amount of tutorials, and they also prepare a thesis. In their final year, undergraduates may be sent to a national research institute (e.g. Institute for Metal Physics) to finish off the Diploma work.

Higher degrees may be awarded by both teaching and research Institutes. The Candidate degree compares with the Ph.D. Several examinations have to be passed during the course of study, usually on theoretical background.

There has been growing emphasis in Russia on the physical and fundamental aspects of metallurgy and a few national research institutes have played a large part in this process, not only in their actual work but by general influence. For example, senior scientists at research institutes may take professorships at teaching institutes for a certain period. Their experience and basic approach is reflected in the instruction at the teaching institute and tends to strengthen the treatment of the fundamental background of the subject.

Financial support for the teaching institute comes partly from the Ministry of Higher Education which supports both teaching and research activities, and partly from industry which pays for research on specific industrial problems carried out on a contract basis.

RESEARCH AND DEVELOPMENT

Statistical Information

Total national expenditures on R&D, as expressed and normalized in various ways, are given for six advanced countries in Table 8.10. While the data refer to the mid-sixties, they are probably relevant to current economic-technological strengths of the nations because the time-lag between R&D and significant commercialization is often of the order of a decade. The relatively heavy expenditures in the U.K. and even more so in the U.S. reflect large commitments to defense R&D, with France being the next heaviest. Canada, Germany, and Japan all showed relatively low expenditures on R&D per GNP.

By 1971 expenditures had risen in France to 1.8% of GNP (Table 8.11) but were then decreasing. Japan had risen somewhat more and was still

Table 8.10 National Research and Development Expenditures (1963–64)

	Canada	France	Germany	Japan	U.K.	U.S.
Gross National Expenditure on R&D in U.S. $M	425.1	1,299.1	1,436.3	892.0	2,159.9	21,035.0
Gross National Expenditure on R&D as % of GNP	1.1	1.6	1.4	1.4	2.3	3.3
Per Capita GNP, U.S. $	2,121	1,676	1,775	678	1,735	3,341
Per Capita Expenditure on R&D	22.5	27.1	24.6	9.3	39.8	110.3
Qualified Scientists and Engineers on R&D	13,425	32,530	33,382	114,839	59,415	469,500
Qualified Scientists and Engineers on R&D/10,000 of Population	7	7	6	12	11	24
Total Manpower on R&D	37,525	133,570	187,013	289,290	–	–
Total Manpower on R&D/10,000	20	28	30	30	–	–

Table 8.11 National Expenditures on Research and Development as Percentage of GNP

Country	1963–1964	1971	Direction in 1971
Canada	1.1		
France	1.6	1.8	Decreasing
Germany	1.4		
Japan	1.4	1.8	Increasing
U.K.	2.3	2.0	Steady
U.S.	3.3	2.6	Decreasing
U.S.S.R.		3.0	Increasing

increasing, while the U.K. had leveled off at about 2.0%. Expenditures in the U.S. had shown a relatively big drop from 3.3% to 2.6% and were still decreasing. On the other hand, expenditures in the U.S.S.R. in 1971 were 3.0% and increasing.

Table 8.12 shows the level of commitment of qualified scientists and engineers to R&D. In 1963–64 the commitment levels in Canada, France, and Germany were only a little more than half of those in Japan and the U.K., and about a quarter of the U.S. level. By 1971 France, Germany, and Japan had roughly doubled their commitments to R&D, and in the latter two countries the commitment levels were still increasing. In particular, Japan had already drawn abreast of the U.S. The U.S., on the other hand, showed little change between the 1963–64 and 1971 levels and in 1971 the trend was actually downward; in contrast to all the above countries, the commitment level in the U.S.S.R. in 1971 was 1–1/2 times that of the U.S. and was increasing.

Table 8.13 shows the distribution in 1963–64 of R&D scientists and engineers among the industrial, governmental, private nonprofit, and higher-education sectors in the various countries. The U.K. and the U.S. had relatively heavy concentrations in industry, while in Canada, France, Germany, and Japan the numbers in industry were about comparable to those in the other three sectors combined. Outside the industrial sectors, the governmental sectors dominated in Canada, France, and the U.K., while universities and nonprofit institutions dominated in Japan, the U.S., and heavily in Germany. This last reflects the importance of the Max Planck Institutes.

A closer look at the industrial sector is given in Table 8.14 which shows the R&D expenditures in terms of sources of support. The heavy support given to industry by the government (presumable mainly defense contracts) is dramatic in the U.S. and, to a somewhat lesser extent, in the U.K. and France. At the other end of the scale, governmental support of industrial R&D is quite low in Germany and nearly zero in Japan.

The breakdown of total national expenditures for R&D by percentage between the defense, space, and nuclear sectors on the one hand, and all other sectors on the other is shown in Table 8.15. Large variations among countries are evident. However, it is worth noting that as a percentage of GNP the expenditures on R&D in the "All Other (civilian) Sectors" differed relatively little, ranging from 1.1% to 1.5%, except for Canada which was 0.8%. Furthermore, Figure 8.2 shows that the dollar expenditures in these sectors in the U.S., Germany, France, the U.K. and Canada followed remarkably parallel growth rates from the mid-fifties to the mid-sixties.

For the purpose of this report, some particularly interesting comparisons are given in Table 8.16 on the structure of R&D expenditures in manufacturing industries. The industrial groupings for statistical purposes are as follows:

Science—Based	—Aircraft Electrical (including instruments) Chemicals (including drugs and petroleum)
Mechanical	—Machinery Basic metals (including fabricated metal products) Other transport equipment
Other	—Allied products (rubber, textiles, food and drink) Miscellaneous Manufacturing

Table 8.12 Number of Qualified Scientists and Engineers on Research and Development Per 10,000 of Population

Country	1963–1964	1971	Direction in 1971
Canada	7		
France	7	12	Steady
Germany	6	15	Increasing
Japan	12	25	Increasing
U.K.	11	?	
U.S.	24	25	Decreasing
U.S.S.R.		37	Increasing

Table 8.13 Total Qualified Scientists and Engineers in Research and Development (1963–64)

	Canada	France	Germany	Japan	U.K.	U.S.
Industry	5,795	16,960	17,678	60,009	41,785	346,300
Government	4,825	9,400	1,967	16,457	12,080	49,600
Private Nonprofit	370	360	4,242	1,943	–	13,600
Higher Education	2,435	5,810	9,495	36,430	5,550	60,000

Table 8.14 Research and Development Expenditures in Industry by Source of Support (1963–64)

Source	Canada	France	Germany	Japan	U.K.	U.S.
Industry	77.9%	60.9%	90.1%	92.7%	59.1%	43.1%
Government	14.9%	29.7%	7.8%	1.1%	34.0%	56.9%
Foreign	3.9%	3.4%	0.4%	1.4%	2.9%	–
Other	3.3%	6.0%	1.7%	4.8%	4.0%	–

Table 8.15 Gross National Expenditures on Research and Development (1963–64)

	Defense, Space, and Nuclear Sectors	All Other Sectors	
	% of Total	% of Total	% of GNP
Canada	26.2	73.8	0.8
France	43.4	56.6	1.1
Germany	15.9	84.1	1.2
Japan	0	100.0	1.4
U.K.	40.2	59.8	1.4
U.S.	56.3	43.7	1.5

FIGURE 8.2 GOVERNMENT FUNDS FOR RESEARCH AND DEVELOPMENT OTHER THAN SPACE, NUCLEAR, AND DEFENSE RESEARCH AND DEVELOPMENT (in millions of U.S. $)

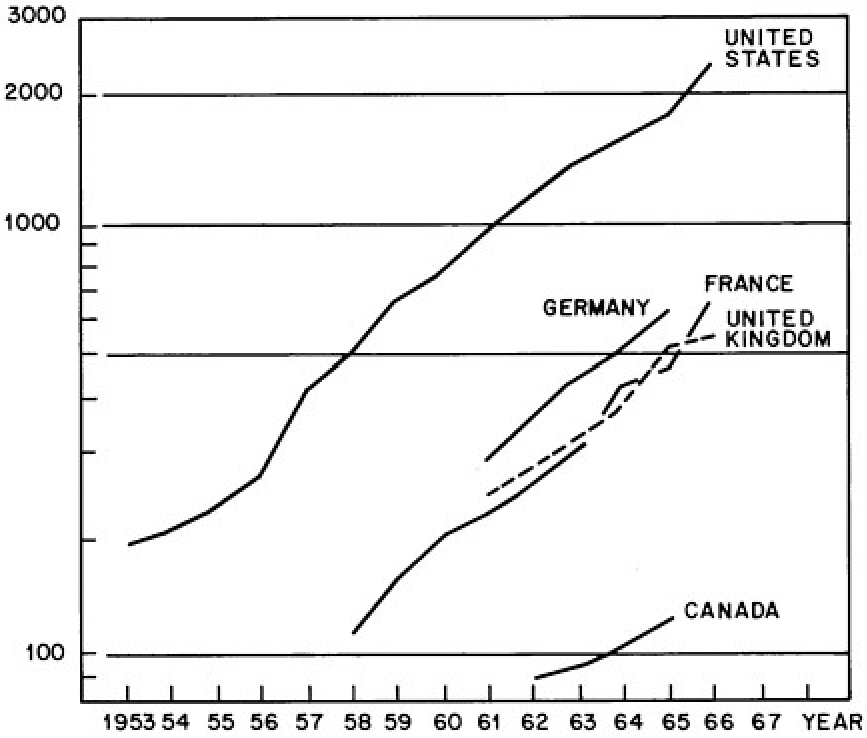

Table 8.16 Structure of R&D Expenditures in Manufacturing Industries (As percentage of total R&D expenditures in manufacturing industries)

	SCIENCE-BASED				MECHANICAL				OTHER			
	AIRCRAFT	ELECT.	CHEM.	TOTAL	MACH.	BASIC METALS	O.T.E.	TOTAL	ALLIED PRODS.	MISC. PRODS.	TOTAL	TOTAL
U.S. 1963–64	38.3	24.8	13.0	76.1	8.0	2.6	8.9	19.5	2.5	1.9	4.4	100.0
France 1964	24.6	28.6	19.4	72.6	7.6	5.3	5.8	18.8	4.6	4.0	8.6	100.0
Canada 1963	16.9	29.1	23.6	69.6	4.2	9.8	0.9	14.9	5.4	10.1	15.5	100.0
U.K. 1964–65	29.0	24.5	14.4	67.9	8.4	8.7	7.3	21.4	6.7	4.0	10.7	100.0
Germany 1964	b)	31.2	34.7	65.9	19.6	8.4	b)	28.0	4.7	1.4	6.1	100.0
Japan 1964	a)	30.3	27.3	57.6	5.1	9.4	11.3	25.8	8.4	8.2	16.6	100.0

a) Included in “other transport equipment.”

b) Included in machinery.

As might be expected, the countries with larger economic resources invest relatively more heavily in the science-based industries (reflecting also, in general, a greater proportion of effort going into defense R&D in those countries).

A more detailed breakdown of R&D expenditure in manufacturing industries in the major countries is given in Tables 8.17, 8.18 and 8.19.

The R&D technical manpower totals in Table 8.20 are particularly informative; there are strong efforts in certain industries in some countries reflecting particular local advantages in natural resources, but in nearly all industrial sectors where data are given, the total effort in the U.S. is greater, often considerably greater, then the combined totals of Canada, France, Germany, Japan, and the U.K. However, if all the figures were available, then probably the U.S. would lag somewhat the combined totals for the ferrous and nonferrous metal industries. This conclusion is further reinforced by the data given in Table 8.21 which, compares the U.S. expenditure and technical manpower on R&D with that of the whole of Western Europe. These figures might suggest that if there is any lag of U.S. industry vis-a-vis the world it is not because of an inadequate quantity of R&D effort; it is noteworthy that the U.S. industries with the narrowest lead, or even a lag, by this measure include predominently the basic materials industries— ferrous and nonferrous metals, chemicals, rubber, and textiles. If there are weaknesses in the U.S. R&D effort in these industries, perhaps one should look for explanation not at the magnitude of effort, primarily, but at its quality, its organization, and the general institutional barriers to innovation.

It appears that massive federally-supported R&D programs in those industries with defense and space contracts has contributed to U.S. leadership in the aerospace, computer, and nuclear industries. But it requires sustained massive support to maintain leadership as other countries are able to follow closely with much smaller R&D efforts simply by copying the technology, often making only modest modifications. The price of a small edge in technical leadership is extremely high and even with its huge resources, the U.S. may well have to select those industries in which, it needs to lead, technologically, and those in which, it can afford to follow closely.

Concerning priorities, it is useful to examine the trends in governmental R&D expenditures in various countries. Some of these are summarized in Table 8.22 where R&D has been grouped into 6 broad categories and given simple rank orderings. (The spacings between industrial rankings differ considerably and, of course, it has to be kept in mind that (i) defense and space expenditures dominate heavily in the U.S. while they are essentially absent in Japan, and that (ii) governmental funding of Japanese industrial R&D is negligible.)

Table 8.23 gives data on the percentages of highly qualified manpower in different industrial sectors and in the total labor force. These exhibit a slightly heavier indulgence in professional and technical people in most U.S. industrial sectors than the average of the Western countries but, apart from the service sector, the Japanese industrial sectors show a very much

Table 8.17 Research and Development Expenditures in Industrial Sector (1963–64)

	Canada	France	Germany	Japan	U.K.	U.S.
Amount in manufacturing sector as % of all industrial sectors	90.4	89.6	91.7	92.9	91.3	97.5
Selected components of these percentages (where known):						
Textiles	1.0	2.2			2.3	
Wood, cork, and furniture	0.2			0.1	0.3	0.1
Paper	6.8	0.1		1.1	0.3	0.6
Petroleum extraction and refining	5.8	4.2		0.9	2.0	2.5
Drugs	2.6	3.6		4.8		1.8
Chemicals	13.5	10.0	32.0	20.5	11.2	7.8
Rubber products	1.2	1.2	1.7	1.4	1.0	1.1
Stone, clay and glass	1.0	1.7	0.9	2.1	1.7	1.0
Ferrous metals	1.7	1.8		5.7	2.2	0.9
Nonferrous metals	5.0	3.0	7.8	2.5	0.9	0.6
Fabricated metals products	2.4			0.8	1.3	1.1
Machinery, excluding electrical	3.9		18.1	4.9	6.4	7.7
Instruments	2.7	5.0			2.1	3.6
Other electrical machinery and apparatus	21.9	26.2	28.2	26.0	19.8	19.7
Aircraft and missiles	15.7	22.5			28.4	38.2

N.B. Underlined figures represent expenditure proportions more than double those of the U.S.

Table 8.18 Percentage of Funds for Industrial Research and Development Coming from Industry (1963–64)

	Canada	France	Germany	Japan	U.K.	U.S.
All manufacturing industries	78.5	58.5	94.4	98.6	58.1	43.6
<u>Selected manufacturing industries</u>:						
Textiles	99.2	100.0				
Wood, cork, and furniture	82.4			100.0		
Paper	84.9	100.0		98.9	100.0	100.0
Petroleum extraction and refining	98.4	74.0		87.9	90.8	92.0
Drugs	72.1	91.5		100.0		95.3
Chemicals	95.5	82.3	99.8	99.1	95.6	79.1
Rubber products	83.5	95.7	96.7	99.6	92.2	82.7
Stone, clay, and glass	47.7	93.8	96.2	98.2	89.4	92.5
Ferrous metals	98.7	72.7		99.6	98.5	98.2
Nonferrous metals	99.4	67.1	96.0	99.3	87.8	93.3
Fabricated metals products	78.9			98.8	97.4	88.2
Machinery, excluding electrical	86.9		82.4	99.1	81.5	74.9
Instruments	59.4	70.9			70.4	56.9
Other electrical machinery and apparatus	75.3	57.2	95.6	97.0	55.0	38.2
Aircraft and missiles	49.3	15.3			9.9	9.6

Table 8.19 Percentage of Funds for Industrial Research and Development Coming from Government (1963–64)

	Canada	France	Germany	Japan	U.K.	U.S.
All manufacturing industries	16.2	31.5	4.0	0.4	36.3	56.4
Selected manufacturing industries:						
Textiles	0.8					
Wood, cork, and furniture						
Paper	0.5			0.3		
Petroleum extraction and refining	0.4				0.5	8.0
Drugs	2.4					4.7
Chemicals	2.4	5.1		0.1	0.4	20.9
Rubber products	0.8	2.2	1.9			17.3
Stone, clay, and glass	4.8	6.2	3.8	1.5	0.5	7.5
Ferrous metals		3.9		0.6	0.5	1.8
Nonferrous metals		18.7	1.7	0.3	2.7	6.7
Fabricated metals products	20.7			0.4	0.1	11.8
Machinery, excluding electrical	3.5		12.0	0.4	16.0	25.1
Instruments	27.3	22.0			23.6	43.1
Other electrical machinery and apparatus	22.6	29.9	4.0	0.5	36.0	61.8
Aircraft and missiles	46.1	78.3			84.2	90.4

Table 8.20 Qualified Scientists and Engineers Working on Research and Development in Industrial Sector (Numbers in full-time equivalents)

	1963 Canada	1964 France	1964 Germany	1964 Japan	1964 U.K.	1964 U.S.
All Manufacturing Industries	5,105	16,260	16,097	56,542	37,124	335,800
<u>Selected Industries</u>:						
Textiles	45	293	.	.	.	.
Wood, cork, and furniture	19	. .	.	168	. .	500
Paper	295	43	.	835	. .	2,600
Petroleum extraction and refining	182	768	.	495	1,104	8,900
Drugs	219	876	.	3,399	.	7,600
Chemicals	896	1,780	5,270	11,893	7,195	33,500
Rubber products	95	230	188	1,147	. .	5,600
Stone, clay, and glass	70	283	220	1,919	.	4,900
Ferrous metals	69	445	.	2,390	.	3,000
Nonferrous metals	270	394	1,494	1,302	2,172	2,300
Fabricated metals products	148	.	.	716	.	6,800
Machinery, excluding electrical	196	.	2,494	4,033	.	32,600
Instruments	258	951	.	.	5,176	16,500
Other electrical machinery and apparatus	1,417	5,550	5,874	15,973	10,621	74,800
Aircraft and missiles	546	3,271	–	–	4,192	101,200
Motor vehicles and parts	.	709	.	2,351	712	.
Shipbuilding	.	.	.	1,655	.	.
Other transport equipment	48	.	.	566	343	24,700
Other manufacturing	126	418	–	2,207	2,802	3,500

Table 8.21 Total Western Europe Research and Development Effort in Certain Industries vs. U.S. (1963–64) (U.S.=100)

	Expenditure	Technical Manpower
Miscellaneous Manufacturing	45.2	91.5
Applied Products	56.0	83.4
Basic Metals	65.2	83.3
Chemicals	42.2	79.0
Machinery	25.6	73.2
Electrical	27.0	54.1
Aircraft	11.6	22.3
Other Transport Equipment	16.3	22.6

Table 8.22 Distribution and Trend of Governmental R&D Expenditures (1961–1969)a

	U.S.		Japan		U.K.		France		W.Germany	
	Rank in 1969	Trend	Rank in 1969	Trend	Rank in 1969	Trend	Rank in 1969	Trend	Rank in 1969	Trend
National Defense	1	–	5	–	1	–	1	–	2	–
Space	2	+	6	?	5	+	5	+	4	?
Community Services	3	+	4	+	6	+	6	+	5	?
Economic Development	4	+	2	–	2	+	4	+	5	?
Nuclear Energy	5	–	3	+	4	–	3	–	3	+
Advancement of Science	6	–	1	+	3	+	2	0	1	+

[a] From Science Indicators, 1972, Report of the National Science Board, National Science Foundation, Washington, D.C.

Table 8.23 Highly Qualified Manpower as Percentage of Industrial Sector (1963/64)

	Canada	France	Germany	Japan	U.K.	U.S.
Scientific and Technical:						
In total labor force	2.0%	2.8%	3.2%	0.8%	2.8%	2.5%
In manufacturing	–	4.9%	4.6%	–	4.5%	5.0%
In metal products	–	8.0%	6.8%	–	6.5%	8.0%
In chemicals	–	9.0%	9.6%	–	10.1%	11.6%
Professional and Technical:						
In total labor force	9.7%	9.8%	7.7%	4.8%	8.5%	10.4%
In manufacturing	5.2%	7.3%	5.1%	1.8%	5.4%	7.4%
In metal products	6.7%	10.3%	7.1%	2.3%	7.2%	10.6%
In chemicals	13.8%	13.0%	10.7%	3.7%	11.1%	15.4%
In services	27.0%	30.4%	26.9%	27.7%	21.4%	29.8%
Managerial:						
In total labor force	5.3%	2.0%	3.2%	2.3%	2.6%	6.3%
In manufacturing	6.7%	2.5%	2.2%	4.0%	3.6%	5.1%
In metal products	6.5%	2.0%	1.8%	4.0%	3.1%	4.2%
In chemicals	8.5%	2.9%	2.5%	4.2%	4.8%	6.6%
In services	6.3%	2.4%	8.6%	2.7%	2.6%	6.2%

lower involvement of such personnel. The manufacturing, metal products, and chemicals sectors apparently perform with relatively fewer managers in the European countries than in their North American counterparts.

Some data on the allocation of resources in the early to mid-sixties for basic research are summarized in Table 8.24. In comparison with other countries, basic research as a percentage of all national R&D is slightly less in the U.S. and U.K. However, the U.S. effort does not seem to be extreme in either direction in all the industry sectors listed, especially when compared with the major industrial countries. Comparisons with the smaller countries are more difficult to make an account of widely varying local conditions. Since the early 1960's, many U.S. industries have tended to reduce their effort on basic research but corresponding data on what industries in other countries have done are not readily available.

Japan

In the early 1970's, the ratio of Japanese R&D expenditures to national income was about 2% and was projected to rise to about 2.7% by 1980 if earlier trends would continue. An ultimate goal of 3% was thought appropriate.

Most of the R&D expenditures are incurred by industry rather than by government in contrast to other advanced countries, though it is expected that the governmental share will increase, particularly for the support of:

Basic research

Research relevant to social or environmental needs

R&D in low-productivity areas of industry

R&D in pioneering areas exceeding the capacity of private industry to support, e.g. many environmental matters.

In addition, the government will continue to promote industrial R&D through tax measures and other incentives, and will guide industrial research efforts through technology assessment.

Promotion of Basic Science

Japan recognizes that basic research is an important element of science policy, and that history shows such research leads to important technological breakthroughs even though these cannot be properly foreseen at the time. Further, the official view that the more applied science and technology is directed toward social and economic needs, the greater is the need for basic research. The higher the level of basic science and technology, the greater the possibility of meeting changing social and economic needs.

Also, support of basic research "helps satisfy man's desire to seek truth and understanding. At a time when people are seeking lives worth living and are beginning to pay attention to the need for qualitative improvement of their spiritual life, basic science merits special attention."

Table 8.24 Data on Basic Research (B.R.) (1963/64)

	Austria	Belgium	Canada	France	Italy	Netherlands	Norway	Sweden	U.K.	U.S.
B.R. as % of National R&D	22.6	20.9		17.8	18.1	27.1	22.2		13.2	13.4
% of B.R. in industry	27	33		10	16	39	11		24	22
in govt. sector	11	18		21	23	2	14		27	14
in private nonprofit		1		2	–	13	8		4	7
in academia	62	48		67	67	46	67		45	57
B.R. as % of all Industrial R&D	9.8	9.0	5.3	4.0	4.8	19.0	4.2	1.3	4.9	4.2
B.R. as % all R&D in each Industry										
Chemical	6.5	15.5	6.9				3.1	0.4	12.6	12.1
Electrical	0.4	2.7	4.3				2.3	0.7	5.0	4.5
Aircraft	–	1.7	0.5				–	–	0.6	1.3
Other transport eqpt.	15.9	15.9	4.2				2.7	0.4	1.2	3.2
Basic metals	6.7	4.9	6.8				2.4	1.6	4.6	4.3
Machinery	4.3	4.7	0.3				2.2	–	3.5	2.5
Allied products	12.7	3.5	11.3				4.8	3.7	15.1	8.7
Other manufacturing	10.9	10.5	12.2				1.9	6.5	7.3	4.6

Promotion of R&D for National Projects

Priority for governmental support of R&D is given to the following projects:

R&D directed toward maintenance and improvement of man’s mental and physical capabilities.

Interrelationships between productive activities, recreation, and optimum environmental conditions for human life.

Prevention and treatment of diseases of high mortality including apoplexy, cancer, and heart diseases, as well as mental and nervous disorders and diseases caused by pollution.

Artificial organs and blood; new methods of diagnosis and therapeutics using electronics, precision engineering, information theories, etc.

Development of new vaccines and safer drugs.

Food distribution and food safety.

Nutrition.

Quantity production of inexpensive, comfortable houses.

Better city planning.

Safer and more effective consumer products.

Super high-speed railways for heavy-load transportation.

Large scale civil engineering, bridges and tunnels.

Aeronautics suited to Japan.

Automatic traffic-control systems.

Information processing and communications; computers.

Safe atomic energy.

Conversion, storage, and distribution of energy.

Development of resources of the continental shelf.

Efficient use of idle resources; exploration for fresh resources.

Develop efficient use of water resources including desalination.

Develop multiple uses of forests.

Prevention and prediction of environmental pollution.

Effects of environmental factors on man and organisms.

Protection of natural environment.

Prediction of earthquakes, heavy downpours. Weather modification.

Prevention of urban disasters.

Prevention of labor and industrial disasters.

Large-scale mechanization of agriculture and biological, chemical, and physical controls in agriculture.

Large-scale stock farming.

Labor-saving in forestry.

Fish culture.

Develop new processes and automation for manufacturing industry.

Develop new industries.

Elevate technical level of smaller enterprises by automation.

Pioneering areas of science and technology:

Atomic energy

Space exploration and development

Ocean development; marine resources

Nuclear fusion

New materials

Soft science
Life science
Basic electronics and information science
Generation of extreme conditions—pressure, temperature
Standards and measurement criteria

Organizational Measures for Implementing R&D Programs

Japan recognizes the crucial importance of arranging for effective collaboration among people from different disciplines and in different institutions if it is to meet its national objectives. Instances of such interdisciplinary cooperation are sparse in Japan compared with Europe and North America. There seems to be little collaboration across disciplinary lines or, for example, interchange of personnel between institutes, or active cooperation between research institutes.

It is felt necessary to establish means for smooth contacts among researchers and for exchange of information. Besides encouraging joint utilization of major research facilities and encouraging personnel exchange, the following measures have been suggested in Japan:

(a) Establish a system of information services for research workers to keep them informed about work being done elsewhere.
(b) Provide opportunities for researchers engaged in related work to get together to exchange knowledge and cultivate research cooperation.
(c) Organize a multidisciplinary research team to promote active cooperation among researchers within the same institution.
(d) Take proper steps to ensure smooth conduct of cooperative research between different research institutes, when appropriate, e.g. between universities and national research laboratories.
(e) In the case of national projects, research organizations should be appropriately mission-oriented, as in the U.S.

National Research and Development Program

In accordance with the Comprehensive National Land Development Act of 1950, the Government of Japan published in May 1969 a “New Comprehensive National Development Plan” which set the tone for the agricultural, industrial, and economic development of the country, taking into account special consideration of different geographical regions of Japan. It notes that the phenomenal development of Japan was achieved by concentrating and accumulating economic activities in urban centers and by providing good communication (particularly rail) networks. But this has led to population density problems in the cities and a manpower draining from the rural areas.

In the earlier Comprehensive National Development Plan of 1962, these demographic problems were recognized and recommendations were made for efficient dispersal of industries and population to attain higher overall efficiency in the national economy. As a result, “New Industrial Cities and Special Areas have been formed as new growth centers for industry. The limitations of overcongested cities have been gradually recognized, and enterprises have started to recognize the advantages of decentralization and technological innovations." In bringing about these changes in social patterns, the government has called for a "frontier spirit" based on the long-range view, not constrained by tradition.

"Japan envisages continued rapid progress in the so-called 'Second Industrial Revolution' based on the information revolution, internationalization, and technological innovation. They term the new society, the 'information society,' in which automation replaces (or augments) brainpower in the same way that machinery replaced muscle power in the first Industrial Revolution. "But this transformation of society will bring with it drastic changes in societal and economic structures and activities. New patterns of education, extending over a lifetime, will be needed.

"In the coming information society there will be a greater number of entities which carry out independent intellectual activities and a greater choice of directions to follow. Information will play a key note in all spheres of social activity. Every business organization will be reorganized as a creative, flexible body with a management information system and program team as its nucleus. Information collection and distribution will be regarded as a national asset. Thus it is necessary to modify and develop the communication network and information industry."

Japan also foresees how "increasing international communications, exchanges of personnel, technology, and information will stimulate the development of the new society. World-wide research and technological innovations in space science, oceanography, biological science and human engineering will drastically change economic life. Laser technology will revolutionize the information system, new methods of rapid transportation will be developed, the technology of desalination will revolutionize water utilization, and progress in housing construction and urban technologies will alter the environment.

"To develop these technological innovations and adapt them to the conditions of Japan, technological development must be pursued on a selective basis. It is indispensible to build up indigenous, innovational technologies."

In an effort to develop such new technologies, the Agency of Industrial Science and Technology of MITI has sponsored a National Research and Development Program directed toward promoting R&D in selected technologies on a large scale with the close cooperation of the industrial and academic communities. The technologies selected are listed in Table 8.25. Particularly noteworthy, and reflecting the information-society goal, is that the two most costly projects are for electronic systems—large-scale computers and pattern-information processing systems. Both include the development of software as well as hardware, but it is of interest to examine the materials and device requirements which have been delineated for the latter. New devices, especially opto-electronic, will have to be developed and a number of development contracts have been let out to manufacturers for:

(a) Infra-red semiconductor lasers
(b) Magnetic bubble devices
(c) Reversible photo-sensitive materials
(d) Functional devices
(e) Spatial modulation devices for deflection and modulation of light beams.

Table 8.25 National Research and Development Program in Japan (1969)

Title of Project	Project Period	Total Cost in Millions of Dollars	Objective of Development
Magneto-Hydrodynamic Generator	1966–72	14.72	Development of an epochal power generating technology
Super-High-Performance Electronic Computer System	1966–71	27.78	Development of super-high performance, large electronic computer systems
Desulfurization Process: (1) sulfur removal from stack gas (2) sulfur removal from fuel oil	1966–71	6.94	Development of technologies for removing sulfur directly from heavy oil
New Process for Orefin Product (This program was later cancelled)	1967–73	10.83	Development of a process for producing orefin (ethylene, etc.) through direct cracking of heavy oil
Sea Water Desalting and By-Product Recovery	1969–75	13.89	Development of a process for desalting sea water and recovery of by-products
Remotely-Controlled Undersea Oil Drilling Rig, first phase	1970–74	14.17	Development of an oil-drilling rig equipped with a remote-control system, capable of drilling oil on deep-water continental shelves
Electric Car	1971–75	13.89	Development of an electric car for citybound transportation

Title of Project	Project Period	Total Cost in Millions of Dollars	Objective of Development
Pattern Information Processing System	1971–78	97.22	Development of information processing system capable of processing pattern, namely, information concerning characters, pictures, shapes of objects and human voice
Turbofan Engine for Aircraft, first phase	1971–75	18.61	Development of a turbofan engine which will be capable of withstanding frequent take-offs and landings, economizing fuel consumption at a sub-sonic flight and generating less pollutants

Some examples of new applications of the pattern-information processing system are:

(a) Character recognition: direct process of manually-written programs, vouchers, etc., automatic typesetting, automatic editing with sentence processing.
(b) Picture recognition: automatic drawing of design and control of metal processing, automatic weather forecasting based on weather charts, automatic diagnosis based on X-ray photos, etc.
(c) 3-D object recognition: automatic drawing, automatic preparation of control program for metal processing, automatic traffic control.
(d) Voice recognition: develop input-output system and voice typewriter, voice-print terminal equipment.
(e) Integration of recognition functions: robots for use in water or space, cashless system, unmanned plant, unattended hospital, etc.

Some general remarks:

The foregoing provides clues about how Japan will continue to implement its proven policy of creating new technologies and finding new markets wherever possible rather than just refining the existing ones. The President of the Sony Corporation, for example, has attributed the world-wide success of his company primarily to this knack of being the first with a new product— first with magnetic tape recorders, transistorized pocket radios, small transistorized TV, video tape recorders.

In the past Japan has also enjoyed a price advantage due to the lower labor costs in Japan. This is no longer the case. As MITI has recognized, the price advantage has, in turn, passed to other less-developed countries and, in addition, any attempts by Japan to cut export prices run up against problems of antidumping laws. So, MITI has declared that in the future more reliance should be placed on quality than on price advantages in the world market, and it has the information-intensive industries particularly in mind.

Recent Trends in Japanese Technology Emphasis[8]

"The economy is being internationalized and thinking is in terms of global markets, but internally there are increasing social needs, environmental problems, and labor shortages. New directions for technical innovation are needed. It is necessary to abandon the conventional, narrowly-focussed approach (e.g., to optimize technically a production process) and to adopt a systems approach covering a broad domain of nature, man, and technology.

(a) Japan must develop more technologies of her own to use as weapons in the international competition.
(b) Technologies important to society must be developed.
(c) The effects of new technologies must be assessed."

Up until 1960, Japan mostly imported new technology to stimulate existing industries (such as iron and steel, nonferrous metals, petroleum, synthetic fiber) and create new ones (electronics, petrochemicals). Since 1960, there have been increasing labor shortages which, have led to development of automation. Also, the liberalization of world trade has resulted in an increased pace of technical innovation. By about 1970, the range of industrial products had broadened considerably, as indicated in Table 8.26.

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[8] Based on "Summary of White Paper on Science and Technology—New Demands on Technical Innovation," Science and Tech. Agency, Govt. of Japan, April 1971.

Table 8.26 Main Products of Japanese Technology

Field	Products
Chemistry	Nylon, vinylin, caprolactum (by PNC process), vinyl chloride monomer (by oxychlorination process), normal paraffin, paraxylene, chloroprene rubber, polycarbonate resin, diethylhexanole, urea (by complete circulation process), ethyleneoxide (by direct oxidation process), melamine, etc.
Electrical machinery	Transistor radio, video tape recorder, transistor TV, washing machine (“Jet Stream” type), ferrite-core memory, tunnel diode, electron range, desk computer, pulse motor, etc.
Other machinery	Automatic spinning machine, large tanker, rotary engine, pump water-wheel, electron microscope, electric eye camera, crystal wrist-watch, etc.
Medical supplies	Bleomycin, sulfisomezole, mitemycin, fiberscope, etc.
Others	Synthetic paper, IN high-tension steel, rapid-transit railway, earthquake-proof skyscrapers, etc.

Some observations:

(a) Technical innovation has been pushed mainly by private industry which has also played the leading role in supporting R&D. But growing social, urban, and pollution problems have brought increasing intervention by the government, with the latter increasing its spending on R&D.
(b) Until recently, innovation in Japan depended heavily upon imported technology, with Japan's own technology making very little contribution to the development of industrial products. Now, there is less to learn from abroad and with the terms of contracts getting tighter, Japan must develop more of its own technology.
(c) Technology has been successfully applied to manufacturing products but not very much so far to their ultimate disposal and reclamation; or to the polluting effects of industrial processes and product uses.
(d) Technological expansion in Japan has been extremely rapid with congruent distortions in the quality and way of life, such that society has not been able to adjust to quickly enough.

The main problems in promoting technological development are seen as:

(a) Few industries have so far paid enough attention to user's needs, initiating appropriate R&D ahead of companies abroad.
(b) Japanese techniques are less concerned with basic elements of industry such as power, materials, hardware and systems.
(c) Few Japanese techniques have been developed through collaboration among industry, government and academia.

When dependent on imported technology, Japan made few demands on its own scientific researches, nor did it try hard to use them. Science was often left to follow Western fashions and was not coupled well into technology.

From 1945 to 1954, basic industrial needs were given high priority— coal, iron and steel were the initial driving forces in Japan's economic recovery. From 1955–1964, electronics and polymer chemistry led other industries. Later, automation became increasingly important and most recently, the development of data communication and other information systems.

Concerning personal needs—needs for food, clothing, and household goods were largely met by 1955. New building materials led to more durable houses. Leisure equipment has been expanding.

As for social needs—improved transport systems were developed, new drugs discovered, and sophisticated medical instrumentation developed. But social needs have kept growing, especially for improved environment and control of public hazards.

Besides all its positive results, technical innovation has helped create environmental problems—other factors also contributed, such as inadequate urban planning. The impacts of technology in Japan have not been thoroughly assessed. Some examples are given in Tables 8.27 and 8.28. On the other hand, examples can be given where some of the negative effects of science and technology have been alleviated by new processes and techniques, as in Table 8.29.

Government and industry in Japan have been spending increasingly on pollution control—R&D and technology. In 1970, governmental expenditures for pollution control research amounted to $3.91 M (including air pollution, water pollution, noise and vibration, odors, etc.). In 1969, industrial

Table 8.27 Merits and Demerits of New Processes or Techniques in Japan

Technique or Process	Merits	Demerits
Mercury electrolysis process for making caustic soda	Better than diaphragm electrolysis methods as products made by the process higher in quality and concentration and lower in price	Mercury responsible for water pollution
Shell mold process for casting	Better than conventional methods as products made by the process higher in quality and quantity	Offensive odors due to combustion of phenol resin
Iron & steel production technology	Increased productivity due to plant expansion and automatic control of production	Sulfur oxide & dust responsible for air pollution
Thermal power production technology	Lower cost of power due to plant expansion and automatic control	Sulfur oxide & dust responsible for air pollution
Aluminum electrolytic refining technique	Lower power consumption per ton of product due to plant expansion	Fluoride responsible for air pollution
Paper & pulp making technique	Lower cost and larger output due to plant expansion and speedier operation	Plant effluent causes water pollution; ground subsidence; offensive odor
Petrochemical technology	Inexpensive and abundant supplies of chemical products	Sulfur oxide causes pollution of air; water pollution

Table 8.28 Positive and Negative Effects of Main Products in Japan

High-octane gasoline	Greater anti-knock properties and less damage to vehicle than regular gasoline	Air pollution by more lead compound emission
Synthetic resin as building material	Better appearance, lightness, prefabrication	Harmful gas and black smoke when catching fire
Electronic computer	Greater capacity for processing information	Inflammation of the tendon sheath suffered by keypunchers
Skyscrapers	Land utilization	Infringement of the right of light
Jet aircraft	Higher speed and increased transport capacity	Noise; air pollution
Pesticides	Increased crop output, extermination of harmful insects	Contamination of food and soil
Antibiotics	Effective treatment of diseases	Anaphylaxis, alternation of bacteria
Synthetic resin products	Lightness, corrosion resistance, workability	Environmental pollution by solid waste dumping
Automobile	Greater convenience, saving of time	Air pollution (carbon monoxide, hydrocarbon, nitrogen oxides, lead compound, particulates); traffic accidents; noise, vibration; solid waste
Durables	Greater convenience, comfort	Environmental pollution by dumping of solid waste

Table 8.29 New Processes or Products and Their Effect in Mitigating or Eliminating Negative Effects

Negative Effect	New Process or Product	
Air pollution	Oxygen converter gas recovery process in steel manufacture	Abatement of air pollution. Steel manufacture is attended with generation of a large amount of waste gas whose main ingredient is carbon monoxide. The OG process has made it possible to recover such waste gas and use it as gaseous fuel or synthetic chemical material.
Water pollution	Process for making acetaldehyde, vinyl chloride monomer, and vinyl acetate monomer from ethylene	Elimination of water pollution by mercury. The new process, does not require use of mercury catalyzer which has been responsible for water pollution.
Noise & vibration	Oil-pressure pile driver	The utilization of oil pressure, instead of hammer power, in driving iron piles has resulted in reducing noise and vibration shock.
Water pollution	“Soft-type” synthetic detergent	While “hard-type” synthetic detergent is resistant to decomposition by microorganisms, causing water pollution, “soft-type” detergent, made of normal paraffin, is easily decomposed by microorganisms.
Anaphylaxis	Penicillin V	While penicillin G had been unfit for oral use because of its unstable effect on acid in the stomach, penicillin V is not only fit for oral administration but has reduced the risk of anaphylactic attacks such as “penicillin shock”

expenditures on developing pollution-control technology amounted to $31.9 M out of a total R&D expenditure of $702 M, or about 4.5% (see Table 8.30).

Principal technical approaches currently being pursued in pollution control are listed in Table 8.31. At present efforts are aimed mainly at improving disposal processes, but future R&D will aim at finding entirely different methods and adopting a systems approach to the whole subject.

So far, technical innovation in Japan has been conspicuously successful at producing new goods and competing in international commerce, less so in meeting social welfare needs and the demands of rising living standards. More attention will have to be paid in future to problems of waste disposal, materials recycling, and pollution arising from manufacturing processes. Furthermore, international cooperative studies will be needed on the overall materials cycle and on the ability of nature to sustain life. And throughout, psychological as well as physiological frictions at the man-machine interface will have to be alleviated.

However, there is a feeling in Japan that its technology must be developed more independently of other nations in the future, both to remain competitive and also to solve problems pertinent to Japan. The systems approach must be adopted with problems being attacked on a total basis. And the impacts of new technical innovations must be more adequately assessed beforehand.

Recent Trends in Research and Development Expenditures in Japan

Recent trends in R&D expenditures by individual ministries and agencies are summarized in Table 8.32. The major component of such public funds goes to the support of education—the universities. A breakdown of recent trends by category of expense or recipient is given in Table 8.33, again showing the universities are principal recipients of public R&D funds.

The relatively low level of support of R&D from public funds in Japan and the virtually zero support given with public funds to private industry has already been noted. As Table 8.34 indicates, public expenditures for R&D have held at about 30% of the nation's total over the past five years, and most of this has been for the support of basic research in the universities. It is therefore of much interest to examine the expenditures for R&D by industry. This has been done recently by the M.I.T. Center for Policy Alternatives; the following data have been extracted from their report.[9]

Total R&D expenditures by industry amounted to 895 billion yen in 1971, or 82.6% of the total private R&D outlay (Table 8.35). Among the five major classifications of industry (namely, agriculture, forestry, and fisheries; mining; construction; manufacturing; and transport, communication, and public utilities), manufacturing industries accounted for 91% of the total, followed by transport, communication, and public utilities industries (6%), and construction industries (3%).

The electrical machinery industry, within the manufacturing category, spent 26% of the total, and the chemical products industry spent 21%. These two industries alone accounted for nearly one-half of the total R&D expenditures made by the manufacturing industries.

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[9] "National Support for Science and Technology: A Description of Foreign Experiences," Center for Policy Alternatives, Mass. Inst. of Tech., 1974 (Report sponsored by NSF Grant DA 39172).

Table 8.30 Private Industry's Expenditures for Development of Pollution Control Technology in Japan (1969)

Type of Industry	No. of Firms	Total R&D Expenditure (A)	Expenditure for Pollution Control Technology (B)	B as Percent of A
		(Unit: ten thousand dollars)		(%)
Food	10	1,115	15	1.3
Textile	14	713	23	3.2
Pulp	14	487	76	15.9
Chemical	85	18,824	625	3.3
Rubber Ceramics	23	1,527	46	3.0
Iron & Steel	21	2,567	64	2.5
Nonferrous Metal	19	1,952	49	2.5
Machinery	23	5,331	362	6.8
Electrical Machinery	24	17,245	318	1.7
Transportation Equipment	25	16,301	1,257	7.7
Power, gas	12	3,311	323	9.8
Others	17	822	27	3.3
Total	287	70,195	3,185	4.5

Table 8.31 Principal Technical Methods for Pollution Control

	(1) Air Pollution	
Change in Mechanism or Principle	Reform in Mechanism or Method	Method for Disposal (Chemical, biological, etc.)
Auto exhaust: Electric car, gas turbine car, steam-engine car, etc.	Dust: Remodeling combustion chamber, etc. Nitrogen oxides: Improving combustion, methods (two-phase combustion, recycling waste gas, etc.) Auto exhaust: Remodeling engine; exhaust manifold; air jet method; exhaust manifold reactor; waste gas recycling; non-leaded gasoline	Dust: Dust collector (gravity method, inertia method, centrifugal method, cleansing method, filtration method, electrical method) Sulfur oxides: Desulfurization of smoke (active manganese oxide method, active carbon method). Desulfurization of heavy oil (fixed floor and suspended floor methods). Using bacteria in sulfurization. Using taller smoke-stacks. Nitrogen oxides: Using CH_4 and NH_3 in deoxidation. Auto exhaust: Catalyzertype converter.
	(2) Water Pollution	
Plant effluent, sewage, waste oil, etc. : Developing nonmercury catalyzer, non-cyanic plating liquid		Plant effluent, sewage, waste oil, etc. : Physical methods— Screening, natural precipitation, chemical precipitation, concentration,

	(2) Water Pollution (Continued)	
Change in Mechanism or Principle	Reform in Mechanism or Method	Method for Disposal (Chemical, biological, etc.)
		floatation, filtration, drying, burning, heating, evaporation, cooling, etc. Chemical methods—Neutralization, oxidation, resolution, concentration, absorption, ion exchange. Biological methods— Activated sludge method, Methane fermentation method.
	(3) Noise & Vibration	
Construction: Supersonic destruction, etc.	Construction: Noiseless pile driver; New construction process. Automobile: tire, exhaust pipe. Aircraft: Remodeling engine (bypass engine), fan.	Automobile: Remodeling muffler, improving road structure. Aircraft: Remodeling muffler
	(4) Offensive Odor	
		Physical—burning, flushing, soil filter, etc. Chemical—wet electrode, ozone oxidation, acid alkali cleansing, neutralizing, absorbing, chlorine, soil filter, etc. Biological— soil absorption.

Change in Mechanism or Principle	Reform in Mechanism or Method	Method for Disposal (Chemical, Biological, etc.)
	(5) Solid Waste	
Plastics: Degradable plastics (photolysis, Oxidation, etc.)		Sludge: Physical– Concentration, filtration, drying, burning. Chemical—Wet air oxidation, etc. Plastics: Physical– Plastics incinerator, compression-pulverization, solidification. Biological—Decomposition by bacteria. Recycling. Household refuse: Batch incineration, mechanized incineration, continuous incineration, compression, pulverization. Recovery and recycling.
	(6) Pesticide	
Low-toxity pesticide, biological pesticide, substance for checking formation of cellwall, etc.		

Table 8.32 Research and Development Budgets by Ministry in Japan (1971–72)

Agency	Unit: one million yen	
	1971	1972
Ministry of Education	164,220	196,436
Science & Technology	70,790	88,949
MITI	21,491	29,155
Ministry of Agriculture & Forestry	18,782	21,477
Defense Agency	12,294	14,072
MOH	6,274	8,142
Ministry of Construction	3,839	4,500
MOT	3,134	3,411
Agency for Environment	384	2,911
Ministry of Telecommunication	1,472	1,659
Economic Planning Agency	634	1,008
MOL	399	455
Public Security Investigation Agency	334	338
Science Council of Japan	366	356
MOJ	280	305
MOFA	192	287
Ministry of Home Affairs	158	180
Ministry of Finance	150	161
Diet	106	111
Hokkaido Development Agency	89	95

Table 8.33 Trend of R&D Budgets in Japan by Allocated Areas (1968 to 1972)

Unit: one hundred million yen

Fiscal Year	Expenses for the National Research & Development Institutes	Subsidies to Private Sectors	Administrative Expenses	Expenses for National Universities	Total
1968	451	251	255	962	1,919
1969	500	347	311	1,056	2,214
1970	571	475	440	1,149	2,635
1971	665	595	514	1,280	3,054
1972	758	838	661	1,482	3,760

Table 8.34 Ratios of Public vs. Private R&D Disbursements, 1965 Through 1971

						Unit: Ten million yen	
		R&D Expenditures		Ratios (%)		Percentage Change from Previous Year	
Fiscal Year	Total	Public*	Private	Public	Private	Public	Private
1965	5,086	1,624	3,456	32	68	16.8	15.8
1966	5,766	1,940	3,819	34	66	19.5	10.5
1967	7,025	2,242	4,775	32	68	15.6	25.0
1968	8,775	2,628	6,139	30	70	17.2	28.6
1969	10,647	2,997	7,638	28	72	14.0	24.4
1970	13,555	3,701	9,847	27	73	23.5	28.9
1971	15,324	4,474	10,838	29	71	20.9	10.1

*"Public" includes local governments

Table 8.35 Industrial Research and Development Expenditures in Japan (1965, 1970, and 1971)

	Industrial Expenditure on R&D (10 million Yen)			
	65	70	71	% of total
All industries covered	2,524	8,233	8,950	100.00
Major Industrial Categories:				
Agriculture, forestry, & fisheries	3	20	9	0.1
Mining	31	60	65	0.7
Construction	43	153	263	2.9
Manufacturing	2,320	7,609	8,107	90.6
Transport, communication, & public utilities	126	391	506	5.7
Individual Industries:				
Food	90	214	274	3.1
Textile Mill Products	80	143	175	2.0
Chemical Products	627	1,751	1,937	21.6
Industrial Chemicals	349	973	1,045	11.7
Drugs & Medicines	146	454	557	6.2
Iron & Steel	148	366	409	4.6
Machinery, except electrical	178	724	752	8.4
Electrical Machinery	515	2,278	2,292	25.6
Transportation equipment	290	949	1,130	12.6
Motor Vehicles	243	789	927	10.4
Other Transportation Equipment	47	164	202	2.3

On the other hand, the increase in expenditure by the transport, communication, and public utilities industries is conspicuous, as is the increase registered by the food products industries. Nevertheless, the overall increase by manufacturing industries in 1971 seems low (8.7%). One striking exception is the enormous increase by the construction industries.

One index of the extent to which a firm's viability depends on R&D is the ratio of R&D expenditures to sales. Table 8.36 shows these ratios for various Japanese industries in the years 1965, 1970, and 1971. Also shown, where known, are the corresponding figures for U.S. industries.

At an aggregate level, Japanese R&D expenditures relative to sales was 1.27% in 1971, a slight increase over the previous year. Drugs and medicines, and communication and electronic equipment industries reported the highest ratios (3.90 and 3.64% respectively). However, these ratios are still considerably lower than those of the U.S. counterparts (6.5 and 8.7%, respectively in 1970). On the other hand, Japan invests relatively more heavily in R&D than U.S. industries in food products, textiles, and notably, iron and steel.

Table 8.37 indicated how private firms have allocated their R&D expenditures between basic research, applied research, and development. The relative distribution of R&D funds among these three areas has remained rather constant over the past six or seven years, whereas the absolute amounts have grown substantially.

Table 8.38 shows how particular industries have proportioned their expenditures among the same three categories of R&D activities.

With respect to basic research, most of the chemical products manufacturing industries, such as drugs and medicines, rubber products, oils and paints, industrial chemicals, and food products industries spent more than the average of 9.1%. Most of the manufacturing industries, on the other hand, spent more than the average for applied research, as did the agriculture, forestry, and fisheries industries. And the industries which spent relatively more money for development research are the construction industries (77.3%), manufacturing industries (73.2%) and transport, communication, and public utilities industries (73.0%).

Industrial R&D in Japan

There is little if any interdisciplinary academic research or education in Japan, and also little coupling between universities and industries through joint or industrially-sponsored research programs. Thus, wherever interactions have taken place between the scientific disciplines, and between scientists and engineers, in order to achieve the technological successes that Japan is noted for, these must have occurred almost always In industrial laboratories and organizations. It is, therefore, of interest to examine the functioning of such organizations.

The President of the Sony Corporation, a company whose name is synonymous with the Japanese economic advance, has given his views on R&D In his company: "Definition of the terms research and development Is very wide and their range and limit vary according to the individuals and for the purpose It Is used. In enterprises it is very important to make the definition of the terms

Table 8.36 Ratios of Industrial Research and Development Expenditures to Sales by Industry (%)

	1965	1970		1971	
Industry	Japan	Japan	U.S.	Japan	U.S.
All industries covered	0.95	1.16		1.27	
Agriculture, forestry & fisheries	0.11	0.25		0.19	
Mining	0.48	0.53		0.75	
Construction	0.20	0.25		0.33	
Manufacturing	1.11	1.36	2.63	1.48	2.47
Food products	0.40	0.46	0.20	0.48	0.20
Textile mill products	0.67	0.59	0.29	0.65	0.26
Pulp and paper products	0.67	0.55	0.74	0.65	0.51
Chemical products	1.76	2.10	3.71	2.30	3.54
Industrial chemicals	1.54	1.77		1.89	
Oil and paints	1.36	1.96		2.08	
Drugs and medicines	3.00	3.39	6.50	3.90	
Other chemicals	1.83	2.44		2.69	
Petroleum and coal products	0.21	0.25	2.29	0.30	1.76
Iron and steel	0.71	0.64	0.34	0.77	0.31
Machinery, except electric	1.04	1.35	3.08	1.64	3.08
Electrical machinery	2.29	2.96	8.51	3.26	8.17
Electrical machinery equipment and supplies	2.10	2.85		2.85	
Communication and electronic equipment	2.44	3.06	8.70	3.64	
Transportation equipment	1.30	1.54	2.73	1.67	2.23
Motor vehicles	1.60	1.68		1.80	
Other transportation equipment	0.66	1.09		1.27	
Precision machinery	1.58	2.03	5.71	2.35	6.39
Transport, communication & public utility	0.40	0.50		0.62	

Table 8.37 Industrial Research and Development Expenditures by Three Areas in Japan

	Research Areas		
Year	Basic	Applied	Development
1965	11.2%	31.3%	57.9%
1969	9.1%	27.0%	63.9%
1970	9.3%	27.2%	63.5%
1971	9.1%	25.9%	65.0%

Table 8.38 Allocation of Industrial Research and Development Expenditures by Industry and by Three Research Areas in Japan (1971)

	Research Areas		
Industry	Basic	Applied	Development
All industries covered	9.1%	25.9%	65.0%
Agriculture, forestry & fisheries	1.9%	28.9%	69.2%
Mining	5.7%	18.8%	75.4%
Construction	6.6%	16.1%	77.3%
Manufacturing	9.4%	26.5%	64.1%
Food products	13.3%	30.3%	56.3%
Textile mill products	7.0%	28.9%	64.2%
Chemical products	16.0%	30.4%	53.6%
Industrial chemicals	10.0%	31.3%	58.7%
Oils and paints	13.1%	36.0%	50.9%
Drugs and medicines	29.4%	24.9%	45.7%
Petroleum and coal products	6.9%	31.5%	61.6%
Rubber products	13.9%	25.6%	60.5%
Iron and Steel	8.1%	24.7%	67.2%
Machinery, except electric	5.8%	21.0%	73.2%
Electric machinery	6.3%	26.5%	67.1%
Transportation equipment	8.1%	23.3%	68.6%
Transport, communication & public utility	5.6%	21.4%	73.0%

research and development very clear, according to the different positions and the different divisions. Often we find different thinking between the top executives and the actual people in charge about the meaning from the start. I have been stressing all along in our company, the terms always mean research and development of new products not in existence and which are related to the aims and works of Sony. At least in companies of the size of ours, I think it is important to watch out that more research for just academic truth should not become the main purpose.

"It is a big mistake to think that the final purpose of research and development should be limited only to products of today. Although we may be engaged in different projects of different stages—the completion of such projects expected for the next year, others for 3 years later and still others for 5 or 10 years later—those who are engaged in such research and development should be clearly oriented and must be appraised of the stage of his work and be shown the direction towards which he must proceed.

"When the project is big, it may be more effective to have the top executives directly giving the instructions. Especially when the tendency of the future industries required skill and technique of combining many heterogeneous fields, it may be more necessary, for the top executives, to start the initial efforts to combine these different activities. To combine the various fields within the company becomes more and more difficult as it gets closer to the actual work level. When I say combination, I don't mean just a combination of technical problems but I mean all sorts of combinations and communications which are necessary to accomplish the project. However excellent the project may be in your company, the feasibility of commercialization must be analyzed from various angles, such as the company scale, financial ability, engineering strength, production capacity, marketing channels, distribution network, etc. I think only the top executives can comprehensively consider these different matters.

"In many enterprises, as their organization becomes bigger, division system becomes more popular. This system may have merits from the viewpoint that it defines clearly the extent and area of responsibility and also from the standpoint of self-supporting accounting system. However, it is not suitable from the viewpoint of developing new products which requires the uniting of the different fields. For this purpose it seems that today we must think of more flexible organization with emphasis on its functions…." "We learned that a programme combining separate items supporting each other is much more effective than the simple exchange of information of separate programmes of each item…." "Quite often, I believe the result of such efforts which have very clear targets have been much greater than what we expected. However, because our understandings were always very difficult the technical force required was tremendous. To compensate for this, we utilized or bought whatever we could from other companies and saved our main technical and production strength for the development of things which we must do ourselves. My conclusion in this matter is that: Deepness is more valuable than wideness."

Concerning the problem of basic research in an industrial laboratory: "It is often said that each individual researcher should have complete freedom in selecting the theme and in determining its direction. However, I wish to express an opposition to this thinking. Even for the sake of searching truth I think it is more effective for the men in the higher level, sometimes top executives, to select the theme and determine the direction in which the researchers should advance because they often have a better view to give accurate judgement than the researcher himself.

"In modern enterprise, I do not believe that the first seed must always be found in basic research. It is pure luck if the basic research could discover a seed with a bright future. If a company evaluates any seed as an excellent one, the company should exert every effort to make it bear fruits through the processes of basic research, development, production and marketing. Often the judgement and appraisal of whether the seed is a good one or not is done on a limited narrow basis and so the seed is discarded. We must be careful not to let this happen.

"It is very risky for a company to place its future entirely in the hands of a basic research, when technical innovation and product revolution are moving forward very rapidly today. I am of the opinion that the seed should be picked up from anywhere, in the course of basic research, development, manufacturing, marketing, sales, servicing, or it can also be generated by the consumers. At any such section, only with overflowing enthusiasm of the creative mind can we expect active growth of an enterprise. If enterprise became only a watchman of automation, then enterprise cannot make any progress in the innovation field.

"Who has the initiative is not important. Problems can spring up at any section of this chain. We must realize that it is important to make a basic research team start functioning by a problem fed back from any section to it.

"I have often experienced that when a basic research team takes up a problem it shows much better efficiency with the same problem when it deals from a well focussed ground than a vague academic interest. When a problem is fed back, realistic data are readily available and the sphere of study becomes more clearly defined…." "In this respect the future tendency will be more mass game rather than individual game, and the meaning of basic research will change. I like to repeat once again—in a modern industry, the seed must not necessarily be found in basic research all the time." [10]

U.S.S.R.

Technical Manpower

The number of persons with a higher education in the U.S.S.R. is very large, amounting to 4,891,000 on November 15, 1965. Of this total, as many as one-third were engineers in the Soviet sense of the term (this includes some personnel who in Western usage would be described as applied scientists and technologists).

In the past few years, there has been continued emphasis on the training of engineers, the proportion among the newly qualified increasing from 33.7 percent in 1961 to 39.0 percent in 1965. Within the broad category of "engineers," the numbers qualifying in technical sciences closely associated with the science-based industries have increased very sharply; the annual number of new graduates with higher education in chemical technology,

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[10] "Gaps in Technology—Electronic Components," OECD, pg. 153, Paris, 1968.

electronics, electrical instrumentation and automatics, and radio technology and communication increased from 5.4 percent of the total in 1950 to 12.1 percent in 1965.

The total number of persons engaged in Soviet R&D in 1966 has been estimated from 1,655,000 to 2,291,000. A somewhat conservative estimate for the equivalent expenditure on R&D in 1965 is in the range $14.8 to $20.7 milliards. It is difficult to find breakdowns of these expenditures into fundamental research, applied research, and development. There has been an enormous expansion of Soviet R&D effort since 1955, but it has slowed down considerably in more recent years—by 1966 the increase in manpower was only 5.5%.

Much attention has been devoted in the past few years to increasing the supply and improving the quality of scientific instruments and materials supplied to research establishments. Nevertheless, outside the priority sectors, the equipment-base apparently lags behind that of other major industrialized countries.

At the All-Union Economic Conference in May 1968, Academician V.A. Trapeznikov, First-Deputy Chairman of the State Committee for Science and Technology, made the startling proposal that expenditure on Science should increase by 20–25 percent a year during the 1971–1975 five-year plan, implying that allocations to science should double every 3–3.5 years.

Some Aspects of Institutional Research

In the U.S.S.R. “mission-oriented fundamental research” is increasing in importance. The strengthened powers of coordination possessed by the presidium of the Academy have been a key element in this process. But of even greater significance is the increased role of governmental agencies outside the Academy in funding the fundamental research undertaken by the Academy establishments.

Fundamental science in the U.S.S.R. retains some autonomy or even independence. Its special status is universally acknowledged. Officials concerned with science planning, as well as the scientists themselves, concur that economic yardsticks cannot be applied to measure its value. Although great emphasis is generally being placed by the Soviet government on economic criteria and economic incentives, no one has seriously challenged the principle that the bulk of Academy research must be financed from the state budget without expectation of measurable economic return to the community. Moreover, it is also accepted that a substantial proportion of the funds of each research institute should be set aside for free research initiated by the institute without specific sanction by higher scientific or other authorities.

Apart from these explicit provisions for free research, the fundamental research system has in practice even more flexibility than it possesses on paper. In spite of the powers of coordination and control possessed by the presidium of the U.S.S.R. Academy, the directors of its major research institutes in fact have some latitude to influence the lines of research of their institutes.

Of equal importance to the autonomy exercised by the different elements making up the research system is the influence which the scientific community can at times bring to bear on the science policy of the government.

The high prestige, authority, financial status, and the relatively good physical conditions of the major Academy institutes have been a major factor in sustaining the strength of Soviet fundamental science in difficult years. But this favorable position of the U.S.S.R. Academy has meant that the most talented students and the best scientists have irresistibly been drawn towards it and to its outstanding research institutes. Other sections of the scientific community, except those concerned with high-priority defense and space projects, have found it difficult to obtain and retain staff of the highest quality.

This has resulted in two major disadvantages. “Branch of the economy” research establishments, and the practical R&D activities associated with them, have tended to be viewed as of rather lower status than Academy institutes, and there is somewhat less public regard for applied R&D than for the fundamental sciences. The Academy constitutes the elite.

At the same time, the organization of fundamental research under a separate administrative authority, subject to its own system of planning and control, has tended to produce barriers between fundamental science and technology, similar to those between universities and private industry in some countries of Western Europe.

The main function of the Higher Educational Establishments is considered to be the training of specialists, and this has a direct influence on the kind of research carried out.

A number of leading universities have established themselves as important centers for research, comparable in professional status with research institutes in the Academy of Sciences or in the ministerial system. These are, however, the exception because the heavy teaching obligations of faculty personnel leave them relatively little time for research.

Metallurgy

Metallurgical research in the Soviet Union was on a relatively small scale before World War II though some Russian scientists were working abroad, in Germany and England. Research really started to expand within the U.S.S.R. during the War and subsequently was broadened even more, partly in recognition of its relevance to the economy.

Most metallurgical research is done in the institutes of the Academy of Sciences, in the institutes of the various Regional Academies of Sciences, and in institutes under various Ministries. There are large centers at the University of Moscow and the University of Leningrad but most centers in other universities are relatively small. Very often there is close interaction between a research institute and a neighboring university, e.g. in Sverdlovsk and Moscow. Sometimes there is also close coupling through joint appointments where a person may hold both a chair at the university and a directorate at the institute, e.g. Kharkov, Kiev. In general, facilities are very good, though crowded, and there is an abundance of technical and administrative help. Some centers have very useful groups for such central activities as crystal growth.

Most metallurgical research centers cover both metals physics and physical metallurgy. Two large institutes for metals physics are:

Institute for Metals Physics of Soviet Academy of Sciences, Sverdlovsk, and Institute for Metals Physics of Ukrainian Academy of Sciences, Kiev. Both of these compare with the Max Planck Institute in Stuttgart in size and scope of activity, with Kiev dividing its attention about equally between metals physics and physical metallurgy, and Sverdlovsk emphasizing metals physics rather more.

There is a large institute for ferrous metallurgy in Moscow under the Ministry of Industry. The institute is very spacious and well equipped with research equipment such as electron microscopes, high-pressure and X-ray equipment. Much of the work at this institute is quite applied in nature and aligned with the needs of industry.

There are several institutes of the Academy of Science that embrace work on metals within the general framework of experimental and theoretical solidstate physics. For example, at the Ukrainian Academy of Sciences in Kharkov, the group under Lifshitz covers electron theory of ideal crystals, dislocation theory, Fermi surfaces, precipitation and crystal growth theory, and the theory of lattice vibrations. Experimental groups are involved in low-temperature properties, especially superconductivity, and point defects in quenched metals.

The Institute of Crystallography in Moscow is concerned with dislocation theory, plastic deformation, electron diffraction, and structure determinations.

The Institute for Physical Problems (under P.L.Kapitza) is an important research center for metal physics with strong theoretical groups on the electron theory of metals, superconductivity, many-electron effects, band structures, ferromagnetism and phase transitions, and experimental groups on Fermi surfaces and hard superconductors.

Moscow University emphasizes particularly ferromagnetism and low-temperature phenomena, while the Physico-Technical Institute in Leningrad is concerned with plastic deformation and fracture.

It appears that there is considerable concentration on some topics in metals, while others are neglected. The prestige of people like Kapitza, Landau, and Lifshitz has led to strong programs on the basic electronic properties of metals. There is also intensive work on the physical metallurgy of transformations, order-disorder, precipitation, mechanical properties, and plastic deformation. Magnetism figures prominently at Sverdlovsk, Kiev, Leningrad, and Minsk. On the other hand, relatively little has been done on point defects and, until recently, on radiation damage. Overall, the emphasis in metals research reflects very much the stimulus emanating from the strong mathematical-physical schools concerned with solid-state problems.

There is also much attention on the liquid-metal state centered in various research institutes in the Urals. These are concerned with experimental investigations of the surface tension of liquid metals, adsorbtion and desorption at surfaces, diffusion in melts, viscosity, electrical and magnetic properties of melts, X-ray methods for determining structures of two-phase liquids, thermodynamic properties, effects of small amounts of additives on nucleation and crystal growth in casting processes, and theoretical foundations of these processes which are relevant to practical problems.

Further expansion of metals research is planned, particularly at Novosobirsk. In addition, a new Institute for Solid-State Physics is planned for Moscow which will include metals. A list of existing establishments involved with metallurgical (and materials) research is given below.

Polytechnic Institute	Kharkov
Physical Engineering Inst. of Low Temperatures	Kharkov
Institute of Radio Physics and Electronics	Kharkov
Institute for Synthetic Superhard Materials	Kiev
Institute of Semiconductors	Kiev
Polytechnic Institute	Leningrad
Semiconductor Institute	Leningrad
Physico-Technical Institute	Leningrad
Institute of Steel (and Alloys)	Moscow
Institute of Nonferrous Metallurgy	Moscow
Central Scientific Research Institute for Ferrous Metallurgy	Moscow
Institute for Metal Physics	Moscow
Baikov Institute	Moscow
Institute of Physical Chemistry	Moscow
Institute for General and Inorganic Chemistry	Moscow
Institute of Crystallography	Moscow
S.I.Vavilov Institute for Physical Problems	Moscow
Lebedev Physical Institute	Moscow
Kurchatov Institute of Atomic Energy	Moscow
Institute for Radio and Electronics	Moscow
L.D.Landau Institute of Theoret. Physics	Moscow
Moscow State University	Moscow
Institute of Inorganic Chemistry	Novosibirsk
Institute of Semiconductor Physics	Novosibirsk
Institute of Metal Physics	Sverdlovsk
Institute of Metallurgy	Tbilisi
Georgian Polytechnic Institute	Tbilisi
Institute for Vise and Hand Tool Production	Tbilisi

Solid-State Physics

Soviet science in general, and solid-state physics in particular, is very vigorous, perhaps remarkably so when one considers the relatively poor physical facilities in many physics laboratories. Modern computers, microcircuits, even lasers are conspicuous by their absence. On the other hand, more conventional pieces of equipment (oscilloscopes, microscopes, spectrometers) are plentiful and seemingly well maintained. Furthermore, science and scientists are held in high esteem and the supply of talented people is substantial. Also, due to the highly centralized organizational structure of research, a number of individuals hold a great deal of power in the scientific life of the country. These individuals may be institute directors, such as V.M.Tuchkevich or P.L.Kapitza, or other prominent scientists whose achievements have placed them in a position of intellectual leadership.

Examples are N.G.Basov, L.D.Landau, V.L.Ginzburg, and B.M.Vul. Most of the important recent Soviet achievements were the product of large groups headed by such leaders.

Many institutes are engaged in solid-state physics, and tend to be highly specialized. The quality of the work differs greatly from one institute to the other, with a few establishments holding dominant positions.

These are:

Group I—Three leading institutes:

A.F.Ioffe Physico-Technical Institute, Leningrad

This institute, founded by loffe, was the first major scientific establishment in the U.S.S.R. and even today its alumni are leaders in a large part of Soviet physics. The present director is V.M.Tuchkevich, and the important groups in solid-state physics are in semiconductors, plasmas, and theory.

P.N.Lebedev Physical Institute, Moscow

This has all the Soviet Nobel Prize winners, of which two (Basov and Prokhorov) can be counted as solid-state physicists. Besides the vast laboratories devoted to optics and lasers, there are also strong groups in semiconductors and in solid-state theory.

S.I.Vavilov Institute of Physical Problems and L.D.Landau Institute of Theoretical Physics, Moscow

These two institutes, formerly together, were separated only a few years ago. The directors are P.L.Kapista and I.M.Khalatnikov. The strongest groups in these institutes are in low-temperature physics (metals and fluids), solid-state theory, and magnetism.

Group II—Some other important institutes are:

Moscow State University
Institute of Semiconductors, Leningrad
Institute of Semiconductors, Kiev
Physical Engineering Institute of Low Temperatures, Kharkov
Institute of Radio Physics and Electronics, Kharkov
Institute of Radioengineering and Electronics, Moscow
Institute of Physics of Semiconductors, Novosibirsk
Institute of Metal Physics, Sverdlovsk

The vast output of solid-state research in the U.S.S.R. can be roughly separated into three categories:

(a) Routine work having little impact;
(b) Systematic investigations of broad areas;
(c) Significant achievements and innovations.

The first category includes much of the research done at second-line institutions in such traditional fields as ferroelectricity, semiconductors, magnetism, crystallography. In contrast to similar routine work done in the West, the Soviet work seems to suffer doubly; from a lack of inspiration and from antiquated equipment and relatively primitive technical means. Although it is impossible to estimate accurately the proportion of Soviet research which belongs in this category, it is probably higher than in the U.S.

Regarding the second category, the Soviet system seems particularly well-suited for this type of work since the centralized structure and the greater emphasis on planning make large cooperative efforts easier to manage than under the more diversified American system. As an example of interesting systematic research in a field which was not especially fashionable at the time, we may cite the exploratory work on amorphous and liquid semiconductors at Leningrad (Regel, Goryunova, Kolomiets and Gubanov). This research anticipated by approximately ten years the recent upsurge of interest in the properties of amorphous materials which has occurred in the West. (It may be noted that switching devices in amorphous semiconductors have not caught on in the U.S.S.R. any more than in the West even though their discovery is attributed by the Russians to Lebedev in 1962 at Leningrad.)

It appears that there are two important areas in which Soviet work in solid-state physics is relatively weak: in band theory, probably due in large measure to the relative scarcity of computers as a research tool, and in the application of neutron-scattering techniques to the study of solids. Because of this situation, some significant recent developments in magnetism, phase transitions, and lattice dynamics have occurred entirely outside the Soviet Union.

However, there have been notable achievements during the past decade in the U.S.S.R. as will be evident from the following list:

(a) Lasers and Nonlinear Optics—Basov, Prokhorov (Lebedev Institute) and Khoklov (Moscow University). Development of high-power lasers, ultrashort-pulse techniques, tunable parametric oscillators, second harmonic generation, and general progress in nonlinear optical theory. In this field, Soviet work has consistently been competitive with work in the West.
(b) Properties of Metals at Low Temperatures—Experimental work at the Institute of Physical Problems (Moscow) and earlier in Kharkov. A remarkable body of theoretical work, on electronic properties and wave propagation in metals, emanated primarily from the School of I.M.Lifshitz.
(c) Field Theory Methods in Solid-State Physics—The introduction of quantum-field theory methods into statistical physics, pioneered by the Landau School, has much influence on many fields of solid-state theory, primarily in superconductivity, quantum fluids, magnetism, and transport theory.
(d) Semiconductors—Fundamental studies of optical properties. Noteworthy device developments include light-emitting silicon carbide diodes (the West has preferred to concentrate on gallium phosphide) and the world's first CW semiconducting laser.
(e) Theory of Plasma Effects and Wave Propagation.
(f) Optical and Magnetic Properties of Excitons.
(g) Condensed Phase of Excitons in Germanium—Experimentally observed.
(h) Polarons—Important theoretical work.
(i) Weak Ferromagnetism—Theory and experiment.
(j) Superconductivity—Important theoretical contributions (Landau, Ginzburg, Aslamazov, Larkin), first observation of Josephson radiation, and original discovery of type II superconductivity.
(k) Effects of High Pressures on Materials.

As for the future, Ginzburg has stated what he considers to be outstanding unsolved problems in "macrophysics:"

Controlled thermonuclear fusion
High-temperature superconductivity
New forms of matter, such as metallic hydrogen or anomalous water
Nature of the condensed state of excitons in semiconductors
Critical-point phase transitions

To sum up, the major characteristics of Soviet solid-state physics are:

Its size and scope (comparable with the U.S.).
Centralized organization and planning.
Definite heirarchy of power and prestige.
Large differences in quality among institutes.
Significant power concentrated in individual hands.
Institutional rigidity which hampers innovation and linkage to technology.

Some major strengths of Soviet solid-state science are:

High prestige associated with science.
An excellent educational system leading to a significant pool of talent in the field.

Top institutes often have large groups, with a well-defined mission, and strong leadership by brilliant scientists. These institutes offer graduate training to the most talented students, thus assuring the maintenance of “ongoing” schools of Soviet physics.

Some weaknesses are:

Scarcity of advanced equipment.
Lack of computing facilities.
Institutional rigidity and inertia.
Existence of a large number of second-line institutes.

Germany

Support Structure for Research

Germany has a federal system of government within which considerable autonomy is enjoyed by the individual states (Lander), especially in cultural and educational affairs. In the realm of academic research, there is more central coordination undertaken by the Deutsche Forschungsgemeinschaft (DFG) and in the role played by the Max Planck Institutes. In the area of applied and industrial research, a strong coordinating and sponsoring role is played by the Federal Ministry für Bildung und Wissenschaft. There is good cooperation between the Ministry and other agencies, especially the DFG, to bring about contacts and joint efforts between industry and universities. This reflects recognition of the serious communications gap that had persisted between the academic and the industrial establishments in Germany where the tradition of the autocratic, independent, securely tenured, professorships still has a very firm hold. Materials research has played a particularly important role in bringing about more collaboration both within universities and between universities and industry. Furthermore, the materials disciplines, including solid-state physics, are receiving much more attention in all respects than they did five to ten years ago when nuclear physics dominated science policy.

The key importance of materials research was recognized several years ago by the DFG. Under its Schwerpunktprogramme (lit. "centers of gravity") in recent years, emphasis has been placed on metals research, semiconductor electronics, and materials-oriented solid-state physics and chemistry. Selection of a particular field into such a program serves to alert academic research organizations to areas of particular and immediate relevance to national needs, to provide stronger financing of such research, and to enhance coordination by means of colloquia and joint efforts among those sponsored.

The DFG has been particularly successful in fostering interdisciplinary research in the solid state, sponsoring facilities for materials preparation and characterization as well as for fundamental studies of the properties of materials. More recently and even more ambitiously, the DFG has undertaken to finance, quite generously and broadly, and coordinate fields of university research under the program called "Sonderforschungs Bereich" (Areas of Special Research). In this program, several institutes of one university are brought together under one theme (e.g. Defects in Solids, Solid-State Electronics) and obtain strong financing provided that a truly cooperative research program is offered and carried out. Again this approach was necessary in order to concentrate the highly individualistic and divergent separate institutes of the typical German university. It appears that materials research as a general theme has played a rather strong role in this program, and many contracts for such research have been granted.

The majority of the 53 Max Planck Institutes are devoted to fundamental research, particularly in the natural sciences, though some institutes do embrace applied research as well. Research in the institutes is complementary to that at the universities in many ways, and the organization can be compared with the Laboratories operated by the Research Councils in Great Britain, the C.N.R.S. in France, and the Academy of Sciences in the U.S.S.R. Institutes are built around highly qualified and productive scientists as directors and when a new director has to be appointed the Max Planck Society reassesses whether continuance of the institute in its present or a different research field is justified. Sometimes it is concluded that the institute should be handed over to a neighboring university, particularly if no suitably qualified successor can be found for the directorship.

The Federal Ministry in Bonn is sponsoring a program for R&D in "New Technologies" where again an important emphasis is being placed on materials development. Industries involved in these New Technologies may obtain partial funding by submitting contract proposals. The Ministry, with the aid of outside evaluating committees, has set clear priorities, particularly for electronic materials R&D where industry faces acute problems.

Deutsche Forschungsgemeinschaft (DFG)

In its 1970 Report, the DFG summarized the total expenditures of the Federal Ministry for Education and Science, namely:

	Increase in Funding (MM)			
Category:	1969–1970	%	1970–1971	%
General Scientific Research	426	44	522	37
Nuclear Research and Techniques	204	29	373	41
Space Research and Aeronautics	–19	–5	174	52
Data Processing, New Technologies	31	34	198	163
Totals for all Education and Science (round numbers)	700	32	1300	45

Priority is being given to education and directed or applied research, in that order. The DFG income from the Federal Ministry or private sources amounted to 257 MM in 1969, 318 MM in 1970 (increase of 24%), and 379 MM in 1971 (increase of 19%). The DFG notes that these increases, large as they may seem, were insufficient to cover inflation and the increase in personnel costs so that the number of projects supported did not increase. In fact, the number of research contracts being accepted dropped from 1969 to 1970 by 23.7% in the General Support Program, and by 27% in the Special Support Program.

The DFG has endeavoured to bring some research groups together into joint research contracts but has been rather disappointed by results except, to some extent, in the nuclear and aerospace fields—the success in the latter accounts for the reversal of the funding trend in the above table. In the international sphere, there has been some progress in joint ventures but also several disappointments—the latter especially when the scientific capabilities of various countries failed to match their national political aspiration.

The DFG, noting the trends in West Germany towards support of important new technologies to extend national capabilities, is tending to give preference to those research programs which have technological inventions with important societal value as a goal, e.g. electronics, communications, and traffic-control systems; biology, medicine, and environmental protection. Research in data processing, with both hardware and software programs, has been accorded a key position among the technology programs with the aim of inproving both the public and private economic sectors.

Much reform of the university and educational system is in progress. It is not clear what the eventual outcome will be, but research at the universities is being reduced relative to the educational effort. Of course, academic scientific faculties are not advocating this themselves—it reflects more the social and idealistic pressures currently at work.

Some relevant statistics reported by the DFG are follows:

A. Overall Levels of Support (1970)	MM	%
General Science and Education	114.4	36.6
Specially Emphasized Areas	66.7	21.3
Interdisciplinary Research Groups (Medicine)	1.8	0.6
Libraries	4.8	1.5
Support of Habilitands	6.5	2.1
International Activities	4.6	1.5
General Support	4.0	1.3
Special Research Programs, Computers etc.	28.6	9.1
Other Large Research Facilities	16.8	5.4
Special Research Fields	64.5	20.6
	312.6	100.0

B. Support of Natural Sciences and Engineering (Totals in MM)

	1965	1966	1967	1968	1969	1970
Natural Sciences	49.6	58.6	63.9	69.8	77.7	96.4
Engineering	23.3	25.8	24.9	28.3	34.0	55.9

C. Distribution of Research Contract Proposals (1970)

	Total Number	No. Accepted	No. Rejected	Handled Otherwise	Pending
Chemistry	681	653	15	13	203
Physics	283	249	12	22	103
General Engineering	119	108	5	6	52
Building Engineering	102	86	8	8	21
Mining	121	112	7	2	33
Machinery	267	254	5	8	96

(Note the relatively small number of rejected contractors.)

D. Specially Emphasized Areas (1970)

	Year Program Started	No. of Applications in 1970	Funds Granted in 1970 MM
Natural Sciences (selected)			
Solid-State Research	1963	113	3.74
	1964	52	1.93
Electron Optics	1967	15	1.43
Theoretical Chemistry	1965	45	0.72
High Temperature and Pressures	1968	20	1.52
Natural Macromolecules	1967	25	1.19
Engineering			
Semiconductor Electronics	1968	32	1.82
High Voltage DC Transmission	1959	5	3.3
Flow of Real Gases	1965	30	0.95
Noise Generation and Transmission	1968	15	0.59
Cavitation	1965	28	1.06
Surfaces and Coating Techniques	1966	20	0.79
Boiling Processes	1967	22	0.11
Welding	1967	21	1.11
Materials	1962	29	1.41
Mechanical Properties of Materials	1969	10	0.33
Composites	1969	18	1.2

Several of the above research areas are worth describing here in further detail.

Solid-State Research—

The original purpose of this program was to establish a central institute of solid-state research in order to provide better support for this field and to create an adequate supply of personnel for this institute. Both goals have been reached with the foundation of the Max Planck Institute for Solid-State Research at Stuttgart and with the completion of solid-state research laboratories at the nuclear research establishment in Julich. At the same time, within this special-emphasis program, the number of applications for research contracts rose from 28 in 1964 to 127 in 1969 although efforts were made to concentrate the contracts into the fields of collective phenomena, electronic structure, and electron-phonon interactions.

Atomic and Molecular Collision Processes–

Investigations have been supported in:

Elastic and inelastic collision between neutral atoms and molecules and electrons.

Electron resonance capture.

Spin exchange and collision processes between free atoms, between atoms and electrons, and between atoms and solid surfaces

Transfer of excitation energy in collision processes.

Scattering of ions on atoms and molecules (charge-transfer reaction).

Electron Optics–

The goal of this program was to support electron and ion optics in general, but in particular:

Ultrahigh-resolution microscopy.

Ultrahigh-voltage microscopy.

Fundamental problems related to the development of superconducting lenses.

In parallel, the Fraunhofer Society has now made a commitment to build an Institute for Ultrahigh Resolution and Ultrahigh Voltage Microscopy.

Theoretical Chemistry–

The primary objective here was to support the education of young scientists in this field since the situation as regard the supply of suitable personnel was inadequate. The program does not include physical organic chemistry and does not embrace the applications of theoretical concepts; it is restricted to those who generate original theory.

Chemistry at Extremely High Pressures and Temperatures–

Support of experimental programs yielding quantitative information on the state, structure, reactions, and properties of matter at extremely high pressures and temperatures.

Semiconductor Electronics–

Physical, technological, and electro-technological aspects of semiconductor electronics are emphasized such as materials, technological problems, thin-films and interfaces, volume effects, electro-optics, integrated circuits, power electronics.

High Voltage DC Transmission–

Theoretical and experimental studies on high-power current rectifiers, first with mercury vapor rectifiers and later with semiconductor rectifiers (thyristors); investigations on the behavior of a network analyzer for high voltage DC transmission with 3 terminals; insulation problems with high DC voltage on open-air transmission lines and cables; testing of rectifiers with low-power synthetic monitoring circuit as well as with full-power installation.

Flow of Real Gases–

Investigations are supported on the physics and mechanics of flow in high-temperature dissociated and ionized gases, but excludes studies of nuclear processes. Included in the program are processes related to interactions between combustion and flow (reactive fluids), e.g. shock waves with subsequent combustion.

Cavitation–

Research on flow mechanics and the destruction of material due to cavitation; interactions of cavitation and corrosion in machines and structures,

Surfaces and Coating Techniques–

Surface treatments of metallic components and shaped parts. Main objective is research on the fundamentals of techniques for protection against chemical attack and mechanical destruction.

Boiling Processes–

Bubble boiling, film boiling, boiling with free convection, boiling with forced convection, local boiling, and boiling of saturated solutions are subjects of investigation supported by this program. Main applications of boiling processes are: steam-power plants, steam reactors in nuclear-power plants, evaporation in refrigerating and air conditioning systems, evaporators in industrial processing, boiling and cooling in chemical industries.

Welding–

Welding techniques with high-energy density, such as electron-beam welding, plasma welding, laser welding, friction and diffusion welding, and ultrasonic welding are investigated.

Materials Behavior for Construction and Shaping–

The goal of this program has changed. First, it was intended to support work on the behavior of materials under mechanical and thermal loading. This was later shifted towards research on the fundamentals of inorganic, nonmetallic materials. Studies of the mechanical behavior of these materials (fracture and deformation of ceramics, glasses, and adhesives) are now emphasized.

Mechanical Properties of Materials–

Special emphasis is given to the dynamic strength and vibration failure of materials and assemblies.

Composites–

Research is supported on production and behavior of composites; includes particle, fiber, and layer composites.

Metallurgical Research in German Industry

Generally, German industry looks for graduates broadly trained in basic knowledge and with evidence of ability and interest in development and manufacturing work. Too often, physicists do not have sufficient understanding of materials while metallurgists have insufficient knowledge of theory and fundamentals.

While physics graduates have a preference for research work they are also often suited for problems in development and manufacturing; yet university education tends to overlook these possibilities.

Industry has a preference for young people and often feels that university education takes too long. There have been various studies of how to shorten the educational period—these typically point to more intensive study and less time spent on technical details. Large classes characteristic of formal lectures are believed to be of little value.

The prevailing attitude of German industries is that fundamental research should be done at universities, leaving development work to industry. Indeed, German industry is inclined to believe that U.S. industry has been wrong in undertaking so much fundamental research even though it was possible because of heavy governmental support, particularly in the defense and space industries. Nevertheless, German metal-working industries have carried out relatively more fundamental research than have other industries, except for the electrical and chemical sectors. The latter industries carry out much more research and seem to gain much more from it. Metallurgical industries may reexamine their attitudes towards fundamental research, and a better understanding between them and the universities might result. As far as breadth of fundamental research is concerned, the metallurgical industrial laboratories in Germany are not quite on a par with their counterparts in the U.S.

United Kingdom

National objectives and priorities for materials R&D in the U.K. fall within the policies for science and engineering as a whole, as carried out principally by the Department of Education and Science (DES), Department of Trade and Industry (DTI), and the Ministry of Defense (MOD).

Department of Trade and Industry

In the DTI, materials R&D is an element in achieving the general objective "to assist British industry and commerce to improve their economic technological strength and competitiveness." Thus, within the Research Division of the DTI, there is a materials section which is responsible for the coordination of work on materials in the research establishments and which seeks to promote bulk markets for new materials where these can contribute to improved industrial efficiency or substantial export orders. In practice, this activity operates mainly by placing extra-mural contracts on a part-cost basis. Materials research figures in the programs of most of the research establishments operated by the DTI.

The laboratory with the largest expenditure is the National Physical Laboratory (NPL) which is organized into three groups, one of them being designated the Materials Group. The Materials Group embraces the Division of Chemical Standards, the Division of Inorganic and Metallic Structure, and the Division of Materials Applications. Its function is to bring scientific knowledge to bear upon the everyday industrial and commercial life.

The National Engineering Laboratory (NEL) is also much concerned with materials; it studies fluids, fatigue, creep, fracture mechanics and brittle fracture, and applications of fiber reinforcement. The Warren Spring Laboratory is mainly involved with pollution, chemical engineering, mineral processing, industrial materials handling. The Safety in Mines Research Establishment studies engineering and metallurgy relevant to the mining industries, and the Laboratory of the Government Chemist is the principal establishment responsible for providing analytical services to all governmental agencies, particularly the Ministry of Agriculture, Fisheries and Food and the Department of Health and Social Security.

Outside the DTI laboratories, the government provides support to industry in a number of ways. There are approximately 40 research associations supported by the relevant industries and by government grants, either from the DTI, the Department of the Environment, or the Ministry of Agriculture, Fisheries and Food. These research associations are autonomous bodies and the determination of their programs is a matter for the individual associations, but the government can give special support for work in particular areas. Many associations deal with engineering materials; others serve the textile industries (see later).

Further direct support for R&D in industry is given by way of government contracts. Major collaborative programs have been organized and in some cases these contain a significant materials content. Examples are—the government support for research on superconductivity and for the development of carbon fibers.

The DTI is also responsible for the United Kingdom Atomic Energy Authority (UKAEA) which, in its own establishments, undertakes a great deal of materials research. In the nuclear field, the Authority has a considerable degree of autonomy in determining its programs, but the DTI may issue directives to the Authority to undertake research in nonnuclear fields. Directives have been given providing for research in a number of fields such as ceramics, carbon fibers, and high-temperature chemical technology. The establishments of the DTI and of the UKAEA are both encouraged to undertake research for industrial firms on a repayment basis. To further this policy at the UKAEA establishment at Harwell, for example, a Ceramics Center and a Nondestructive Testing Center have been organized. Materials research appears to a considerable extent in the programs of the nationalized industries (transport, gas, coal, electricity, etc.), and they are virtually autonomous in the determination of their projects although these are formally subject to approval by the Secretary of State of the DTI.

The National Research Development Corporation (see later) is a quasigovernmental body, financed by public funds through the DTI, which undertakes the commercial development of research carried out by governmental establishments, universities, private industry, etc. A number of its projects are in the materials area.

Department of Education and Science

Research in universities is the concern of the Department of Education and Science (DES), which operates through the University Grants Committee (UGC), and the Research Councils.

The Councils are incorporated bodies whose staff are noncivil servants and are responsible for allocating funds to specific research projects. In the materials field, the most important council is the Science Research Council (SRC) which covers, among other things, support for research in chemistry, enzyme chemistry and technology, chemical engineering and technology, metallurgy and materials, and polymer science. The Council gives grants to universities for programs directed by specified individuals and to enable postgraduate students to study for higher degrees. DTI liaison with the Research Councils is maintained by the appointment of DTI “assessors” to the Grant Awarding Committees.

In recent years the Science Research Council has identified special areas which merited support and has encouraged certain universities to develop special expertise in these areas. Examples in the materials field include polymer science, high-temperature technology, ion implantation, and composite materials. (See below for further discussion of the work of the SRC.)

Another governmental agency involved in civilian materials research is the Department of the Environment, which is now responsible for the Building Research Station and for the Forest Products Research Station.

Ministry of Defense

In the Ministry of Defence (MOD), it is policy to maintain R&D programs in all relevant materials fields so as to enable the engineering of advanced weapon systems planned by the military staffs. The timescale of materials development necessitates a strong forward view to anticipate future requirements. The most advanced requirements are in aerospace where major objectives include improved structural efficiency by weight reduction and improved propulsion efficiency by increasing turbine entry temperatures. Especial emphasis is placed on the development and engineering of advanced composites.

It is MOD practice to conduct R&D as closely as possible to the engineering applications. Apart from a number of special governmental laboratories, materials R&D is conducted in government engineering establishments or extramurally, in the defense industry. Some specialized or fundamental elements are also funded in materials-supplying industries, research associations, or the universities, though the latter support is diminishing. Responsibility for financial and technical control rests in the Headquarters of MOD acting through technically-qualified officers from either research establishments or the Headquarters. Program definition is sought by close collaboration with the users, i.e. the weapons-system designers or service client. Appropriate scientific advice is obtained as needs and problems emerge. Budgetary and economic constraints impose severe limits on the practical projects that can be undertaken; the potential of competing technologies demands careful assessment.

It is clear that the whole of the U.K. national effort on materials is not planned in an overall fashion according to any set of criteria or according to considerations of technological forecasting; nevertheless, a high degree of deliberation goes into the formulation of individual programs.

Total expenditures on R&D by governmental agencies in the U.K. are given in Table 8.39.

Science Research Council (SRC)[11]

The fields of research supported by the SRC include mathematics, physics, chemistry, biology, and all branches of engineering. The SRC manages national and international facilities which cover, particularly, nuclear physics, astronomy, radio, and space research.

The SRC was formed in 1965 and in its early years was mainly concerned with assimilating and consolidating its responsibilities inherited from various predecessors of SRC. Key features of SCR policy that have emerged involve:

(a) Balance of effort in the overall program.
(b) Need to determine priorities on basis of thorough reviews of the different fields of research.
(c) Importance of long-term planning in the creation of major facilities.
(d) Selectivity and concentration in the support of university research.
(e) Manpower and studentship policy in relation to growth of universities.
(f) Collaboration between SRC Laboratories and universities.
(g) Encouragement of collaboration between universities and industry regarding graduate education and research.

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[11] "Report of the Council for the Year 1969–1970," Her Majesty's Stationary Office, Science Research Council, London, 1970.

Table 8.39 Research and Development Expenditures by Governmental Agencies in the U.K. (1971–72)

	Million Pounds
Ministry of Defense	259.3
Department of Trade and Industry	205.0
Department of Education and Science*	109.5*
Department of the Environment	33.2
Ministry of Agriculture and Scottish Department of Agriculture	12.7
Health	10.9
Overseas Development Administration	3.5
Home Office	2.5
Miscellaneous	8.9
	645.5

*Science Research Council	50.9
Medical Research Council	22.4
Agricultural Research Council	18.7
Natural Environment Research Council	15.3
Social Science Research Council	2.2
	109.5

It should be noted that research in the universities can be supported either through the SRC or through the University Grants Committee (UGC). Funding through the UGC recognizes the fact that teaching and research are essential academic functions while the SRC support, in general, is used for initiating researches of special timeliness and promise.

Over the period of 1965–1970, financial stringency has forced the SRC to develop steadily its policy of selectivity and concentration. Emphasis has also shifted in the direction of supporting more graduate studies rather than research studentships, and overall to favor awards in applied science and those having industrial potentiality rather than awards in pure science. Awards have also been used to encourage the movement of graduates into industry and schoolteaching and to promote university-industry collaboration. The SRC has leaned toward research and training in engineering, for example, by limiting the support for research assistants and increasing the support for technicians. It has increased the number of fellowships to facilitate the return flow of graduates from North America to the U.K. It has encouraged coupling between secondary schools and SRC Laboratories through joint appointments.

The SRC principles that guide selectivity and concentration in the support of research are broadly:

(a) Certain areas, within a discipline or embracing a number of disciplines, will be selected for more favorable-than-average support during a given period, on the basis of a review of their special potential for advancing basic science, or their economic or community value, or all three. Other important criteria will be the economy of scarce manpower and the optimum utilization of unique or expensive facilities in universities, national and international laboratories, and in industry.

(b) A limited number of university departments will be given more favorable-than-average support to enable them to concentrate effort in certain areas; such departments will be selected on the basis of their leadership, past achievement, present expertise, or other relevant factors (e.g., ability to collaborate with industry).

(c) This concentration of resources will be planned by shifting to favored areas from less favored areas rather than by simple addition.

(d) Nevertheless, it will be essential part of SRC policy—and well publicized—that some support will always be available to any outstanding individual in any part of any subject for work of sufficient “timeliness and promise” (e.g., imagination, novelty or relevance to valuable goals).

(e) The pattern of preferred topics and places will be kept under continuous review and not frozen. This, with item (d) above, will make it possible for any department or individual to grow, with SRC help, from a small start to a major group in any field, provided there are sufficient ideas, effort, and backing from the university itself. With a limited growth rate for SRC as a whole, it will be necessary to reduce support in major areas where programs have been completed or have lost their impetus, in order to provide backing for new centers.

(f) The degree of concentration, i.e., the proportion of the funds given to selected areas or to selected departments, must depend upon the nature of the subject (e.g., need for very large equipment), the existing degree of concentration, the resources available (e.g., the number of trained experts in the field), and so on. But it will be the subject of appropriate review by SRC, in the light of open discussion with university and other people concerned.

(g) Some of the principles to be followed in exercising selectivity in support of astronomy, space and nuclear physics research differ in important respects from those arising at present in other branches of science and engineering. Because of high threshold costs and large capital installations, consideration has to be given to the creation of regional or national facilities or participation in international organizations. The selection and support of university teams by the SRC to take advantage of such facilities requires close collaboration between university personnel and the staff of national and international laboratories as well as an obligation to accept the discipline which such collaboration entails. Similar considerations are likely to arise in other fields where major engineering installations are required to be shared by universities in furtherance of particular research programs.

(h) The research program of the SRC Laboratories and Observatories will be kept under review to ensure the selection of the most promising subjects for study and the consequent necessary concentration of resources. SRC establishments will also provide the optimum help within their power to those engaged in research and development in universities and industry who need to use the special facilities and expertise possessed by the establishments.

(i) Because the implementation of these policies means that SRC will inevitably exercise more influence over university research, it is essential that SRC should make sure that its policy is fully known and understood throughout the university sector, and that adequate opportunities are provided for the policy to be discussed with the University Grants Committee, with the other Research Councils as appropriate, and with universities; and for provisional proposals in particular topics to be examined and discussed before decisions are taken.

In spite of the SRC's increasing concern to support work of economic and social value, most of its funds go to supporting fundamental, long-term, curiosity-oriented research as distinguished from mission-oriented research. "But as far as the research scientist or engineer himself is concerned, the interest and methods in either kind of research are often the same and one may turn into the other at short notice." The SRC proclaims that "Basic research is of great intellectual and cultural interest but it also leads to advances in scientific knowledge which may have practical importance in the long-term and it provides an indispensible training medium at the graduate level in universities. One of the characteristics of fundamental science is the way in which discoveries in one field permeate other fields of science and technology so that the bodies of traditional disciplines are blurred and progress depends on interdisciplinary collaboration." Nevertheless, as the data show, the SRC over the years 1967–1969 has reduced somewhat its support for basic research and increased its support for applied science and technology. This is in recognition of the fact that the SRC "must relate its support of university research and graduate education to national needs, for example in the engineering industries, and to social needs in transport, building, noise, and pollution."

However, there are signs that, on the average, those students going into applied science graduate work have lower quality first degrees than those going on into pure science—"All eligible candidates for Advanced Course Studentships with first and upper seconds were successful. In applied science all eligible candidates with lower seconds received awards." And for the research studentships, "all eligible candidates with first class honors were successful. In applied science all eligible candidates with upper second class honors were successful. In pure science 225 eligible candidates with upper second class honors were unsuccessful." In connection with its awards, the SRC is trying a number of variations designed to enhance better university-industry coupling and the training of people for industry.

It should be realized that, roughly speaking, the number of SRC awards is approximately half of the number of graduate students working in fields within the realm of the SRC.

The number of first degree graduates was still rising in 1970—the forecast figures were 13,700 scientists and 9,700 engineers, with an estimated increase above the 1969 level of 8% overall, 3% in scientists, 16% in engineers. The overall increase in gradiations forecast for 1970–72 is 5% per year. The SRC is basing its planning up to 1975 on a growth rate of 5% per year in the number of graduates.

Policies, priorities and their implementation in the various scientific fields within the preview of the SRC are handled by various Boards. Those of most interest to COSMAT are the Boards of Engineering and Science.

Engineering Board:—Membership of the Board is about equally represented by the universities and industry. The Board is responsible for the support of research and graduate training in aeronautical and civil engineering, chemical engineering and technology, electrical and systems engineering, mechanical and production engineering, control engineering, metallurgy and materials, computing science, and polymer science. Separate committees are responsible for each of these areas.

The Board recognizes the underlying unity of science, technology, and engineering and expects to continue to give a measure of research support to pure science departments insofar as this is relevant to the furtherance of its own broad objectives; for example, in the field of materials science and polymers. The Board is also concerned with studies of creativity and innovation in engineering.

The pursuit of research aimed at advancing the state of knowledge in engineering or applicable science is not in question, nor the need to develop areas of potential importance bridging accepted disciplines since it is here that much work of immediate relevance is to be found. It is at the interface or overlap with industrial or governmental research and exploitation that the university role has to be more clearly defined.

From a review undertaken by the Metallurgy and Materials Committee, the following areas have been identified as meriting special attention: composite materials, surface and interfaces, and process metallurgy.

The Aeronautical and Civil Engineering Committee has identified in descending order of priority: transport, building design, sound and vibration, fluid flow, structures, and aeronautics.

The Mechanical and Production Engineering Committee has selected the following areas for further study: medical engineering, marine technology, and computer-aided design. It is also proposed to sponsor research into the fundamentals of grinding. Areas previously rated meriting special support include desalination, high-temperature processes, and electro-chemistry.

The Control Engineering Committee has sponsored concentrated programs at universities which include, for example, development of a mathematical model for a hot-strip rolling mill, its application in a much simplified overall control strategy, and the specification of an automation scheme which is expected to lead to increased productivity.

The Polymer Science Committee, relatively new, is concerning itself initially with synthesis, thermal stability and degradation, processing and physical/mechanical properties.

Science Board:—The Science Board, with its various committees, is responsible for pure and applied research and graduate training in biology, chemistry, enzyme chemistry and technology, mathematics, and physics (other than astronomy, nuclear physics, radio and space research).

The Science Board emphasizes the individual in research, and the cultivation of depth of thinking together with a measure of breadth of outlook. It emphasizes the support of high-quality work, and favors especially a few selected areas of high scientific promise or value to the community.

The Chemistry Committee identified photochemistry, especially research on nanosecond and picosecond flash photolysis, and organometallic chemistry as meriting special support.

The Physics Committee has surveyed needs in the whole of its field (see below). Experiments using neutron-beam facilities at Harwell are being sponsored covering studies of the magnetic structure of solids, the dynamics of magnetization, the position of light atoms in crystal structures, the dynamics of atom movements in liquids, molecular rotations and vibrations, and defects in crystals.

A Physics-Chemical Measurements Unit is providing an analysis service (infrared, NMR, Mössbauer spectroscopy) to universities, making use of facilities at Harwell and Aldernaston.

The Physics Committee has identified the following problems, new areas, and techniques likely to need special support in the near future. Solidstate physics, generally. Plasma physics; neutron beams and the need for a high flux beam reactor; synchrotron radiation for studying gases and solids; ion implantation in semiconductors and other solids; amorphous state; surface studies; use of on-line computers; collisions between atoms and low-energy heavy particles; dye lasers; radiative recombination and energy-transfer processes in solids; mode-locked lasers giving picosecond pulses; ferroelectric materials; technological magnetism; electronic structure of alloys to match recent advances in pure metals; laser scattering spectroscopy;

nonlinear optics; electronic properties of polymers; inert-gas solids; critical phenomena at very low temperatures; superconductor tunnelling phenomena.

Clearly the physics community in the U.K. will be putting much of its emphasis on materials science.

Detailed breakdowns of recent support patterns by the SRC are given in Tables 8.40 and 8.41.

Scandinavia

The Scandinavian countries, Denmark, Finland, Norway, and Sweden, are relatively small, poor in many natural resources, but are highly developed countries. Survival and progress of their living standard in the face of competition from the larger economic units of the world are spurring mutual attempts to cooperate in the technological spheres; one of the areas for these attempts has been materials though so far not with very tangible results.

Denmark

Denmark has no natural materials resources except for lime, clay, sand, and gravel.

There are three State Universities and a Technical University which perform research in building materials, metals, polymers, ceramics, textiles, and solid-state physics.

The Danish Academy of Sciences operates 22 applied research institutes; within the materials field these cover electronic materials, asphalt, wood, radioisotopes, paint, and natural organic materials. Some contract research is conducted in these institutes.

There is considerable activity in solid-state physics which embraces the Technical University, the Orietal Institute of Arhus University, and the Ris Research Center of the Danish A.E.C.

Industry sponsors some research institutes, for example, in building materials, and much in-house R&D in the chemical and electrical industries.

There is no official policy in the field of materials research but the Danish Loan Fund for Industrial Research provides some risk money for industrial R&D. Attempts are being made to establish a program in the field of building materials research by the Danish Council for Scientific and Industrial Research. For a time, attention was given to the possibility of establishing a central building materials research institute but the estimated costs were prohibitive and, instead, it was concluded that research in this field must be covered by co-ordinating the activities of the existing institutes and industries.

Finland

The most important raw material in Finland to date is wood—for building, fuel, paper and pulp, and pulp products. The industry now runs at the

Table 8.40 Analysis of Support Given Through the Science Research Council in the U.K.

	Research Studentships and Fellowships			Advanced Course Studentships		
	1967	1968	1969	1967	1968	1969
Aeronautical & Civil Eng.	235	279	316	124	140	170
Biological Sciences	832	903	916	60	83	109
Chem. Eng. and Tech.	199	204	252	74	84	122
Chemistry	1621	1645	1552	73	77	104
Computing Science	39	64	101	49	84	99
Elec. + Systems Eng.	329	367	426	108	148	156
Science Courses including Management	69	54	40	47	53	90
Mathematics	480	524	531	252	318	345
Mech. and Production Engineering	178	200	234	101	109	166
Metallurgy & Materials	229	272	297	50	51	51
Astronomy			107			
Radio			13			
Space	1069	1058	39	117	122	117
Nuclear Phys.		223				
Other Phys.		642				
Control Eng.	–	–	–	–	–	–
Neutron Beam	–	–	–	–	–	–
Polymer Science	–	–	–	–	–	–
Totals	5280	5570	5689	1055	1269	1529

	Grants Awarded					
	1967–68		1968–69		1969–70 (provisional)	
	No.	£’000	No.	£’000	No.	£’000
Aeronautical+Civil Eng.	56	420	48	362	66	785
Biological Sciences	190	1090	182	1138	178	1453
Chem. Eng. and Tech.	66	539	56	490	61	548
Chemistry	246	1518	211	1714	228	1160
Computing Science	18	918	17	357	18	230
Elec.+Systems Eng.	65	477	66	828	63	851
Science Courses including Management	–	–	–	–	–	–
Mathematics	41	164	48	172	32	189
Mech. and Production Engineering	91	528	104	836	130	1040
Metallurgy & Materials	98	876	95	960	100	1296
Astronomy	34	816	42	486	31	293
Radio	5	26	9	47	6	46
Space	24	129	28	769	19	1101
Nuclear Phys.	42	1071	51	1605	79	1868
Other Phys.	150	847	146	988	163	1341
Control Eng.	–	–	3	36	19	839
Neutron Beam	–	–	–	–	138	287
Polymer Science	–	–	11	94	55	681
Totals	1126	9419	1128	11210	1414	14605

Table 8.41 U.K. Science Research Council Program Analysis C1970–1971) (in thousands of pounds sterling)

Fields of Support	Research Establishments Central University Support Facilities	Research Grants	Total*
Astronomy	2,422	655	3,171
Space Research	3,204	625	8,914
Radio Research	1,050	30	1,096
Nuclear Physics Research	11,585	1,520	20,051
Biological Sciences	–	1,020	1,925
Chemistry	140	970	2,556
Enzyme Chemistry and Technology	–	140	155
Mathematics	–	100	750
Neutron Beams	554	10	564
Physics	28	770	1,456
Aeronautical and Civil Eng.	–	480	867
Chemical Eng.	–	440	718
Computing Science	1,243	540	1,962
Control Engineering	–	440	496
Electrical and Systems Eng.	–	330	762
Mechanical and Production Eng.	–	850	1,171
Metallurgy and Materials	50	1,030	1,383
Polymer Science	10	50	89
Transport			–
Administration	1,126	–	1,126
NATO	–		400
Total	21,412	10,000	49,612

*These totals include Fellowships and Studentships and International Contributions for Space and Nuclear Physics Research not listed separately.

capacity of the forests. Research is directed at more efficient processing and use of wood.

Other industries have developed significantly since World War II, particularly in metals—iron and steel, nonferrous metals such as copper, zinc, cobalt, nickel, chromium, selenium, vanadium, titanium, and rare earth oxides. Finland is relatively well endowed with the relevant minerals even though production so far is small. As a consequence, research is very active in the metals and mining industries and associated Geological Survey-sponsored programs. By contrast, little R&D is done in the metals-consuming industries though there are signs of growing awareness of materials questions. The chemical industry is expected to expand most rapidly in the next few years, and it is in need of more R&D not only because of its relation to the metals and forest industries, but also because of the increasing production of plastics.

Nuclear energy is also expected to grow in importance, and the Finnish A.E.G. has initiated programs for research on radiation damage, corrosion, etc.

There has been much university expansion going on, and the need for expanding teaching staff and facilities made it difficult to provide at the same time for research or the setting up of new interdisciplinary materials departments. Instead, academic research is carried out more along traditional departmental lines, metallurgy and solid-state physics being the most prominent in the materials field. However, the former is performed in engineering departments and the latter in physics departments, with the traditional sharp division between them.

This division between science and engineering also projects into the organization of National Scientific Commissions and the State Research Institutes. The State Institute of Technical Research is organized along traditional lines with laboratories specializing in various technologies. In a pending reorganization of this Institute, there is an attempt to make it more interdisciplinary by establishing an integrated materials division.

Norway

There are 4 universities in Norway (Oslo, Bergen, Trondheim, and Tromso). Trondheim University also includes the Technical University of Trondheim where most of the academic research in materials in Norway is conducted. Some is also done at Oslo and only minor amounts elsewhere. Materials research is carried out in the traditional departments at Trondheim and Oslo— physics, chemistry, metallurgy, etc. but at Trondheim there is a Professional Coordinating Council for constructional materials research.

There are research institutes to support industry and to cover specific technological fields; e.g., building research, pulp and paper research, wood working and wood technology, atomic energy, materials testing, etc. There are also some broader institutes such as the Central Institute for Industrial Research at Oslo (where about 40% of the activity can be termed materials research). Overall, most research is carried out in government or government-supported laboratories.

There is no national policy for materials research. The Research Council for Scientific and Industrial Research includes committees organized along traditional lines—chemistry, metallurgy, technical physics, etc. There is no committee for materials, and so materials research gets split up among the committees. Furthermore the projects are to a large extent evaluated by committees which are use-oriented. This has its advantages and disadvantages; an example of the latter is that separate corrosion programs are sponsored by each of several committees. However, there is growing awareness of the need to coordinate the activities of the committees in the materials field.

More than 25% (i.e., 9.5x10 of all the funds allocated by the Council go to projects directly concerned with materials. Of this, approximately 60% is directed to metallurgical research (e.g., electro-metallurgical processes, alloy development, corrosion, composite materials, quality improvement, welding problems, fracture mechanics, etc.); less than 10% (i.e., 0.8x10 Kr) to plastics and high polymers; somewhat more than 10% to electronic materials; about 6% to ceramics, and the rest to specific materials projects (e.g., building construction problems). The emphasis on metals reflects the fact that metallurgical products constitute the country's largest export field, while shipbuilding and machine tools are the larger industries in the country.

Sweden

Materials research is conducted at Swedish universities, special institutes, and industrial laboratories. The first two tend to emphasize fundamental research but are recognizing the interdisciplinary nature of materials research. They are beginning to coordinate the programs of research groups and to cooperate in optimizing the use of expensive equipment and facilities. Indeed, the Royal Institute of Technology KTH (Stockholm) and the Chalmers Institute of Technology CTH (Gothenburg) have organized materials research centers comprising various departments of the two institutions as well as interested parties from the outside. There is also an interdepartmental materials research body at Uppsala University.

In addition there are trade research institutes oriented to specific industries and sponsored by industrial groups. Certain special research institutes, though oriented towards particular industries, are not industrially-sponsored and are therefore rather independent.

Materials research, principally ferrous, is conducted mainly at KTH, the Institute for Metal Research, and the Swedish Atomic Energy Company. At KTH and the Institute for Metal Research the emphasis is on physical metallurgy and metallography.

Polymer research is also conducted at KTH and some at CTH.

Materials research at CTH is primarily solid-state physics and applied physics, with broad emphasis on surface physics and chemistry and the border area between solid-state theory and physical metallurgy. Applied work is focused on composites and powder metallurgy.

Materials research at the Lund Institute of Technology (LTH) is concerned mainly with building materials and fracture mechanics.

Materials research at Uppsala University is mostly physical metallurgy.

Ceramics and glass research is conducted at the Silicate Research Institute (Gothenburg) and the Glass Research Institute (Vaxjo) —both trade research institutes.

The Defense Research Institute is concerned with heat-resisting materials, composites, corrosion (especially with titanium metals), and protective coatings.

The Atomic Energy Company works on reactor applications, deformation and repture mechanics, structural defects, and corrosion.

The principal governmental body for sponsoring and overseeing materials research is the Swedish Board for Technical Development (STU), officially subordinate to the Ministry of Industry but enjoying considerable freedom while cooperating with other sponsoring agencies, private research organizations, and private industry. It makes use of expert committees to advise on R&D matters. One of these committees is concerned with the materials field; its chairman is the President of the Academy of Engineering Science. The STU offers three types of support—for research with no obligation for repayment, to industrial development projects with a conditional obligation to repay, and to collective trade research with the industrial sector in question as a financial partner to at least 50%.

The STU has given high priority to materials technology in its appropriations budget, amounting to between 15 and 20% of its total budget.

Steel is regarded still as a pivatal material for the future through advances in strength, toughness, weldability, and by improved production processes and the development of new alloys. Steam and atomic energy technologies call for greater heat, corrosion, and radiation resistance. Powder metallurgy is expected to grow in importance for forming more complex structural parts. It is anticipated that similar trends toward better toughness and heat resistance will also occur with the nonferrous metals based on aluminum and titanium.

Polymers are projected to become a rapidly growing structural material. Research will be necessary for developing polymers with advanced mechanical properties to substitute for metals, also with high-temperature and radiation resistance. Environmentally degradable polymers will also be needed.

Consumption of ceramics in the building industry is expected to decrease; bricks will be replaced by prefabricated wall sections, plastics will replace ceramic drain and sewer pipes. For lining furnaces, ceramics better able to withstand thermal shock will require continuing R&D.

Composites are regarded as a growth field—for aeronautical engineering, for weapons, transportation equipment, and for many parts in industry (e.g., pumps, pipes, etc.), where the extra strength is worth the extra cost. Less expensive composites and fibers are needed, particularly carbon fibers, and more automation of manufacturing processes.

RESEARCH AND DEVELOPMENT INSTITUTES: INSTITUTIONAL COUPLING

General Remarks

Every advanced country has research institutes, situated operationally between university research departments on the one hand and mission-oriented governmental and industrial laboratories on the other. The genesis of these institutes are as varied as their purposes, but there are some general factors lying behind their existence: the recognition of the need for research capabilities over and above those available in traditional university departments or in mission-oriented laboratories; the opportunity for individuals to devote full time to research; and importantly for our purpose, to facilitate multidisciplinary research programs unconstrained by traditional disciplinary boundaries. In many cases, needed research programs were judged to be too large for universities to manage properly, or for individual industries to support, or elaborate pieces of equipment or other facilities were needed. Whatever the reasons, there exists today in all advanced countries what might be called peripheral research systems, being neither wholly within any of the more traditional academic, governmental, or industrial sectors.

Such peripheral systems of research institutes present obvious dangers— unless wisely established and managed—they can become closed universes, self-contained, and noninteracting with the broader scientific community. They can be set up with too much central control and governmental administrative procedures. On the other hand, too little care in management of the institute, particularly locally, can result in research programs of less than adequate effectiveness and insufficient exploitation of opportunities. The setting up of research institutes also tends to be a lengthy business, and once set up they often seem to be immortal—there is thus the danger that “when the need arises they are not there, when the need has disappeared they still go on.” If research institutes are deemed necessary, therefore, they must have built-in flexibility and adaptability of management and programs, they must work synergistically with the greater scientific community and, in particular, there must be effective personal contacts among scientists in the research institutes and those in other pertinent institutions, departments, and disciplines. The most direct way of achieving these objectives is to site research institutes at universities and to use fully the opportunities for joint staff appointments, personnel exchanges, and joint research and education programs between the institute and the parent university. This also facilitates involvement of first-rate scientists at the universities.

Though needs for research institutes are widely recognized, different countries adopt different approaches. Some of these (for France, Germany, and the U.K.) have been documented recently.[12] “In Germany the financing and committees of the peripheral institutes (i.e. the Max Planck Institutes) are independent of the DFG; the Research Councils in the U.K. and the CNRS in

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[12] The Research System. Vol. 1, OECD, Paris, 1972.

France combine the functions of aiding the universities and of running their own laboratories (like the NSF), and their financing and committees are common to the two functions. In the U.K., moreover, research is organized by sectors (there are five Research Councils, four of which are concerned mainly with oriented research), whereas the CNRS in France and the DFG and the MPG in Germany are each responsible, in their own sphere, for the whole of fundamental research." Yet "methods of organization and financing do not yet seem to have succeeded in adjusting research to the new performance expected of it…. Specifically, it is the individualistic conception of research which has colored the whole system and governed the trend of university and peripheral research in each of the three countries. The result is that comparable behavior is found in dissimilar contexts." Despite a diversity of approaches in the three European countries "university research centers have rarely succeeded in conducting multidisciplinary research, and even more rarely than the peripheral centers." The materials field, however, should offer potent opportunities and needs for such multidisciplinary approaches and institutes. These needs for institutes include not only adding to the reservoir of knowledge about materials but also to effect coupling and knowledge transfer between research and engineering, between universities and industries, and, increasingly, between science and society.

Large industrial companies generally support in-house nearly all the R&D they feel they need, and in most cases, proportionately much more R&D then do small companies. The latter, even when highly entrepreneurial, usually put most of their effort into product differentiation and development, engineering and marketing; if they need inputs of a more research type, they usually depend on the larger industrial centers of excellence (from which they have often spun-off or with which they are cross-licensed) and on expertise in the universities. In most countries, there are R&D institutes set up principally to serve the smaller or more backward or developing industries which, for various reasons, feel unable to support adequate efforts of their own.

Various types of institute are described below.

Large Government-Funded Institutes for Initiating Major Civilian Technologies

The most obvious example in this category is nuclear energy, a technological field that did not exist prior to World War II and for which there was no suitable industrial base. Furthermore, and importantly, such development programs are inherently of long duration and commercially risky; it is generally accepted that these factors make a field appropriate for largescale and long-term governmental sponsorship. Thus, we see national laboratories such as Harwell in the U.K., Saclay in France, and Jülich in Germany, established to carry out R&D programs aimed at innovating nuclearenergy technology. They are, by and large, successful at achieving their technical objectives, but there are often problems in transferring the technology into a suitable industrial and commercial framework. If such laboratories are set up under governmental auspices, it appears necessary to adopt a working partnership with industry right from the start in order to ease the subsequent technology transfer process.

Government Research and Development Institutes for Technologies where the Government is the Principal Customer

Defense and aerospace are prime examples of such institutes. Such institutes have many impressive technological achievements to their credit and these achievements, even if their cost-effectiveness can sometimes be questioned, were no doubt greatly facilitated by the steadiness of governmental support and the virtual certainty of a customer. In the civilian area, there exist many government-funded laboratories carrying out R&D in areas of national concern which may not have an appropriate industrial or commercial base (e.g. highways, pollution control) or are in state-owned and operated service or industrial areas (e.g. railways, electric power, coalmining).

Government-Funded Institutes Directed at Civilian Industries

There are several varieties of such institute. In the U.K. there are, for example, the National Physical Laboratory, the National Engineering Laboratory, and the Warren Spring (Chemical Engineering) Laboratories. The first performs activities rather similar to those of the National Bureau of Standards in the U.S. All three are primarily for serving the needs of industry through R&D programs, particularly in the application of techniques and discoveries to design, production, quality control, and distribution.

In France the laboratories of the CNRS, whose primary function is to promote the progress of science, tend to emphasize more basic areas of research, while the more applied institutions tend to be associated with various technical ministries. Government-managed institutes specifically aimed at enhancing civilian industries are for the most part conspicuously absent.

In Germany, government-funded research establishments oriented towards industry are mainly diffused and scattered among Federal and Lander Ministries and Departments for support. Some applied research institutes are organized and supported rather like the Max Planck Institutes (the latter tending to be more basic-research oriented) and often have close associations with universities.

Japan has a quite extensive array of government-funded laboratories. Those most relevant to the materials field are listed in Table 8.42. Many of these come under MITI, the Ministry of International Trade and Industry, which takes a leading role in coordinating governmental and industrial R&D programs. It is perhaps worth repeating that essentially no R&D in industry itself is supported by the government.

In Canada, which by and large does not have large industrial research

Table 8.42 Government Research Institutes in Japan (1971–1972) —Those that bear some relation to the field of materials science and engineering.

	Number of Personnel	
	Total	Scientific
Hokkaido Development Agency		
Civil Engineering Res. Inst.	103	
Science and Technology Agency		
National Aerospace Laboratory	485	352
National Res. Inst. for Metals	479	320
National Institute for Res. in Inorg. Materials	131	79
Ministry of Agriculture and Forestry		
Forest Experiment Station	821	514
Pearl Research Laboratory	23	11
Ministry of International Trade and Industry		
Nat. Res. Lab. of Metrology	271	144
Mechanical Engineering Lab.	339	221
Govt. Chemical Industry Inst.	457	307
Govt. Industrial Technology Res. Inst. (Osaka)	264	182
Govt. Industrial Technology Res. Inst. (Nagoya)	298	215
Fermentation Res. Inst.	76	56
Res. Inst. for Polymers and Textiles	134	101
Geological Survey of Japan	467	248
Electrotechnical Lab.	814	585
Industrial Products Res. Inst.	157	113
Nat. Res. Inst. for Pollution and Resources	409	280
Govt. Industrial Develop. Lab. (Hokkaido)	110	78
Govt. Industrial Tech. Res. Inst. (Kyushu)	90	71
Govt. Industrial Tech. Res. Inst. (Sikoku)	39	28
Govt. Industrial Tech. Res. Inst. (Tohoku)	53	33
Ministry of Transport		
Ship Res. Inst.	299	209
Electronic Navigation Lab.	35	30
Port and Harbour Res. Inst.	264	139
Mateorological Res. Inst.	194	147
Traffic Safety and Nuisance Res. Inst.	61	40

	Number of Personnel	
	Total	Scientific
Ministry of Posts and Telecommunications		
Radio Res. Lab.	446	259
Ministry of Labor		
Res. Inst. of Industrial Safety	56	
Nat. Inst. of Industrial Health	60	
Ministry of Construction		
Public Works Res. Inst.	544	310
Building Res. Inst.	182	113
Ministry of Autonomy		
Fire Res. Inst.	61	

laboratories, the National Research Council through its various establishments undertakes widespread R&D services for industry as well as for the Federal Government.

Jointly- or Industrially-Supported Research Associations

In France, Germany and the U.K., the governments help to finance research associations whose aim is to enable firms in the various sectors to carry out cooperative research which they could not have undertaken separately. These institutions are usually quite small and collectively they account for a very small percentage of national expenditures on R&D. “Apart from a few outstanding exceptions, the research associations have not had all the success hoped for: the conservatism of certain sectors of industry has often prevented them from undertaking more fundamental longer-term research than individual firms; they have thus been obliged to confine themselves to relatively short-term applied research which is too frequently of marginal significance because important subjects are ruled out by competition between the member firsm. Governments have so far been unable or unwilling to intervene directly to remedy this state of affairs.”[13]

In the U.K. specialized research associations are now available for about 50 percent of British industry. These are listed in Tables 8.43A and 8.43B (government-industry supported) and in Table 8.44 (totally industry supported). Some of these laboratories are sited alongside relevant university departments (e.g. the Glass Research Association and the Glass Technology Department at Sheffield University).

A novel venture to diversify the activities and develop a partially-supporting contract research base has been under way for some time at Harwell, the central R&D establishment of the U.K. Atomic Energy Authority. The principal purpose was to develop commercial spin-offs for expertise, techniques, and equipment resulting from their main nuclear energy program. Among the activities developed at Harwell under this policy are some which are particularly relevant to the materials field, such as a national center for nondestructive testing and another for ceramics. The commercialization program, perhaps viewed suspiciously at first by industry as a curious use for the tax-payer’s money, appears to have been reasonably successful; a persistent problem, though, is finding areas of R&D which need tackling, which are potentially profitable and yet are not already being addressed by industry, or which industry regards as research which should be contracted to them. Furthermore, there is some danger of it being rather dispiriting to the talented scientists and engineers of a great establishment having to “hawk their wares and services” and undertake “odd-jobbing”. One cannot help feel that a national asset such as Harwell functions best when coupled to an important national mission—recent world-wide developments in the energy field suggest, for example, a renewed, broadened, and continuing role that the establishment could play which would be central and vital to the national interest.

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[13] The Research System, Vol. 1, page 158, OECD, Paris, 1972.

Table 8.43A Annual Expenditure of Research Associations in the U.K. (1963)

Research Association	Expenditure (including depreciation) 1,000
Iron and Steel	1 154
Ships	1,059
Cotton	666
Production Engineering	639
Electrical	594
Coal Utilization	515
Wool	339
Ceramics	318
Welding	314
Nonferrous Metals	304
Motor Vehicles	288
Cast Iron	273
Rubber & Plastics	226
Printing & Packing	207
Scientific Instruments	184
Coke	182
Timber	167
Paper	161
Food Manufacturing	147
Tar	141
Boots & Shoes	135
Steel Castings	128
Paint	125
Machine Tools	114
Water	107
Int. Combustion Engines	107
Baking	100
Flour-Milling	95
Glass	94
Linen	91
Leather	91
Hosiery	90
Laundry	88
Hydromechanics	77
Jute	69
Furniture	61
Civil Engineering	49
Industrial Biology	48

Research Association	Expenditure (including depreciation) 1,000
Heating and Vent.	45
Fruit & Veg. Canning and Quick Freezing	41
Lace	33
Gelatine and Glue	30
Lime	29
Drop Forging	27
Whiting	26
Springs	23
Cutlery	19
Felt	19
Files	18
Brushes	12
Total	9,870

Table 8.43B Numbers of Staff in Research Associations in the U.K. (1963)

Key to Staff Categories			
A -	Qualified Scientists or Engineers	1654	(27%)
B -	Holders of Higher National Diploma or Higher National Certificate	356	
			2085 (35%)
C -	Other Technical Workers	1729	
D -	Workshop Employees	690	(11%)
E -	Other Staff	1612	(27%)
	Total	6041	

Research Association	Numbers					Total
A	B	C	D	E		
Baking	20	–	24	2	17	63
Boots and Shoes	10	10	43	8	28	99
Brushes	4	1	2	1	1	9
Cast Iron	54	11	50	16	41	172
Ceramics	67	2	108	9	23	209
Civil Engineering	2	–	–	–	2	4
Coal Utilization	81	46	63	58	64	312
Coke	37	4	59	13	18	131
Cotton	146	6	184	63	89	488
Cutlery	4	1	3	–	2	10
Drop Forging	5	–	10	–	4	19
Electrical	101	17	96	24	112	350
Felt	7	–	5	–	3	15
Files	3	1	3	1	–	8
Flour-Milling	23	–	24	2	17	66
Food Manufacturing	41	7	25	2	24	99
Fruit & Veg. Canning and Quick Freezing	12	–	10	4	8	34

Research Association	Numbers					Total
A	B	C	D	E		
Furniture	12	2	4	2	13	33
Gelatine and Glue	9	3	3	1	6	22
Glass	14	8	14	2	19	57
Heating and Vent.	11	3	9	2	8	33
Hosiery	20	–	29	5	15	69
Hydromechanics	13	1	8	8	16	46
Industrial Biology	13	2	11	–	7	33
Int. Combust. Engines	10	5	11	24	20	70
Iron and Steel	172	68	108	75	190	613
Jute	14	5	17	4	10	50
Lace	8	–	15	5	6	34
Laundry	14	–	27	8	35	84
Leather	20	–	34	–	–	70
Lime	7	–	6	1	5	19
Linen	18	1	33	16	14	82
Machine Tools	14	6	–	2	14	36
Motor Vehicles	34	18	45	19	47	163
Nonferrous Metals	55	10	78	18	31	192
Paint	30	1	40	7	20	98
Paper	30	2	40	3	15	90
Printing and Pack.	32	–	26	5	42	105
Production Eng.	94	51	106	32	129	412
Rubber and Plastics	45	4	52	10	52	163
Scientific Instruments	42	8	18	16	42	126
Ships	106	16	30	138	133	423

Research Association	Numbers					Total
A	B	C	D	E		
Springs	8	1	3	–	1	13
Steel-Castings	24	6	27	13	37	107
Tar	22	19	27	3	21	92
Timber	15	2	24	14	31	86
Water	23	–	12	3	19	57
Welding	44	6	50	38	70	208
Whiting	5	–	9	1	5	20
Wool	59	2	104	12	70	247
Total Numbers	1654	356	1729	690	1612	6041
Percentage of Total	27	2085 35		11	27	100

Table 8.44 Nongrant Aided Co-Operative Industrial Research Associations with Subscribing Members in the U.K. (1963)

Name	Expenditure (including depreciation) 1000
Cement and Concrete Association	501
Natural Rubber Producer’s Research Association	298
Aircraft Research Association Ltd.	349
Institute of Brewing (Research Fund)	141
Tin Research Institute	94
Aluminum Federation (Research Department)	58
Dyers’ and Cleaners’ Research Organization	22
Shipowner’s Refrigerated Cargo Research Association	20
Permanent Magnet Association	23
British Flame Research Committee	12
Produce Packaging Development Association Ltd. (Research Committee)	4
Research Committee for the Cast Stone and Cast Concrete Products Industry	7
Research Organization of Ships’ Compositions Manufacturers Ltd.	5
Institute of British Foundrymen (Technical Research Fund)	2
Reclamation Trades Research Organization, Ltd.	1
Total	1539

Institutes and Research Programs Associated with Universities

In France there are a number of institutes and programs, often associated with universities, that are sponsored by the CNRS (which is similar in its functions to the NSF). Germany is known for its privately-operated, though government-aided, Max Planck Institutes and the DFG programs. In the U.K. one finds institutes or programs operated by the Research Councils. All of these agencies have responsibility for identifying national science research needs and responding by supporting individuals in universities, multiinvestigator research programs, and even research facilities.

In recent years all of these agencies have been placing increased emphasis on applied research in the national interest. Much sound new knowledge undoubtedly results, but it is difficult to assess what direct impact their programs have had on the technical competitiveness of industry. However, like the interdisciplinary materials science centers supported by the NSF, they are undoubtedly enhancing the educational level of scientists and engineers who pass through them into industry, and thereby they contribute indirectly to industrial technological prowess.

It should be noted that the U.S. appears to have led the way in the successful establishment of government-financed, interdisciplinary materials science centers and perhaps also in government, mission-oriented laboratories associated with universities. Notable among the latter are the Lincoln and Stark Draper Laboratories at M.I.T., Livermore at Berkeley, and the Jet Propulsion Laboratory at California Institute of Technology.

Research Institutions in Smaller Industrialized Countries

"With comparatively slender resources, without any spectacular political mobilization and often even without any deliberate effort, the five countries (Belgium, Netherlands, Norway, Sweden, Switzerland) have succeeded in creating a climate conducive to innovation based on the spontaneous initiative of individuals and groups…." "These countries do indeed seem in many respects to have achieved the degree of technological drive which is still being sought by other countries whose structures have often proved a difficult obstacle to innovation".[14]

It is instructive to quote further from the same source: "For the most part, the scientific and technological systems in the five countries have traditionally tended to respond to economic imperatives…." "Industrial scientific activity is therefore the essential objective and purpose of traditional research policies…." "At the service of economic growth, research in the five countries is therefore mainly centered in industries and the universities, the part played by the State being more unobtrusive and less direct than in such countries as France and the U.K. The State's task is not so much to lay down the major options or stimulate large-scale developments, but to guarantee a favorable context for exchanges between the economy and the universities, which has always been a necessary condition for cross-fertilization".

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[14] Research System, Vol. 2, page 183, OECD, Paris, 1973.

"With regard to industry, the dominating fact is the concentration of all industrial, and to some degree even all national R&D in a very few hands…." "(This) situation was not the result of any deliberate governmental plan or strategy in the field of research, but resulted indirectly from the workings of a liberal economic system".

In the larger European countries the research system is characterized by two features: (1) basic institutional financing of universities and some specific projects, and (2) the system of university and peripheral institutions. The smaller countries display only the first of these characteristics. There is a virtually total absence of a peripheral sector. Instead, and perhaps because of their small-country status, research scientists make exceptional efforts to keep in good contact with the rest of the world. In a sense, industry is the peripheral sector; it fosters contacts between isolated research workers and highly differentiated disciplines and is an instrument for opening up new sectors.

Space does not permit delving more deeply into the causes of the success of the smaller industrial countries in enhancing technology, but it does appear that there are many lessions to be learned by the U.S., particularly regarding effective coupling between universities and industry.

United Kingdom

Government Research Establishment—Harwell, A Case History Harwell makes an interesting case history of a governmental research establishment having to adjust its activities in keeping with changes in national goals.

As of 1969, Harwell employed about 5500 staff of whom about 1200 were qualified scientists and engineers. It spends about 15 million on R&D, the major part of which is directed at the nuclear power program.

Until the 1950's the main task was to establish the scientific background required for the design and construction of production plants for fissile material; this led to the setting up of production facilities elsewhere. Next, work was started on developing nuclear reactors as producers of economic power. This grew and led to the creation of a new establishment for reactor development. Similarly, Harwell's early work on plasma physics and fusion led to the formation of the Culham Laboratory. Work on high energy physics, which also started at Harwell, was transferred out of Harwell into the Rutherford Laboratory (operated by the SRC) in 1961. As a result of all these changes, Harwell emerged as primarily a materials R&D establishment, but one experienced at rapidly transforming scientific knowledge into technology. In this connection, Harwell has found that a coordinated, multidisciplinary attack on problems is vital if the development is to succeed both technically and economically.

As a result of the nuclear program, Harwell became equipped with an excellent range of resources—physical, intellectual, and motivational— capable of application to other technologies. At the same time, the technical success of the nuclear program has diminished the need for a research push in this direction. So, with national priorities turning to improving the efficiency of industry, it was natural for Harwell to consider ways in which at least some of its resources could be redeployed.

Harwell began such redeployment at a time when, to the public at large, the glamour seemed to be wearing off R&D as a prerequisite for economic growth and innovation, and attention was turning to marketing problems. Could Harwell turn itself, therefore, towards market-oriented R&D? As the evidence of the previous changes at Harwell shows, it is not difficult to change emphasis or orientation in such a multidisciplinary and multipurpose laboratory. It is more difficult to bring about change in a single-disciplinary, single-objective laboratory: such laboratories have many attractions but it is difficult to know what to do when their objective or mission has been achieved.

It was natural for Harwell to look for areas where its special expertise in nuclear technology might couple most effectively with industrial R&D problems. This was regarded as “missionary” work work, e.g., showing where isotopes, radiation and other nuclear tools could be used in industry. But this was too vague an objective for Harwell. It was decided, instead, that each project should be chosen to give an identifiable, economic benefit and, whenever possible, pursued in partnership with an industrial company, i.e., Harwell should be mission-oriented.

In 1965, an Act was passed which enabled Harwell to undertake work in nonnuclear fields. As a result, Harwell extended its nonnuclear program in, for example, ceramics, quality control, and computer software. However, all new activities of this sort had to meet a number of criteria designed to establish clearly that Harwell is an appropriate center for such work and that the work is desirable.

Some of the projects Harwell undertakes are of a national-benefit type, to develop a new technology, e.g. high-temperature fuel cells, or for purely social reasons, e.g. atmospheric pollution. But for most projects, the commercial aspects are extremely important, e.g. the desalination program. There is also an independent Program Analysis Unit which analyses the national benefit to be gained from each proposed program.

A second general point is that, for each program, only one industrial partner is sought out. If Harwell were to work with several firms in any specific program, then inevitably the final market would have to be divided among them, the incentive to each firm would be diluted correspondingly, and the probability of true commercial success would be sharply reduced. Furthermore, the firms would then be obliged to compete primarily with each other instead of with foreign competitors.

Harwell has learned from experience that it is essential to assess the eventual market for each program. And to improve the market emphasis in the R&D program, Harwell finds that as soon as a program is well launched it is effective to have the program directly under the control of the relevant industrial partner. This insures that the R&D is properly oriented, that there is an efficient two-way flow of information, and the not-invented-here factor is minimized. An example of such a program is the sol-gel method of preparing oxide powders of closely controlled crystallinity, particle size, and shape. Another concerns a production process for the refractory bricks used to line steel furnaces. It has been found particularly effective to form joint teams of Harwell and industrial personnel working either at Harwell or in the industry as appropriate. This is particularly useful for effecting technology transfer.

Another example of a materials program in which Harwell was involved is carbon fibers for fiber-reinforced materials. This program illustrates the synergistic effect of research being carried out in the same place and, in many cases, by the same people. Harwell was originally interested in graphite as a moderator in gas-cooled reactors and this led them naturally into carbon fibers. They are examining a range of possible uses for carbon fibers in the atomic energy field. Thus, a laboratory like Harwell can have a large number of objectives without fragmenting the whole. It is the scientific content of the research which links all the projects together.

Increasingly Harwell now finds industry bringing its ideas and problems to them, demonstrating the acceptance of Harwell's role by the industrial community after an initial, somewhat suspicious period. There are also examples of coupling with universities as well as industry where Harwell has, in essence, developed the ideas of university people, collaborating closely with them, and then made the appropriate connection with industry.

Regarding the costs of R&D performed at Harwell, auditing has shown these to be rather similar to those of industrial partners. One substantial advantage of a large laboratory like Harwell is its ability to construct sizeable pilot plants quickly. But the main advantage is the synergistic effect of all its activities and the ability to bring wide ranges of disciplines and techniques to bear on a specific project.

Germany

Max Planck Institutes: The majority of the 53 Max Planck Institutes are devoted to fundamental research, particularly in the natural sciences, although some institutes do embrace applied research as well. Research in the institutes is complementary to that in the universities, and the organization can be compared in some ways to the laboratories operated by the Research Councils in Great Britain, the CNRS in France, and the Academy of Sciences in the U.S.S.R. Institutes are built around highly qualified and productive scientists as directors; when a new director has to be appointed, the Max Planck Society reassesses whether continuance of the institute in its current or a different research field is justified. Sometimes it is concluded that the institute should be handed over to a neighboring university, particularly if no suitably qualified successor can be found for the directorship.

The purposes of the Max Planck Society are:

(a) to support new trends as well as new methods in research, in particular where these are developing on the borderlines between traditional disciplines and have not yet found a place in the universities because of the institutional ties between research and teaching;

(b) to develop new types of institutes, and to take charge of research projects which demand equipment of such size and specialization that the universities do not take them on for fear of disturbing their internal balance;

(c) to provide scientists of exceptional ability, who wish to devote themselves to pure research, with working facilities adapted to their specific requirements so that they can bring to bear their entire energy towards achieving their scientific aims.

The Max Planck Society is subsidized by the Federal and State Governments which share equally in the cost (which, for 1970, was 320 million DM) of supporting the institutes. These subsidies are not earmarked by the government for specific research projects but can be allocated by the Society as it sees fit. There are also private donations.

The sizes of the institutes vary greatly, depending on their research areas. The numbers of personnel range from very few to several hundred. In 1969 the Society employed 7000 personnel of whom 1750 were scientists.

The Directors and Scientific Members are free to choose their scientific research topics and to manage them as they wish. All that is required is a simple annual accounting by the Director to the Society. There is no fixed form for the internal organization of an institute; it can be adapted to varying requirements at any time. It is claimed that one advantage of this internal flexibility is a close interdisciplinary cooperation.

Those institutes wholly involved in various aspects of materials science and engineering include: Metallurgy (Stuttgart); Iron and Steel (Düsseldorf); and Solid State Physics (Stuttgart). Other institutes partly involved in MSE include: Chemistry (Mainz); Physical Chemistry (Göttingen); Inorganic Chemistry (Frankfurt); the Fritz-Haber-Institut (Berlin-Dahlem), and Spectroscopy (Gottingen).

The fact that a Solid State Institute (Stuttgart) was recently formed indicates the importance attached by the Max Planck Society to this field. Together with the large and well-known Metals Institute this represents a major concentration in materials science at Stuttgart.

Organized somewhat similarly to the Max Planck Institutes but devoted more to applied science is the recently-formed Fraunhofer Gesellschaft for Applied Solid State Physics at Freiburg where solid-state electronics is emphasized. There is also an Institute for Ceramics at Würzburg.

With the shift in emphasis from nuclear physics towards materials in Germany, the well-known nuclear installation at Julich has recently established an enlarged solid-state laboratory whose activities are coordinated with those in materials science at Stuttgart by a joint council.

A summary of the research specialties in the metals field at various German institutes and universities is given in Table 8.45.

U.S.S.R.

Coupling Science and Technology:[15] The view is now generally accepted in the U.S.S.R. that research, development, and production must be brought more closely together. A variety of organizational forms are the subject of active experiment. Of particular interest are:

(a) What has been called the “factory center,” in which research institutes, design bureau, and production enterprises are brought together in a

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[15] Science Policy in the U.S.S.R., OECD, Paris, 1969.

Table 8.45 Institutes Primarily Concerned with Metals Research in Germany

x Experimental
o Experimental and Theoretical
+ Theoretical

		Composition	Structure	Thermodynamics	Lattice Theory	Point Defects	Dislocations	Plasticity	Radiation Damage	Material Transport	Recrystallization, Texture	Grain Boundaries	Surfaces	Electrical Properties	Electronic Structure	Superconductivity	Magnetism	Order/Disorder Precipitation	Transformations	Ultra-Pure Metals	Melts, Structure, Physical Properties	Corrosion
Aachen	Met. & Met. Phys.					x	o	o	o		o	x	x									
	Theoret. Phys.				+		+	+	+					+								
Berlin	Metallurgy	x	x								x							x	x		x	x
	Met. Physics					x				x	x			x						x		x
Clausthal	Met. & Met. Phys.							x			x							x	x			
Dusseldorf	MPI Iron & Steel	x	x	x				o			x			x			x		x		x	x
Erlangen-Nuremburg				+				o		x		o		x				o				
Göttingen	Met. Phys.						o	o			x			x	+	o		o	o	x		

		Composition	Structure	Thermodynamics	Lattice Theory	Point Defects	Dislocations	Plasticity	Radiation Damage	Material Transport	Recrystallization, Texture	Grain Boundaries	Surfaces	Electrical Properties	Electronic Structure	Superconductivity	Magnetism	Order/Disorder Precipitation	Transformations	Ultra-Pure Metals	Melts, Structure, Physical Properties	Corrosion
Julich	Nuclear Inst.		x		+	o	o		o	+							o					
Munster	Metallurgy	x		x						x			x	x				x	x		x	x
	Theoret. Met. Phys.													+	+						+	
Munich	Metallurgy										x							x				
Saarbruchen	Met. & Met. Phys.		x				x											x			x	
Stuttgart	MPI Metallurgy	x	x			x	x	o						x	+		o	o	o		x	x
	MPI Special Metals	o	x	x	x	x	x	x	o	x	x	x	x					x		x	x	x
	MPI Physics	+	+	+	o	o	o	o	+					o	+	o	o	+	+	x		

single administrative complex—this has particularly found application in the heavy engineering and machine-tool industries;

(b) The "research complex" in which research institutes in related fields are brought together and associated closely, through contracts and other means, with industry. Soviet publications stress here the advantages of combining research and teaching activities into a single, interdisciplinary unit—the Leningrad Polytechnical Institute and the Novosibirsk Science Center and University provide examples of this form of organization;

(c) The "research corporation," an enterprise with research and experimental production facilities which works for industry on a self-supporting basis, either providing the know-how for new production processes or else offering a complete new plant.

It appears that the traditional Soviet form of research organization, with a large research institute and attendant design bureaux in each industry separated from the production factories, is partly being replaced by a variety of arrangements of kinds familiar in the West and particularly in the U.S.: the large industrial firm with its own complete R&D facilities; the university with its attendant research facilities working closely with industry; the contract-research firm; and the civil engineering company. But all this is being done cautiously and gradually, with the object of retaining the economies of scale and the ability to concentrate effort on major objectives which are a prominent feature of Soviet R&D organization. What emerges in the next decade or so is likely to be an interesting combination of traditional Soviet and Western arrangements.

While Soviet administrators are devising means of bringing research and production more closely together, there is much less certainty about the way to provide an organic connection between innovation and the industrial or individual consumer of new products. Two proposals have now received general acceptance.

The first is that industrial research establishments and design bureaux, or any new forms of R&D organizations which are created, must be financed not by direct grants but by some form of contract funds being provided to the user of the research and not directly to the research institute. It is felt, however, partly as a result of the experiments with contract research since 1962, that dependence on individual enterprises for finance would narrow and subdivide the activities of research institutes; the agreed solution is, therefore, that most contracts should be made with ministries or other large organizations rather than with individual enterprises.

The second agreed proposal is that in any field no one research institute should have a monopoly and that an element of competition between R&D organizations responsible for new products and processes is desirable.

The intention seems to be that the ministry in which the research organization is located should be responsible for awarding contracts or choosing between alternative proposals. The main consumers of new products may be represented on the committee which makes the decision, but the administrative responsibility will apparently rest with the ministry producing the new product. Moreover, the competition between R&D organizations will only be taken to the mock-up or at most the prototype state—commercial production of a new product will apparently then be transferred to a single production firm. The argument for this mode is that, while there is a case for "conscious duplication" of R&D concerning new products, there is no case for the losses in economies of scale which would result from the duplication of expensive production facilities.

These proposals are intended to provide strong incentives for invention and for the carry-over of invention into practical forms. The measures so far undertaken to encourage the commercial production of new products are primarily designed to compensate industrial enterprises for losses due to the introduction of new products and processes, e.g. through the special Funds for the Assimilation of New Technology in each ministry, rather than to provide positive incentives to innovate. Numerous proposals have been made to enlarge the scope of these arrangements; some authors have suggested that the initial costs should be met, as is usual in the West, from profits and bank loans, and thus be treated in effect as an investment cost.

Such arrangements are, however, difficult to introduce successfully at present, because industrial prices are unsatisfactory. Prices of new products, which like other prices are usually fixed centrally by the State, do not provide an adequate margin, either in the short or in the longer term, for initial costs to be met. A number of Soviet specialists have instead proposed that prices for new products should be fixed by negotiation between producer and consumer, so that what amounts to a limited market for new products would be introduced.

Together with economic incentives for research establishments and factories, strenuous efforts have been made to introduce individual economic incentives, both to R&D staff and to production personnel, which are similarly intended to encourage rapid application of research results. These range from special lump-sums promised in advance to leading scientists and designers for the prompt fulfillment of major projects, to bonuses to factory workers for successfully-completed prototypes. Attempts are being made to relate the size of the bonus to the economic return received from the research project or the new product.

Paradoxically, therefore, Soviet government leaders and administrators appear prepared to rely to a greater extent on the economic calculus and on the desire of enterprises and individuals to maximize their earnings in their planned economy than many Western Ministers of Science and Technology would be prepared to propose even in their own largely private-enterprise economies. The recent Soviet stress on automatic economic incentives provides a healthy corrective to past emphasis on detailed administrative control from the center; but is is unlikely to provide a complete solution to Soviet problems. Our knowledge of the mainsprings of innovation is limited; but it seems certain that successful innovations in the West cannot be explained entirely in terms of the higher profit-margins obtainable from innovation. Innovation often emerges in a competitive context: the innovating firm is driven by the need to forestall its rivals and to maintain its share of the market. In a modified form, this often also applies in the case of governmentally-financed R&D, where competitive bidding for contracts encourages innovation by industrial firms.

Soviet efforts in the next few years to measure and reward the economic return on R&D are likely to be relevant and interesting to Western countries.

In the latter, it is commonly held among most makers of science policy that the spur of competition no longer operates everywhere in innovating activity, and that therefore new economic relationships between government and industry, and new methods of governmental management of research, must be devised.

Some doubt also exists about the feasibility of Soviet proposals to rely on personal economic incentives tied to the return on particular new products and processes. Western experience would seem to indicate that it is unwise to tie personal earnings too closely to the fate of particular projects. But here again experience in the West as well as in the U.S.S.R. is somewhat limited.

Scandinavia

Cooperative Research in the Materials Field—Internationally and Nationally: There are many similarities in the materials research interests of the four Scandinavian countries, but national pride works against efforts to pool research or to form one big institute in the interests of greater efficiency. Any new cooperative venture has to take into account the materials research activities that already exist as well as the geographic distribution of materials-related activities (the trend is toward greater geographical spreading of industry).

Thus, each country probably has to support one or more centers of excellence in materials research. This must necessarily involve a degree of specialization to avoid undue overlap, and for the same reason, cooperation at the management level is needed.

In addition, to facilitate the transfer of research information to user organizations the latter must have comparable expertise and must therefore conduct some of their own research.

For several years, a group of Danish scientists sought support among several of the smaller European countries (e.g., Belgium, Denmark, Finland, Iceland, Luxemburg, Netherlands, Norway, Poland, Sweden) for setting up an interdisciplinary organization for graduate education and research in materials. They noted that few European institutes were organized to cover the broader field of materials research, whereas in the U.S. there was a concerted effort to establish materials research at the universities. It was proposed that such a center could serve as an important supplement to the existing university systems and might represent innovation in advanced education and research. Staff and students in such a center might acquire a broad understanding of the interrelationship between science and human, welfare; they could benefit from association with scientists from many different disciplines; and a rich environment for creative ability should result.

In the proposal, five research divisions were suggested—Materials Preparation, Structure and Morphology, Electron Physics, Studies of Dislocations and Corrosion Problems, and Materials Theory. Emphasis was to be on fundamental research but with an openmindedness towards practical applications.

It was visualized that the administrative organization might be patterned after that at CERN. An essential feature was that the center would be located close to an existing or prospective university and in or near a major city.

To conclude, although the Danish government has supported the proposal, widespread agreement from other governments has not been forthcoming.

All the Scandinavian countries are attempting to stimulate and create new industry, but government-university-industry cooperation is most evident in Norway and Finland. The technical university plays a role in Denmark and a lesser role in Sweden.

Norway: SINTEF, the Engineering Research Foundation at the Technical University in Trondheim, employs 475 full-time people (200 professionals). It is an integral part of the Technical University (which employs 1100 including 544 faculty members). SINTEF employs many of the faculty members on a parttime consulting basis. Electronics and computer application comprise 60% of the technical effort, the remainder being largely in chemistry, metallurgy, hydraulics, and tool and production engineering.

Some new venture firms have been formed as a result of work in the Automatic Control Division—one of these companies produces computerized typesetting systems. An interesting feature is that product development goes on in the university laboratories on behalf of the private company.

A similar close-working relation is found near Oslo—a company formed in 1965 to produce integrated circuits and semiconductor devices that was spun-off from the university-industrial research institute combination. Again one finds prototype development and production being carried on in the academic institute. Another new company that resulted from this interaction produces medical instrumentation. The university-institute arrangement has also made valuable contributions to the shipbuilding industry (computer-controlled flame cutting of steel plate) and the electric power industry (explosive joining of electric power lines). Risk capital for all these ventures stems from existing industries and the government.

Finland: At Helsinki the State Center for Industrial Research is located on the campus of the University of Technology. Some of the laboratory heads at the Center are professors at the University and some of the University laboratories are used for industrial research, some product development and even some manufacture of products for sale. Spinoff companies are encouraged, and much of the early work of such a new company continues in the University laboratories. The laboratory does, of course, serve its primary purpose of research and educational functions and has several candidates working on their Ph.D. thesis.

Denmark; The Technical University has led to some spinoff firms. For example, the Laboratory for Semiconductor Components has generated a company aiming to exploit ion-implantation techniques and is making semiconductor counters and pressure transducers. Another spinoff company from the same laboratory produces chemical reactors for the oxidation and doping of silicon.

Sweden; The role of the technical university in Sweden is rather different from that in the other Scandinavian countries. Strong technical departments are building up at the Royal Institute of Technology which reports directly to the Swedish Board for Technical Development. Sweden's posture therefore appears rather traditional, maybe because Sweden is larger and more heavily industrialized than the other Scandinavian countries. Thus, the larger firms may be able to afford more of their own research (e.g. Volvo and Saab— automobiles and aircraft; SKF—ball bearings; ASEA—Sweden's counterpart to General Electric; and L.M.Ericsson—the world's second largest telephone manufacturer).

The Size of Industrial Research and Development Organizations

In the mid-sixties, the OECD gathered data[16] on R&D efforts as a function of size of firm in various countries. Among the findings:

(a) In the larger industrialized countries, the major fraction of a country's industrial R&D is undertaken by a comparatively few large firms.
(b) The average expenditure per qualified scientist and engineer on R&D increases with company size.
(c) On the other hand, the "research intensity," as measured by the ratio of R&D personnel to total personnel, tends to be higher in the smaller firms than the larger. Several reasons for this were suggested:

(i) "Small- and medium-sized firms are obliged to employ a relatively large number of researchers if they wish to stand up to the competition of large companies. Apparently a threshold exists below which R&D is not profitable."
(ii) Large companies may provide higher salaries to research workers than small companies, perhaps partly due to employing more highly qualified (Ph.D. instead of B.S.) personnel.
(iii) Research workers in small companies may often spend less than full time on research, in contrast to the situation in large companies.

(d) The size of R&D programs, regardless of firm size, can vary considerably according to the nature of the activity.

This point is worth amplification. The size of the R&D effort needed to bring to fruition a new material process is probably quite different from that required for a communication network. Table 8.46 suggests how typical sizes of R&D departments may vary. For any given area of technology there seems to be an approximate lower limit to the size of an R&D effort in order to be viable.

(e) "There appears to be a very close relationship between the size of the firm and both the average number of researchers employed and the average expenditure per scientist."

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[16] Gaps in Technology—Analytical Report, OECD, Paris, 1970.

Table 8.46 Suggested Typical Sizes of Research and Development Staff According to Area of Technology

1–10	10–100	100–1000	1000–10,000
Food items	Paper	Automobiles	Nuclear reactors
Drinks	Textiles	Advanced machine tools	Aircraft
Leather goods	Modular houses	Polymers	Missiles
Stone products	Consumer goods	Prosthetics	Communication networks
Wood products	Machinery	Computers	Large computers
		Electronic components	

(f) In international comparisons at the large-company level, average R&D expenditure per firm is much larger in the U.S. than in Europe, whereas at smaller-firm level, they are about the same.

The OECD study goes on to observe that:

(i) "The smaller firms first obstacle to the launching of an R&D program is the average cost per researcher, which remains relatively high, multiplied by the minimum number of qualified scientists and engineers required." Larger firms have greater facility than small ones for self-financing or drawing on outside sources. Also, the risks inherent in achieving long-term profit-ability of research weigh more heavily on the smaller firms.
(ii) "In basic research the role of large firms is overwhelming."
(iii) Possibly, "the large firm is better equipped than its smaller counterpart to sustain both the financial burden and the risks occasioned by the time-lapse necessary to find a practical industrial application of the theoretical knowledge acquired in basic research. It is wise for a small company to limit its R&D activity to projects which will become marketable within a short time limit and whose success is virtually assured. In addition, theoretical knowledge is more easily turned into a profit-making proposition by the large firm because of its greater diversification. A further advantage for large companies is the relative ease with which they can move into foreign markets. It is certain that the narrow limits of some domestic markets discourage a number of firms, particularly those in the smaller classes."

In a recent detailed study* of factors determining success or failure in innovation in the chemical and scientific instrunent industries, it was concluded that the most important size factor was the size of the project team at the peak of the R&D effort rather than the size of the firm or the size of the R&D department. Clearly, large firms can support more above-critical-size R&D projects than smaller ones; they thereby avoid "putting all their eggs in one basket" and, in addition, with a larger diversity of product interest there is more likelihood that any given R&D project will find an outlet somewhere in the range of product interests. Furthermore, with the increasing complexity and sophistication of science and engineering, it is likely that the full innovation process, from R&D to successful commercialization, will increasingly be concentrated in the larger companies in the future.

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*"A Study of Success and Failure in Innovation", (Project SAPPHO), carried out at the Science Policy Research Unit of the University of Sussex in England.

TECHNOLOGY ENHANCEMENT PROGRAMS

General

Because all advanced countries are concerned to remain at the forefront of technology, recognizing the connections between technological prowess and national prosperity, they invariably undertake government-motivated efforts to enhance technology. The feeling in the U.S. is that, while we have concentrated much on defense and space, other countries have deliberately pushed to upgrade their civilian-oriented technologies. As we have seen, the differences in net effort in these areas between the U.S. and other countries are not as great as might be imagined. Nevertheless, other countries have experimented with a number of mechanisms for implementing civilian science and technology, and it is wise to review these attempts in order to assess whether any have lessons for the U.S.

It is usually impossible to separate out, for a given country, a special national policy aimed at materials technology as distinct from policies for technology in general. We shall therefore review these broader policies, keeping in mind whether they will have special relevance to the materials field.

A particularly valuable review of “Technology Enhancement Programs in Five Foreign Countries”, (Canada, France, Germany, Japan and the U.K.) has been provided recently by the Department of Commerce (COM-72–11412). Among its findings:

“The effectiveness of technology enhancement programs appears to be greater in those countries in which national science and technology (S and T) policy and goals, particularly as they affect designated industries, are welldefined and less subject to change. In Japan and France, governmental involvement in the formulation of S and T policy and the implementation of technology enhancement programs has been direct and substantial, in Germany less so, but still significant. In Canada and the U.K., doubt about the nature and extent of government involvement may have contributed to the lack of effectiveness of several such programs.”

On an organization for implementing policy:

“Effective management of technology enhancement programs seems to require the establishment of an S and T agency at the highest level of government to perform a planning and coordinating function for the S and T programs of all the other agencies in the government.”

And on attitudes:

“Open channels of communication and mutual trust between representatives of government agencies and the private sector are essential elements for effective operation of technology enhancement programs.”

All five countries maintain broad technology enhancement programs to improve the entire industrial spectrum. These programs offer a variety of incentives such as tax credits, accelerated depreciation allowances, low-interest loans, and outright grants for the direct support of R&D.

Programs for supporting designated areas and industries exist in four of the five countries. These areas, generally regarded as of high risk, great cost, and beyond the means of private companies, include atomic energy, space and ocean development, computers electronic data processing, and telecommunications. In some cases, the government has offered substantial benefits and incentives to the private sector to engage in mergers for “industrial rationalization” and to increase competitiveness.

Many mechanisms and incentives are used to encourage the commercialization, utilization, and diffusion of newly-developed technologies and products, particularly through modernization of plant and increasing productivity. This forms part of a continuous process of industrial technological renovation. The approaches include, e.g., the Preproduction Order Support Program and Investment Grant Program in the U.K., and first-year depreciation allowances and tax deductions on newly-acquired fixed assets (Japan).

“The stimulation of invention and innovation and the commercialization of research findings that are in the public interest and appear to have a good industrial potential have received strong support by the governments of the five countries. All have established a special agency to deal specifically in this area. All five agencies underwrite part or the full cost of developing a new technology or product and require repayment of their investment plus the payment of royalties only in the event the venture is successful.”

Other mechanisms for enhancing technology found in one or more of these countries include special government-supported independent lending agencies to provide development funds, and incentives for stimulating R&D, particularly for small- and medium-sized enterprises.

“The establishment of research associations and joint ventures both among private firms and between a government agency and one or more private firms is generally encouraged and supported whenever such action is likely to stimulate greater R&D activity or develop a needed new technology. Such arrangements are condoned in the interest of avoiding duplication of R&D, pooling resources, and spreading the risks.”

The study warns that:

“A high level of funding provided for the implementation of a specific technology enhancement program does not necessarily ensure success or accomplishment of objectives. Several technology enhancement programs in the five countries have not been successful in spite of the availability and spending of large amounts of money; e.g. Investment Grant Program, Financial Support for R&D in Industry, and Launching Aid (U.K.), Plan Calcul (France), IRDIA (Canada), New Process for Olefin Products (Japan). Fear of government interference and excessive ‘red tape’ were the principal reasons given by the private sector.”....“On the other hand, several technology enhancement programs have been successful-after only a short period of operation, suggesting that, more than anything else, the inherent characteristics of a program rather than either duration or level of funding determine its effectiveness.”

Some Specific Mechanisms for Technology Enhancement in Various Countries

In this section, we summarize some of the more important mechanism in various countries that have been used for catalyzing the technology transfer out of the research phase and through development into the commercialization phase. Those marked with an asterisk are regarded as particularly successful.

Canada

The cost-effectiveness of governmental investment in R&D has been controversial and it was felt there had been a failure to coordinate efforts. A Ministry of Science and Technology has now been established. The government interacts with industry through technology enhancement programs, through full or partial ownership of some enterprises, and through joint capital ventures. However, industry tends to be reluctant to cooperate through fear of governmental control and intervention. There is a need for improved communications and relations.

The principal instruments for technology enhancement are:

National Research Council (NRC) ($134M): This is a crown corporation influential in matters of science policy. Its main purpose is to serve the R&D needs of industry.

*Industrial Research Assistance Program (NRC) ($44M from 1962–1972): This program provides grants for salaries of scientists and engineers on approved R&D projects (Pharmaceuticals, chemicals, food products, aircraft, iron and steel industries).

The program is regarded as successful by industry and government.

Canadian Patents and Develpments Ltd.: This subsidiary company of NRC acts as the governmental patent and licensing agency. It may fund part of the costs of developing patents.

*Program for the Advancement of Industrial Technology (Department of Industry, Trade and Commerce) ($57M from 1965–1972): This program provides direct financial assistance to industry for development, manufacturing, and the marketing of products and processes. Companies receive not more than 50% of the total estimated cost of the project. Patents remain the property of the company.

The program is well received by industry.

Industrial R&D Incentives Act (Department of Industry, Trade and Commerce) ($34M annually); This program is generally aimed at assisting current R&D rather than stimulating new R&D. It supports up to 25% of capital expenditures on R&D, thereby easing the financial burdens to industry of maintaining R&D facilities.

France

The trend in recent years and in the current five-year plan is towards greater pragmatism in the support of R&D. High-technology industries (electronics, chemicals, measurement instruments) are still being given priority, but emphasis on selected industries is being reduced in favor of more broadly applicable R&D.

The General Delegation for Scientific and Technical Research (DGRST) is the central agency, under the Ministry for Industrial and Scientific Development, for coordinating public and private research proposals. Among the governmental agencies, highest priorities are given to atomic energy, space, oceanography, telecommunications, and governmental research laboratories, It also dispenses research contracts to industry.

Government-industry relations are influenced by the fact that the government owns a significant fraction (wholly or in part, the government owns 10% of all industrial output). Consequently, there is much regular consultation between government and industry.

The principal instruments for technology enhancement are:

*Concerted Actions Program (DGRST): This arrangement provides a 100% grant for up to 5 years in a cooperative program for industry with university and governmental laboratories. A requirement is that a project cannot be undertaken by existing governmental apparatus, i.e. it is interministerial or interagency. Development loans can be granted for following-up; these are reimbursable only if the project is successful.

The program is generally felt to be successful, particularly in enhancing university and industry cooperation.

*Aid-to-Development Program (DGRST) ($42M in 1972): The aim of this program is to facilitate development of new products, processes, and materials that appear economically promising. It pays 50% of total cost of the project, and provides for reimbursement if successful. Important factors are: the degree of foreign competition and foreign-government support of competitors; the degree of fragmentation of industry; the degree of risk; the social benefits from the project.

The program is regarded as successful, and is attractive to industry.

Letter of Agreement: This mechanism is for encouraging large projects entailing substantial initial production costs. The government guarantees the difference between sales and break-even points. Major projects so far have included the Caravelle aircraft and computers. Interest in the scheme is increasing.

Agence Nationale de Valorisation de la Recherche (ANVAR) ($3M in 1972): This independent public corporation aims to stimulate invention and innovation. It collects research results, inventories from public and private laboratories (especially universities and government laboratories), and from these selects and offers invitations to industrial firms likely to make best use of them. It also helps inventors find the best company for handling the development and commercialization. ANVAR may assume the whole or partial costs. It is partially supported by royalties from inventors it sponsors; the rest comes from the government.

The program is regarded as moderately successful, doing about as well as might be expected. Some have criticized it, though, for trying to fit industrial needs to existing technologies rather than the other way round.

Germany

During the 1960's, federal support for science and technology was concentrated in the big science areas of nuclear energy, space research, civil aviation, and data processing. But in recent years, emphasis has been shifting from one of reacting to foreign technological achievements and towards the solution of social problems. There is a complex of interactions between the federal government, industry and universities, and at the federal-state level for overall policy, education, basic research, and the promotion of science. Likewise, there is a host of coordinating organizations and committees.

The principal instruments for technology enhancement are:

Privately-Operated, Publicly-Supported Organizations: The German Research Society (DFG) supports basic research in the universities. The Max Planck Society supports basic research, and the Fraunhofer Society supports applied research in their own laboratories. The Confederation of Industrial Research Associations conducts industrial research in its own laboratories.

Federal Support for Research and Development: Industrial R&D can be supported up to 50% from governmental grants, with the patent-ownership generally retained by the company.

Low-interest loans are available for small or medium-sized firms with repayment excused in cases of failure.

Joint industrial ventures for R&D are permitted, often encouraged, particularly through the mechanism of cooperating firms forming a jointly-owned subsidiary.

Direct and indirect federal support has been available for large ventures such as nuclear energy, space research, civil aviation, data processing, oceanography and ocean resources, and environmental protection. Recent emphases embrace communications, transportation, health, food, and the environment.

Japan

After World War II, Japan recovered and advanced its technological base by relying heavily on: (i) importing, modifying, and assimilating foreign technology, (ii) heavy governmental subsidies to industries, and (iii) the dedication of its people. Managing the national program resulted in a complicated system of interlocking agencies, advisory councils, quasi-public corporations, industrial R&D laboratories, and technology enhancement schemes. Perhaps the most remarkable feature of the Japanese scene is the highly cooperative relationship between government and industry.

At the government level, the principal agencies concerned with technology enhancement are the Science and Technology Agency (STA) and the Ministry of International Trade and Industry (MITI). The STA is concerned primarily with science and technology policy, budget planning, and the overall coordination among ministries. MITI, through its Agency of Industrial Science and Technology (AIST), promotes R&D in mining and manufacturing, co-ordinates the R&D of affiliated institutes and laboratories, manages national R&D projects, exercises authority over technology imports, exercises authority over tax and other incentives to channel support to designated industries in the national interest, and balances the needs for technology imports against the protection of domestic industry.

The principal instruments for technology enhancement are:

*Research and Development Corporation of Japan (JRDC) ($6.5M in 1971): Ten to fifteen high-risk scientific projects are selected for support each year out of proposals submitted by universities, and public and private institutions. It funds 60–80% of the cost, and failures are written off as a loss. If successful, the commissioned company repays the investment, interest-free, within 5 years. Royalties from the firm are shared between JRDC and the inventor.

The program is regarded as exceptionally successful. Developments are 90% successful and two-thirds of the current operating budget derives from repayments and royalties.

*National Research and Development Program ($38M in 1972): This program provides full subsidies for projects urgently needed by the nation and which can lead to building new industries. Current projects (1972) include: MHD generator; high-performance computers; desulfurization process; sea-water desalinization and resource recovery; remote-controlled undersea oil drilling rig; electric car; pattern recognition systems; and turbofan aircraft engine.

The program is operated by MITI and is regarded as successful. All major firms are involved, cooperating fully with the government.

Joint Government-Private Sector Technology Projects: Large projects, accorded high funding and priority, are usually organized as quasi-government “corporations under special charter” established especially for the purposes. These corporations may eventually qualify for loans from the Japan Development Bank. Private-sector funding participation varies from a token 3% up to about 50% depending on total cost, risk, etc. The government solicits proposals from companies for projects, preferring to deal with large conglomerates because of their R&D expertise. Funding usually covers development up to final prototype or prototype plant, and there is close day-to-day contact and working relations between government and industry.

Projects given high priority include: Atomic Energy ($182M in 1972—to develop power reactors, nuclear fuel and uranium resources, reprocessing of spent fuel, and nuclear ship); Space Program ($78M in 1972—to develop, launch, and track scientific satellites and develop launching rockets); and the Ocean Development Program ($29M in 1972—to develop a remote-controlled oil-drilling rig, survey the Japanese continental shelf, develop acquacultural techniques, establish experimental facilities, and develop engineering techniques for marine structures.

United Kingdom

The British Government set up a Department of Scientific and Industrial Research (for supporting applied R&D) as long ago as 1916. Research Associations to foster R&D throughout various industries proliferated in the 1920's. Under the Labor Government in the 1960's, the overall responsibility and coordination of these applied R&D activities were assumed by the Ministry of Technology.

Policies of centralization versus decentralization tend to vacillate according to the political party in power. Under the Labor Government, the Ministry of Technology acquired sponsorship for virtually all electrical, electronic, and mechanical engineering industries. The Conservative Government replaced "Min Tech" with the Department of Trade and Industry and proceeded to decentralize government support for R&D, with the control over R&D reverting to mission agencies. Except for new programs, the new policy was one mainly of "hands-off" instead of one with the government seeking to lead, control, and stimulate R&D in industry.

The government tends to formulate science and technology policy with relatively little input from industry. Industry cooperates more in implementation of the policy, as handled through the Department of Trade and Industry.

The principal instruments for technology enhancement are:

*Preproduction Order Support Program (DTI): The aim of this program is to accelerate adoption of technologically-advanced equipment (especially machine tools) by industry. The DTI buys tools and lends them free to potential purchasers or users. A typical purchase is 3–4% of projected total sales in 3 years. The user subsequently has the option of purchasing at substantial discounts.

The program is regarded as highly successful. Both the machine tool suppliers and users have benefited.

Investment Grant Program (about $1.3B per year); The aim was to provide incentives for increased capital investment in machinery and plant for particular industries e.g., computers, ships, hovercraft. The new government in 1970 started phasing out the program in favor of tax incentives to promote higher investment.

The Conservative Government felt the program involved high public expenditures and did not achieve intended objectives. Furthermore, the program benefited firms whether or not they were profitable and discriminated against service industries.

Financial Support for R&D in Industry (DTI) ($9.3M); This program seeks to aid small firms and research associations which cannot afford the costs of sustaining R&D programs themselves. The DTI contribures 50–100% of the cost.

The program has been of some benefit to industries but is not a financial success itself.

Grant Program to Research Associations ($11M): This program provides financial help to groups of companies with similar interests to set up research associations. Grants are for 5-year periods and the amount is related to the amount contributed by industry. Some special, nonrecurring grants are also given.

The objectives are more or less achieved, but the value to small firms is limited because not many participate.

Launching Aid: This program provides interest-free loans for civil aircraft and engine development. The amount lent is proportional to the estimated development costs and is repaid by levies and sales, usually less than 50%.

Several successful products have resulted, but the program is not regarded as a success by the government. Alternative means of support are being sought.

Programs of Assistance to Computer, Electronics, and Telecommunications Industries: The purpose is to establish and maintain viable industries in these three areas. The aid is short- to medium-term as the government wishes to avoid continued support.

*National Research and Development Corporation (NKDC) (~$19): This quasi-government corporation, which started in 1949, is now a major force. It aims to develop and exploit inventions and support research likely to lead to inventions. NRDC acts commercially and expects its investment back, with a profit, if the venture is successful. It licenses industrial firms to exploit public sector inventions and pays the full costs of further development if it considers chances of recovering the investment to be good. NRDC enters into joint development projects with firms, when it usually contributes 50% of the costs and usually requires royalty payments. NRDC gets involved in about 500 inventions per year and supports about 120.

NRDC is universally considered successful. It is now operating in the black and further government input is regarded as unlikely to be necessary. The benefits to industry are numerous and include the development of new technologies and products, increased competitiveness in world and domestic markets, increased productivity, employment, production, sales and exports.

Some further details:

Over 25,000 inventions have been submitted since 1949. Of these, about 6k000 have been accepted for development and/or licensing. A substantial part of NRDC's income, however, is derived from a comparatively small group of inventions, the primary one being in the pharmaceutical industry. The phenomenon is not unexpected, for NRDC is usually concerned with projects entailing a high degree of risk, and has been referred to as the "lender of last resort".

The success of NRDC has led many other countries to adopt similar plans; these countries include Australia, Canada, France, India, Japan, New Zealand, and South Africa.

Factors considered important to the success of NRDC include: (i) the time element, in that sufficient time is necessary for a program of this sort to "bear fruit", (ii) the structure, in that NRDC is not in the Civil Service, and (iii) the selection of the portfolio of projects to be sponsored.

About 10% of the supported projects have been exploratory, i.e. leading to inventions. About 75% have led to development of inventions, and the remainder to the production of commercial products.

Projects have included hovercraft, computers, fuel cells, flexible barges, pharmaceuticals, cryogenic engineering, diesel engines, variable speed gears, potato harvesters, automatic foundary equipment, photo-typesetting, electrochemistry, plastics, computer time-sharing systems, stored program telecommunications control, printed circuits, and many more.

Some Broad-Gauge Factors and Policies Affecting Technology Enhancement

Most of the mechanisms discussed in the preceding section can be regarded as capable of being oriented towards specific national needs. There are a number of broader-gauge government policy options available to enhance industrial efficiency generally, and these, in turn, often reflect national and societal attitudes towards technology. These options and factors include:

(a) Miscellaneous Lending Agencies: All countries field an array of lending banks and other agencies for financing industrial development and facilities. These are often aimed at small- and medium-sized firms and can be at favorable terms, such as in Japan through the Japan Development Bank. The World Bank performs a similar function on an international scale, aiming especially at the smaller and developing countries.

(b) Tax Exemptions and Incentives for R&D: Most countries employ tax incentives to stimulate R&D. Canada exempts R&D from taxable income, uses accelerated depreciation allowances for machinery and manufacturing equipment, and eliminates sales taxes on scientific equipment for product development and testing. France and Germany use tax incentives to promote industrial R&D. Japan allows a 25–50% tax deduction on R&D expenses; first-year accelerated depreciation up to one-third of the acquisition cost of the equipment and facilities; and a 50% tax deduction on newly-acquired fixed assets, including buildings, during the first three years following purchase.

(c) Government Procurement: Government procurement programs to stimulate industry are employed in several countries. France uses such schemes to provide advance credit for financing R&D and for protection of selected industries from foreign competition. The Preproduction Order Support Program in the U.K. has already been mentioned.

(d) Patent Policies and Rewards: Patent ownership in publicly-aided R&D programs varies from country to country, and with the type of program. In some programs the patents remain the property of the inventing firm (e.g., the Program for the Advancement of Industrial Technology in Canada). In some, rights to them are shared with the government (e.g., Research, and Development Corporation of Japan), and in others the patents become the outright property of the sponsoring agency (e.g., some projects sponsored by the National Research and Development Corporation in the U.K.). In Japan, patents that result from government-funded R&D belong to the government and may be licensed to any company on a nonexclusive basis with royalties going to the government. Exceptions are patents obtained under the National R&D Program which can be exclusive to the participating company for the first two years.

(e) Governmental Ownership: The degree of governmental ownership of industry varies considerably from country to country. Partial or full governmental ownership is found in Canada, France, and the U.K. In France, about 10% of all industrial output results from government-owned industry and about 30% of French investment is government-funded. In the U.K., the government owns half of a major oil company, while some industries, such as coal and steel, are fully nationalized. It is impossible to generalize as to the effectiveness of government-ownership in improving industrial efficiency and competitiveness. In some cases, the industrial sector had become so run down, poorly managed, or fragmented, that nationalization seemed the only way to upgrade them. However, once restored to financial health, the reverse process of returning such industries to the private sector is conspicuous by its absence. In other cases, where governments have been tempted to take over successful enterprises, it is by no means obvious that any further improvement or national benefit has resulted.

(f) Policies Towards Consortia and Mergers: Most countries outside the U.S. take a rather liberal view towards industrial mergers and the formation of consortia. The argument is that large concentrations of industrial strength put the country in a more competitive position versus foreign enterprises. As a result, mergers and consortia are not only often condoned but actively encouraged by the government. It is felt that such concentrations help avoid duplication of research, and allow the pooling of resources as well as the spreading of risks.

(g) Government-Industry Partnerships: In several countries, one can find examples of government and industry forming commercial partnerships, usually with the aim of creating or exploiting export markets. In the face of such strong partnerships, industries in the United States have often felt at a definite disadvantage. Japan is regarded as the principal exponent of this approach.

(h) National Spirit: Despite all the exhortions and conscientious efforts of governments to enhance technology and, thereby, economic strength, in the last resort much depends on the attitudes of the people. Most nations, given inspiring leadership and/or recognition throughout the population of the urgent need, can respond to the call for greater effort. The peoples of Germany and, especially, Japan seemed to sense for themselves the need for exertion after World War II to rebuild their shattered economies. Churchill during World War II was able to count on great efforts by the British people because they knew survival was at stake. DeGaulle was able to count on the psychological need of the French to restore their national pride. The problem in the U.S., until recently at least, is that the people have not really felt a sense of national urgency about the economy or survival. And probably such national urgencies are needed for inspiring leadership to emerge.

RESULTS OF SCIENCE AND TECHNOLOGY POLICIES

The fruits of the efforts put into education and R&D in various countries should be visible today, assuming there is some correlation. In this section, we will review some of the indicators of innovational prowess.

Economic Comparisons

Table 8.47 gives some data on per capita and real GNP. The per capita figures show: the strong progress made by France and Germany to their current position only slightly short of the U.S.; the rapid growth of Japan from a point low compared with the major industrial countries of W. Europe in 1960 to its current position somewhat ahead of the U.K., but still some way behind France, Germany and the U.S.; and the almost static performance of the British economy. The data are normalized to the U.S. being 100 each year; but the GNP of the U.S. has been rising also—taking it as 100 in 1960, in 1965 it was 127, and in 1973 it was 172. In these terms, it can be concluded that the U.K. has roughly maintained its position relative to the U.S. while the other countries have improved their positions considerably. On the other hand, the data on growth rates of real GNP, with the latter normalized to 100 for each country in 1960, show that since 1960, the U.K. has achieved a slower growth rate than the U.S.; Germany has performed about the same; France has performed somewhat better; and Japan dramatically so. All these trends, however, have to be interpreted carefully, taking cognizance of the caution mentioned earlier in this chapter that at any given time different countries are at different positions on their "sigmoidal curves" and that it is misleading to interpret data always in terms of exponentials (like compound interest rates), even if only implicitly. For example, the major shifts in world resources triggered by the rise in price of oil and the possibility that similar effects might take place with mineral resources could result in major changes in the economic picture in a relatively few years.

More detailed comparisons on economic trends are given in Tables 8.48 and 8.49. The caution about sigmoidal curves again applies. Furthermore, growth rates show relatively large fluctuations from year to year so that the figures for a single year are not necessarily a good basis for comparisons. However, the trends over ten years show the dominance (in growth terms) of Japan followed by France and Germany, while the U.K. and U.S. have generally trailed along on rather paralleled courses.

Because of inadequate data and analysis, it is difficult to establish. definite cause-and-effect relationships between national commitment levels to R&D and subsequent industrial and commercial performance. (Regression analysis of this sort for various industrial sectors in various countries would appear a fruitful area for investigation.) Most direct comparisons between the larger industrial countries become confused by the enormously different levels of effort on defense and space among these countries. These efforts and their associated spin-offs affect not only the levels of R&D but also the whole industrial picture.

Some productivity comparisons for the iron and steel industry since 1964 are given in Table 8.50 (from "Productivity and the Economy, 1973; Bulletin

Table 8.47 Relative GNP Performance*

	1960		1965		1973[#]	
	Per Capita	Real	Per Capita	Real	Per Capita	Real
France	47	100	58	133	83	208
Germany	46	100	56	128	92	179
Japan	17	100	26	161	60	367
U.K.	48	100	52	118	53	146
U.S.	100	100	100	127	100	172

*From “International Economic Report of the President,” transmitted to the Congress, U.S. Government Printing Office, Stock No. 4115–00055, February 1974,

#Estimated. Based on the average monthly rate of exchange for 1973.

Table 8.48 Economic Trends—Average Annual Rate of Growth (Percent)

	1961–72	1971	1972	1973*
Real GNP:				
United States	4.1	3.4	5.9	5.9
United Kingdom	2.7	2.3	3.8	5.8
France	5.7	5.7	5.4	6.7
West Germany	4.5	3.1	3.7	5.3
Japan	10.5	5.9	8.9	11.0
Industrial Production				
United States	4.7	0.6	6.7	9.0
United Kingdom	3.1	0.8	8.3	8.6
France	5.9	6.2	7.0	9.5
West Germany	5.2	1.7	3.4	7.6
Japan	12.3	3.3	6.6	17.4
Consumer Prices				
United States	3.0	4.5	2.9	6.2
United Kindgom	4.7	9.5	7.5	9.3
France	4.5	5.3	6.3	7.1
West Germany	3.2	5.3	5.8	7.0
Japan	5.8	6.2	4.8	11.7

*Estimated.

	1961–72	1971	1972	1973
Productivity*				
United States	3.5	7.1	5.3	5.4
United Kingdom	4.2	5.0	8.3	3.0
France	5.7	4.8	7.2	8.0
West Germany	5.8	4.7	6.7	7.6
Japan	10.1	3.6	10.1	18.8
Hourly Compensation#				
United States	5.1	7.0	6.3	8.0
United Kingdom	8.3	12.4	12.3	13.6
France	9.9	12.4	12.5	13.0
West Germany	9.9	13.8	11.1	12.8
Japan	14.5	15.7	16.2	20.8

*Output per man-hour.

#Based on hourly compensation in national currencies,

Table 8.49 Rank in Each Category of Economic Performance Indicators

Growth Rate in	France		Germany		Japan		U.K.		U.S.	
1961–72	1973	1961–72	1973	1961–72	1973	1961–72	1973	1961–72	1973	
Real GNP	2	2	3	5	1	1	5	4	4	3
Industrial Production	2	2	3	5	1	1	5	4	4	3
Consumer Prices	3	3	4	4	1	1	2	2	5	5
Productivity	3	2	2	3	1	1	4	5	5	4
Hourly Compensation	2	3	2	4	1	1	4	2	5	5

Table 8.50 Productivity Comparisons in the Iron and Steel Industry*

Country	Index of output per man-hour: 1964=100			Relative output per man-hour: U.S.=100#		
1964	1970	1971	1964	1970	1971	
United States	100.0	104.8	108.8	100	100	100
Japan	100.0	232.6	234.2	43.54	96–119	93–116
United Kingdom	100.0	115.3	110.6	46–50	51–55	47–51
France	100.0	148.2	147.6	48–51	68–73	65–70
Germany	100.0	139.6	137.0	54–63	73–84	68–80

*"Productivity and the Economy," 1973, Bulletin 1779, U.S. Bureau of Labor Statistics.

#The data for Japan and the Western European countries are presented in terms of ranges, with high and low estimates, because of data gaps and limitations.

1779, BLS). Quoting, "In 1964, productivity in the U.S. iron and steel industry greatly exceeded the levels reached in other major steel-producing countries. Output per man-hour was about 60 percent of the U.S. level in Germany and around 50 percent in France, Japan and the U.K. In 1971, however, though labor productivity in the British steel industry was still only about half the U.S. level, the French industry was up to two-thirds the U.S. level, the German to about three-fourths, and the Japanese may have exceeded it."

Productivity levels may be considered not only in the light of expenditures on R&D but, and perhaps even more importantly, to levels of capital investment. From the same source as that for Table 8.50, data for several countries are given in Table 8.51 for industry as a whole—breakdowns by industry sectors are difficult to obtain. We quote: "During the 1960's the U.S., Canada and the U.K. had the lowest average capital investment (to productivity. At the other end of the scale, Japan had the highest investment ratio and the highest rate of productivity gain."

Implicit in these comparisons is that the productivity gain is important in itself. However, productivity, like GNP, is not necessarily a human happiness index. While there is probably some correlation between these quantities and qualities, it is not inconceivable that the ground rules are changing for the advanced countries, that they are reaching the upper levels of their sigmoidal curves and that their societies may soon come to feel that they have enough productivity and GNP to satisfy their own desires. This still leaves scope for greater productivity if the increase benefits a wider circle of nations.

International Trade

The U.S. has traditionally been a net exporter, based in its earlier history on materials and then slowly shifting to manufactured goods, beginning in the mid-1960's, this position began to erode and lately has produced substantial adverse trade balances. Contributing factors have been:

(a) Reduced productivity growth and high rates of inflation, resulting in favorable unit costs of production, cpmpared to other industrial countries. This has attracted imports and created obstacles to exports.

Table 8.51 Trends in Capital Investment

	Average annual percent change in output per man-hour in manufacturing, 1960–72[*]		Capital investment as percent of output, 1960–70
		All Industry	Manufacturing
United States	3.1	[#]14.5	12.3
Belgium	6.6	19.9	19.6
Canada	4.4	21.0	15.1
France	5.8	21.2	N.A.
Germany	5.8	[+]22.2	N.A.
Italy	6.0	17.9	N.A.
Japan	10.4	28.1	31.4
Netherlands	7.2	21.4	N.A.
Sweden	7.1	18.8	16.7
United Kingdom	4.2	16.6	13.4

Source: Bureau of Labor Statistics, Bulletin 1779, Washington, D.C.

[*] For many of the foreign countries, 1972 estimates are based on data for less than the full year.

[#] Excludes construction.

[+] Capital investment, excluding residential dwellings, as percent of total output,

(b) Rapid growth of direct U.S. investment abroad, largely in order to overcome competitive disadvantages of U.S.-based exports.
(c) Final fruition of postwar recovery period in Europe and Japan, making these areas highly efficient competitors, equipped with new plant and technology.
(d) More rapid diffusion of new technology and corresponding shortening of time during which U.S. innovations provide trade advantage.
(e) Outside of the agricultural sector, increasing drafts on foreign raw materials in order to benefit from their lower costs.

These developments, coming on top of U.S. foreign commitments such as military costs and foreign aid, plus prolonged U.S. reluctance to engage in currency devaluation, have brought about an atmosphere of concern bordering at times on crisis. In this context, various attempts have been made to locate “the key” to the foreign trade problem.

While one must not fall into the trap of segmenting foreign trade and other transactions in such a way as to judge each in terms of balance (the very basis of exchange between countries is, indeed, that each does better in some fields than in others; and so foreign trade is by nature “unbalanced,” on an item-by-item basis), nevertheless a number of recent studies have drawn attention to emerging trends (see Tables 8.52, 8.53 and 8.54). Among these seem to be:

(a) Excellent performance in exports of capital goods, such as computers and aircraft.
(b) Poor performance in automotives and manufactured consumer goods.
(c) Rising adverse balance in materials.
(d) A healthy rate of increase in exports as a whole, but not sufficient to overcome the faster increase in imports.
(e) A concentration of the trade problems in specific nations: Japan, Canada, and West Germany. Excluding trade with these three- countries, the U.S. trade balance with the world improved between 1960 and 1970. With Japan, Canada and West Germany, it worsened by 5 billion between 1964 and 1970.

Table 8.52 U.S. Trade Balance in Illustrative Product Categories*

	(millions)		
	1960	1965	1970
Aircraft and Parts	$1,187	$1,226	$2,771
Electronic Computers and Parts	44	219	1,044
Organic Chemicals	228	509	715
Plastic Materials and Resins	304	384	530
Scientific Instruments and Parts	109	245	407
Air Conditioning and Refrigeration Equipment	135	207	374
Medical and Pharmaceutical Products	191	198	333
Rubber Manufacture	108	119	–28
Textile Machinery	104	54	–37
Copper Metal	–62	–132	–171
Phonographs and Sound Reproduction	15	–36	–301
Paper and Paper Products	–501	–481	–464
Footwear	–138	–151	–619
TV's and Radios	–66	–163	–717
Iron and Steel	163	–605	–762
Petroleum Products	–120	–464	–852
Textiles and Apparel	–392	–757	–1,542
Automotive Products	642	972	–2,039

*Statement of Secretary of Commerce at Hearings before the Subcommittee on Science, Research and Development of the Committee on Science and Astronauties, July 27–29, 1971.

Table 8.53 U.S. Foreign Trade in Manufactured Goods, 1970, and Trade Patterns, 1925–70 (From "Trends in U.S. Trade and Comparative Advantage, "William H.Branson and Helen B.Junz, Brookings Papers on Economic Activity, Vol. 2, p. 285, 1971; Brookings Institute, Washington, D.C.

Dollar amounts in millions

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Fuels and lubricants	$1,596	$3,063	–$1,467	Surplus to 1957; growing deficit since 1958
Nonagricultural industrial supplies and materials, except fuels	9,878	10,695	–817	Steady deficit except 1938–40, 1947 and 1949; slightly increased 1965–70.
Chemicals, excluding medicinal preparations	3,059	836	2,223	Balance prewar; surplus since 1946, growing since 1953.
Nonagricultural industrial supplies and materials less chemicals and fuels	6,819	9,859	–3,040	Deficit throughout except 1940 and 1947; fairly steady 1950 to mid-1960's, growing since.
Basic material for iron and steel	547	509	38	Surplus 1933–40; deficit since 1947 except 1955–57, 1961, and 1970.
Iron and steel products excluding advanced manufactures	1,389	2,193	–804	Surplus to 1962 (except 1959); growing deficit since 1963.
Other primary metals, crude and semimanufactured	1,444	2,408	–964	Deficit throughout the period.

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Finished metal shapes and advanced manufactures	428	464	–36	Surplus narrowing to balance in 1966–70.
Lumber, wood, pulp, and paper, including newsprint	1,782	2,434	–652	Deficit throughout the period, steady since early 1950's.
Industrial textile fibers, yarn, fabric	674	1,008	–334	Deficit prewar, except 1932 and 1940; surplus 1946–64, except 1963, showing postwar bulge; deficit since 1965.
Other nonagricultural industrial materials	555	843	–288	Deficit throughout the period.
Capital goods, less automotive	14,366	3,782	10,584	Surplus throughout the period, growing since 1951.
Electrical machinery	2,078	1,017	1,061	Surplus throughout; rapid import growth since 1964.
Construction and contracting machinery less nonfarm tractors	1,379	536	843	Surplus throughout; rapid import growth since 1960.
Nonelectrical industrial machinery	4,823	939	3,884	Surplus to 1956; deficit in growing since early 1950's with import growth since mid-1960's.
Machine tools and metal working machinery	528	194	334	Surplus throughout, rapid import growth since 1965.

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Industrial machinery less machine tools and metal working machinery	4,295	745	3,550	Surplus throughout with small import growth since 1963.
Agricultural, scientific, and business machinery less tractors	2,521	887	1,634	Surplus throughout, growing since mid-1950's; rapid import growth since 1962.
Agricultural machinery, except tractors	180	177	3	Surplus except 1958–59; near balance since 1966.
Business machinery	1,703	471	1,232	Surplus throughout, growing since 1955; imports picking up since 1965.
Scientific and medical instruments and equipment and equipment and tools for photo and other service industries	638	239	399	Surplus throughout; imports picking up steadily since 1960.
Tractors, nonfarm, and farm and garden tractors and parts	763	212	551	Surplus throughout; rapid import growth since 1958; especially 1966.
Civilian aircraft, engines, and parts	2,661	191	2,470	Little trade to 1952; rapidly growing surplus since.
Complete aircraft, civilian	1,529	48	1,481	Surplus since 1958 (trade began in late 1950's); growing rapidly.

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Civilian aircraft, engines, and parts, except complete aircraft	1,132	143	989	Surplus throughout, growing rapidly since 1952.
Automotive vehicles, parts and engines	3,652	5,955	–2,203	Surplus to 1967, shrinking irregularly 1947–67; growing deficit since 1968.
Passenger cars, new and used	837	3,730	–2,893	Surplus 1953–57; deficit since 1958, growing with rising imports since 1962.
Trucks, buses, and special-purpose vehicles	560	729	–169	Substantial surplus ($300 million) to 1965; import growth brought deficit by 1968.
Automotive parts	2,255	1,496	759	Surplus throughout; imports picking up rapidly since 1965.
Consumer goods, less automotive	2,745	7,551	–4,806	Deficit to 1938; tiny surplus 1938–40 and large surplus 1946–49 dwindling to balance in 1958; growing deficit since 1959.
Consumer durables, manufactures	1,007	4,069	–3,062	Deficit to 1933; balance 1934–36, surplus 1937–40; postwar surplus 1946–54; deficit since 1955, growing rapidly since 1958.

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Electrical household appliances	404	1,455	–1,051	Surplus to 1961; deficit since 1962 with rapid import growth since 1955. Example of product cycle.
Nonelectric cooking and heating equipment	141	587	–446	Deficit before war; surplus 1946–51; deficit since 1952, growing rapidly.
Clocks, watches, jewelry, and antiques	116	614	–498	Deficit throughout, growing rapidly since 1950.
Toys and sporting goods	169	1,129	–980	Little trade before 1946; growing deficit since.
Other consumer durables, manufactured	177	284	–107	Surplus to 1956; deficit in 1957, balance in 1958, deficit since 1959, except 1964. Example of postwar export bulge,
Consumer durables, nonmanufactured	123	495	–372	Deficit throughout the period, growing since 1950.
Consumer nondurables—textiles, except rugs	247	1,246	–999	Deficit 1925–40; postwar export bulge and surplus 1946–54; growing deficit since 1955.

	1970 trade			
Commodity	Exports	Imports	Surplus	Trade pattern, 1925–70
Consumer nondurables, except textiles	1,367	1,711	–344	Prewar surplus; postwar bulge and diminishing surplus to deficit, growing since 1968.
Footwear, luggage, apparel of leather, fur, rubber, plastic	38	793	–755	Balance prewar; postwar export bulge and surplus 1946–54; growing deficit since 1955.
Medicinal and pharmaceutical preparations	545	150	395	Surplus throughout; large surplus opened in 1946; maintained since 1947.
Other consumer nondurables	784	768	–16	Surplus throughout; export bulge in 1946–50; surplus steady 1950–65, shrinking since 1965.

Table 8.54 1970 Industrial Profiles (From U.S. Industrial Outlook 1971, U.S. Department of Commerce)

No.	Industrial Sector	Value of Industry Shipments $M	Employment (thousands)	Exports as % of Product Shipments	Imports as % of Apparent Consumption	Annual Growth Rate (1963–70) % Value of Shipments
1.	Concrete and cement	6,490	189	1	2 to 3	4.1
2.	Fabricated structural Steel	3,850	109	1 to 2	—	10.5
3.	Plumbing and heating equipment	2,400	77	3	—	4.6
4.	Glass containers	1,820	75	1.2	0.3	9.0
5.	Metal cans	3,960	66	0.3	—	9.7
6.	Household appliances	6,212	180	2.6	4.6	5.0
7.	Household furniture	5,104	287	0.4	2.8	6.1
8.	Sporting and athletic goods	1,010	51	6.4	20.0	6.4
9.	Cellulosic man-made fibers	1,011	41	2.7	2.3	4.1
10.	Noncellulosic man-made fibers	2,514	74	5.4	2.4	10.5
11.	Industrial chemicals	16,492	254	10.0	4.6	5.8
12.	Plastic materials and resins	4,500	75	13.9	3.0	8.4

No.	Industrial Sector	Value of Industry Shipments $M	Employment (thousands)	Exports as % of Product Shipments	Imports as % of Apparent Consumption	Annual Growth Rate (1963–70) % Value of Shipments
13.	Synthetic rubber	1,085	13	15	4	5.2
14.	Tires and inner tubes	4,655	102	2	5	6.7
15.	Aluminum	5,300	192	6.8	4.6	9.0
16.	Copper wire and cable	4,050	66	1.2	2.1	10.5
17.	Brass mills	2,870	40	1.1	4.2	8.2
18.	Copper smelting and refining	2,700	16	10.0	6.6	11.7
19.	Steel	18,470	538	7.7	13.8	5.2
20.	Ferrous castings	4,810	230	1.8	0.6	6
21.	Metal cutting machine tools	1,011	70	21	11	6
22.	Metal forming machine tools	451	27	19	7	2
23.	Metal cutting tools	670	37	3.6	1.9	6.3
24.	Farm machinery	4,002	118	10	8	5
25.	Construction machinery	4,100	89	36	2.6	6.2
26.	Mining machinery	684	21	34	1.6	7.3

No.	Industrial Sector	Value of Industry Shipments &M	Employment (thousands)	Exports as % of Product Shipments	Imports as % of Apparent Consumption	Annual Growth Rate (1963–70) % Value of Shipments
27.	Textile machinery	643	35	32	37	2.7
28.	Printing machinery	805	31	21	10	8.7
29.	Materials handling equipment	2,560	87	8.0	4.2	8.5
30.	Pumps and compressors	2,620	79	16.5	3.5	9.2
31.	Air conditioning, refrigeration	4,200	112	9.5	1.0	10.4
32.	Valves and pipe fittings	2,525	96	10.9	3.2	6.1
33.	Ball and roller bearings	1,256	61	9	7	3.3
34.	Consumer electronics	3,300	139	4	30	5.5
35.	Telephone & telegraph equipment	4,056	172	2.1	1.6	13
36.	Electronic systems and equipment	8,400	330	9	2	3
37.	Electronic components	6,080	335	12.8	5.1	6.0
38.	Electric lamps (bulb)	857	32	4	4	6
39.	Lighting fixtures	1,952	65	2	2	5

No.	Industrial Sector	Value of Industry Shipments $M	Employment (thousands)	Exports as % of Product Shipments	Imports as % of Apparent Consumption	Annual Growth Rate (1963–70) % Value of Shipments
40.	Transformers	1,491	39	3	3	10
41.	Power boilers	631	31	9.5	n.a.	8.5
42.	Steam, hydraulic and gas turbines	1,464	38	9	8	11.4
43.	Internal combustion engines	995	72	41	37	8.0
44.	Electrical measuring instruments	1,450	72	17.2	5.1	9.9
45.	Engineering and scientific instruments	1,250	70	14.0	2.7	12.9
46.	Measuring and controlling instruments	1,560	70	21.7	2.0	4.5
47.	Automatic temperature controls	750	41	4.0	n.a.	5.2
48.	Optical instruments and lens	530	18	10.3	18.8	15.5
49.	Surgical and medical instruments	688	32	13	2	11.1
50.	Photographic equipment and supplies	4,280	111	11.5	6.9	12.7

No.	Industrial Sector	Value of Industry Shipments $M	Employment (thousands)	Exports as % of Product Shipments	Imports as % of Apparent Consumption	Annual Growth Rate (1963–70) % Value of Shipments
51.	Business machines	5,350	185	27	11	14
52.	Electronic computers	3,800	65	27	0.6	—
53.	Automobiles	17,900	354	5	21	2.3
54.	Truck and bus chassis	4,235	—	15.9	15.1	12.1
55.	Truck and bus bodies	580	36	1.5	—	4.9
56.	Truck trailers	675	23	2.8	1.2	—
57.	Railroad cars	1,400	33	0.7	0.2	7.8
58.	Shipbuilding and repair	2,730	133	—	—	7.2
59.	Aerospace	24,177	783	15	2	7

In the judgment of the Report to the President of the Commission on International Trade and Investment Policy (July 1971), the competitive strength of the U.S. "…clearly lies in capital goods and other manufactured products involving advanced technology, and in basic agricultural products, while we may expect increasing deficits in manufactured products which do not involve advanced technology."

A mature economy need not be considered in difficulty if it develops an adverse trade balance. Returns from capital investment, payment for services including management and technology supply, and other forms of earning, are ways of paying for import balances. How one views such structural changes depends in part on the magnitude of emerging maladjustments and on the prospects for balance among these factors.

Without attempting to strike a balance among the factors causing our present difficulties and ranking the remedies, one must afford a significant role to any attempts to render those U.S. products more competitive that have the greatest potential for finding ready markets. Past events suggest that these are the products that incorporate a high-technology content and are the result of continuing innovation. This points to the role of R&D and, in the context of this report, especially of MSE R&D.

Materials science and engineering can make significant contributions to U.S. foreign trade, as well as to international concerns over environmental quality and the exploitation of natural resources. These include ways to:

(a) reduce the importation of raw materials and fuels;
(b) develop new processes and manufacturing methods to reduce production costs;
(c) innovate new materials, products, and technologies (particularly in the civilian and low-technology sectors); and create new high technologies especially in fields where labor component is low and technological input high;
(d) reduce deleterious effects on the environment associated with manufacturing processes and the disposal of waste.

On the key question of reducing materials consumption, MSE can contribute vitally by:

(a) improving extraction and manufacturing processes;
(b) finding substitute materials made from more readily available raw materials;
(c) finding economic ways to improve material qualities such as durability;
(d) finding ways to achieve comparable material performance with less material; and

(e) raising the rate of recovery of used materials (recycling).

Patterns of Industrial Competitiveness and Technology Diffusion

There is a familiar pattern in the growth, development, and international diffusion of a technology. At the birth and in the early stages of a new technology, such as solid-state electronics or nuclear-power reactors, the pace of invention is high and the innovating company or country may well achieve a commanding position in the market for its new technology. In this stage, cost is of secondary importance. Later the inventive pace begins to slacken while, at the same time, other companies or countries with the necessary educational level and technical competence, are acquiring the knowledge and skills so that they may catch up. The formerly commanding position of the original innovator is gradually eroded as the relevant technological capability diffuses nationally and internationally. In this stage, where the technology is termed as becoming mature, commercial advantage is kept by, or passes to, that company or country that can most effectively minimize production and marketing costs. In this phase, process innovation can assume more importance than further product innovation.

The early stage of a technology, when the inventive pace is high, is often science-intensive; it is then commonly referred to as a “high technology.” It seems that high technologies, in which the U.S. has been at the forefront, such as aerospace, computers, and nuclear reactors, have been generally associated with international trade surpluses for the U.S. In the more mature stages, the science content of further developments in the technology is usually less and the technology can be referred to as experience-intensive or “low technology.” Such technologies are more readily assimilated than the high technologies by developing countries and are more likely to be associated with trade deficits since these countries usually enjoy lower costs, primarily through lower labor rates (though not necessarily lower unit costs). When a technology reaches this phase, the U.S. runs the risk of becoming quite dependent on foreign enterprise for further developments in that technology. This may be acceptable for some technologies but not for others critical to national economic and military security. The fabricated metals industries are prime examples of such experience-intensive technologies that face very severe foreign competition. Other industries in which technological leadership may have been lost by the U.S. are tires and various consumer goods such, as shoes and bicycles. Still other technologies, some of which, are regarded as high technologies, are moving in the same direction e.g. automobiles, consumer electronics, and certain aircraft sectors.

Thus, as one study[17] has concluded, within a given industry, such as steel or petroleum, the U.S. trade balance tends to move from deficit to surplus along the industrial scale from raw materials to semifinished products to finished products (i.e. proceeding around the materials cycle). Iron and steel and finished metals provide a good example (see Figure 8.3); in time

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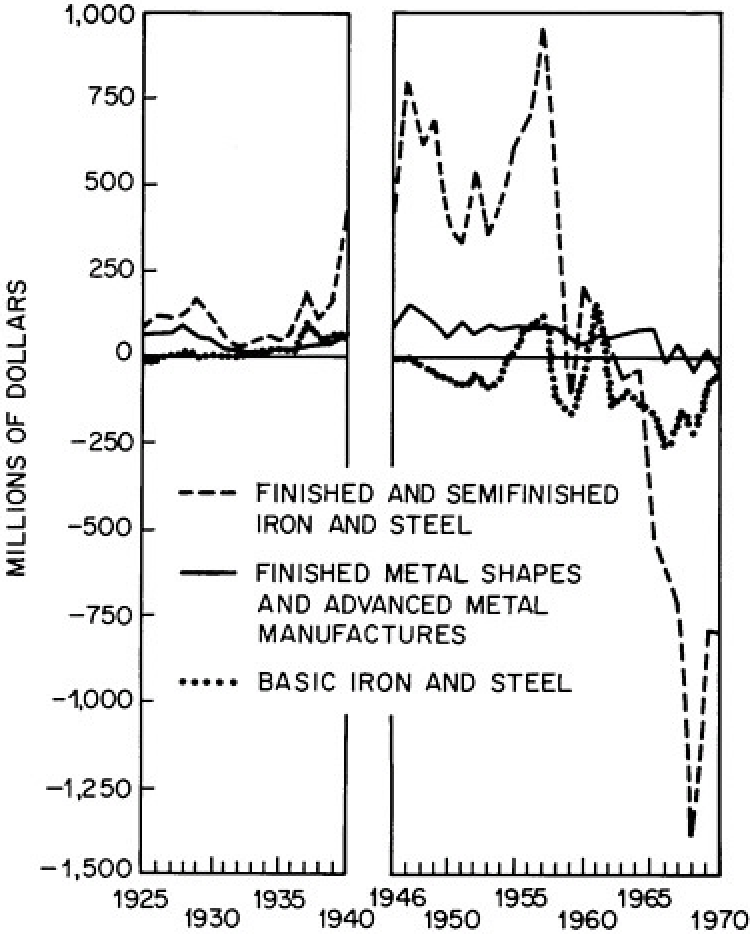
[17] W.H.Branson and H.B.Junz, Brookings Papers on Economic Activity, Washington, D.C., Vol. 2, p. 285, 1971.

FIG. 8.3
U.S. TRADE BALANCE IN IRON AND STEEL, 1925–70[a]



a. EXCLUDING WAR YEARS 1941–45

first basic iron and steel run into trade deficits, then finished and semifinished iron and steel, and later, finished metal shapes and advanced metal manufactures. The advanced product of today is the standard product of tomorrow.

Another example of this product-cycle phenomenon is given by man-made fibers in which the U.S. enjoyed a trade surplus during the "shake-down" period from 1955 onwards, reaching a peak around 1965, but then went into decline and was heading for a deficit after 1970.

There are many factors that can contribute to trade surpluses or deficits, such as physical capital, human capital (professional, skilled, and unskilled), economies of scale, monetary policies, R&D expenditures, and so on. We are concerned here primarily with the role of R&D. The relation of R&D expenditures, as a percentage of value added, to net exports by industry has been noted by Keesing. This finding (D.B.Keesing, "The Impact of R and D on U.S. trade," Journal of Political Economy, 75, 38 (1967)), could supplement both the human capital and product-cycle hypotheses; i.e. that science-intensive industries are likely also to be human capital-intensive and occur in the early part of the product cycle. Branson and Junz conclude from regression analysis, however, that the R&D measure is a significant variable in explaining variations in net exports of manufactured goods even when variations in human capital have been allowed for; that the role of R&D expenditures in explaining U.S. comparative advantage is not simply that of a proxy for human capital or for the product cycle.

The above discussion has focussed on trade in traditional commodities. But the U.S. is sometimes regarded as being in a post-industrial phase, where service industries are becoming more important than manufacturing industries in the economy. Services such as banking, insurance, and trading activities may grow increasingly important in the export market, too. A service of particular relevance to MSE is R&D and technical managerial ability. These are services not necessarily tied to U.S. labor or U.S. natural resources; in fact, one often sees these factors of production combined with foreign labor and foreign natural resources in U.S. direct investment abroad, e.g, the multinational corporation.

A lesson to be learned from the analysis of product cycles is the importance to the trade balance of innovating new products through. R&D. But other countries have recognized this as well. The U.S. maintains a much higher absolute level of R&D expenditures than any other country in the world but others, notably West Germany and Japan, are in a position to place a much higher relative emphasis on R&D for civilian market-oriented technology and economic development, and are doing so.

But there is little reason to doubt that the capacity of European and Japanese firms to innovate successfully, and to imitate quickly the innovations of others, has increased in the 1960's and early 70's and will continue to increase in the near future. Several reasons account for this trend toward innovation. First, per capita incomes in several other industrial countries are growing very rapidly; as a result the share of income available for discretionary spending, beyond the bare necessities of food and shelter, is growing even more swiftly. This means a rapidly growing demand for new products and new designs.

Second, European and Japanese attitudes have become much more receptive to change, much less tradition-oriented, than they once were.

Third, today new ideas and products are much more rapidly diffused across boundaries, with the result that an innovating country will enjoy the export advantages of innovation for a much shorter interval than has been true in the past. Very quickly its new products can be produced abroad and perhaps exported back to the country of origin. For example, within a year of the introduction of stainless-steel razor blades by a British firm (Wilkinson Sword), several American companies had competing blades on the market. This response was defensive and rapid. Float glass was produced in the U.S. only four years after the pioneering production began in England although the basic patent was issued in the U.S., around 1900. Similarly, several computers have been produced in Europe only a few years after they were first marketed in the U.S.

Studies of imitation-lags for various industries suggest that, as compared with a period of some 20 years during the 19th century, the imitation-lag was generally reduced to less than 10 years in the second quarter of this century, and to less than three years by the 1960's—in short, a sharp reduction in the period required for new, commercially successful ideas to be imitated abroad.

There are various reasons for this acceleration in international diffusion. It results, in part, from technological changes in transportation and communication, which make international transmission of new ideas much easier. It also is due to the attitudinal changes discussed above, which make other nations much more receptive to new products and processes than they once were. Finally, the very rapid growth of American investment in Europe during the past decade fostered international diffusion of new ideas and techniques. Very often, subsidiaries of American firms have been the first to introduce innovations to European countries. Direct business investment abroad is an important conveyor of management and technical skills, which is often more significant in its effects than the movement of capital. In a sense, it represents a return to reliance on migration for the international transmission of technical knowledge, although here the migrants are mobile employees of multinational corporations rather than independent entrepreneurs and craftsmen who hope to settle where they can use their knowledge to best advantage.

Technical Achievements

Much of this section is based on the "Gaps in Technology" studies undertaken by the O.E.C.D. in the mid-1960's. "Gaps" is perhaps a misleading word; the technological performance differences between the U.S. and other countries are more in the nature of time lags fluctuating both in magnitude and sign. For example, the quantitative lead that the U.S. had in shipbuilding in World War II has passed to Japan and northern Europe through their development of better designs and manufacturing techniques; Europe's lead in steel technology at the beginning of the century passed to the U.S. only to be challenged by Europe and Japan more recently. In high-technology areas, the almost absolute dominance of the electronics industry that the U.S. has enjoyed since the discovery of the transistor is now being selectively challenged by Japan where profitable. At the same time, European countries have achieved many important innovations in the less glamorous and longer established industries, such as metallurgy and chemicals, industries which have often contributed more to export performance and economic strength than the new-product and rapidly changing technologies. In these and a variety of traditionally low-technology areas, such as constructional materials, there is now concern that the U.S. is falling behind Europe and Japan technologically.

U.S. export performance has been strongest in the science-intensive industries, and it is surely no coincidence that it is generally these which have indulged in large, government-sponsored R&D programs (particularly aerospace and computers). Despite this, however, particularly in the field of electronics, other countries, notably Japan, are able to challenge the U.S. in its home as well as world markets. In the past, cost conditions in other countries have often been sufficiently favorable to offset the export advantages of the U.S. resulting from heavy R&D expenditures, but this is no longer so important a factor. As new technologies mature and become better established, perhaps in the process passing to low technologies, it becomes easier for different countries to draw abreast of each other technically; then, economic dominance transfers to that country which can produce most efficiently. Under these conditions, process improvements and innovations can be more important than product innovations. Since World War II, the U.S. has often led with new products but has paid rather less attention to process innovation.

Thus, in both high and low technologies, U.S. export performance has not been as strong as might have been expected: lower labor costs abroad have enabled other countries to capture much of the high-technology market, while paying more attention to process innovation has enabled other countries to gain strong positions in low-technology areas.

This is, of course, a grossly oversimplified view. Export performance depends on much more than just novelty and cost; for example, there must be a foreign demand for the product and a country's manufacturing capacity must be more than that required to satisfy the domestic market. Nevertheless, the economic strength of a country will be weaker the less it captures new business for itself through product and process innovation.

A European Success in High Technology—Civilian Nuclear Technology[18]

Despite the early U.S. advance in nuclear science, Europe has done much to apply this knowledge to civilian energy uses. At one time the U.S. had a commanding lead over Europe in nuclear-power technology; today, there is no significant difference between the two regions in this field. European companies and government establishments can now speak with scientific competence equal to that of their U.S. counterparts. Indeed, by the late 1960's, in certain areas, such as fast-breeder reactors, heat-transfer fields, and

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[18] "The Technology Gap: U.S. and Europe," The Atlantic Institute, Praeger, 1970.

plutonium applications, Europe reached the forefront of progress. Currently, Europe has three times the nuclear generating capacity of the U.S., more than two-thirds of which is located in Britain, giving it more nuclear powergenerating capacity than any other country. France has the world's largest operating commercial reactor, while Germany is engaged in a program to develop both sodium and steam-cooled, fast-breeder reactors.

Much of Europe's recent advance is the result of the fact that market considerations were much more favorable for establishing nuclear power plants in Europe than in the U.S., where nuclear energy has had to compete against such (previously) low-cost energy sources as coal, oil, and gas. The U.S. played a major role in establishing Europe's first nuclear power plants by granting numerous incentives, such as (a) a low-interest loan from the Export-Import Bank; (b) a guarantee to supply enriched uranium for the full life of the plant, under favorable conditions; and (c) an option to reprocess spent fuel in the U.S. at the U.S. domestic price. Such cooperation is continuing by means of the Joint Research and Development Program of the U.S. Atomic Energy Commission and EURATOM.

At first, Europe depended heavily on U.S. nuclear technology, e.g. through licensing agreements with the two major American companies in the field—Westinghouse and General Electric. However, this did not prevent European scientists and engineers from introducing a number of important innovations of their own, which the U.S. in turn has become interested in adopting—such as using reinforced concrete instead of steel to protect the power-plant enclosure, because steel is more expensive, especially since the enclosure has to be constructed on the site; and EURATOM's system of "Key words," which simplifies the computerization of nuclear information. The European contribution to civilian nuclear technology has been hailed by Glenn T.Seaborg, chairman of the U.S. atomic Energy Commission:

> "The rapid growth of nuclear power development in some countries, most notably in Europe and Japan, is resulting in the production of valuable technical information. The availability of this information to the United States, as called for under the cooperative arrangements, should both increase the rate and decrease the cost of developing nuclear power in the United States."

However, progress in European nuclear technology appears to be restrained by the industrial structure in many of the countries, where a large number of small firms are not especially suitable for the large-scale development of nuclear energy, as well as by the fact that the electric power networks of European countries are not interconnected.

In addition, Britain and France are using natural uranium gas-cooled reactors, which have not proved to be as competitive as the U.S. enriched-uranium reactors. At the same time, American orders for nuclear reactors have increased rapidly and should soon exceed the European lead in number of installed megawatts, but not necessarily in the promising field of fast reactors.

A European Failure in High Technology—Electronics

There was a well-established, capable electronics industry in Europe, as in America, at the time of the discovery of the transistor. It might be thought that European companies should have been able to move about as rapidly into the new era of solid-state electronics as their American counterparts. Yet the record shows otherwise. By far, the majority of the product and process innovations stemmed from a few U.S. firms but the additional firms which moved rapidly into this new field were also mostly American in spite of exceptionally liberal cross-licensing arrangements. A major factor was the heavy U.S. government financing of R&D in solid-state electronics because of its important potential for defense applications. Other countries, with much smaller defense aspirations, took a much more modest approach as less risk money was available. Furthermore, the wave of American success swept into Europe where much of the electronic components business soon became dominated by subsidiaries of U.S. companies. It was only natural that these subsidiaries should rely principally on their parent organizations in the U.S. for their innovations in products and processes.

On the other hand, Japan took a different approach, represented typically by the story of the Sony Corporation. This company quickly recognized the potential of solid-state electronics for the consumer market and fairly soon established itself as a leader in pocket radios, home-entertainment electronics, and the like. To achieve this position Sony, like other Japanese companies, took the deliberate decision to import its technical know-how and concentrate its energies and resources on the production and marketing phases of innovation. Europe, on the other hand, by and large had striven to emulate the U.S. by devoting much of its resources to R&D in the hope that this would likewise lead to successes like the transistor. With one or two minor exceptions, the results were disappointing. European companies and other organizations were not able to catch up and keep up with the American companies. In consequence, Europe has not enjoyed R&D successes (and the associated market dominance) that compare with the transistor, while at the same time it has lost out to Japan in the production and marketing phase.

Metallurgical Technology

General Remarks: Both the U.S. and Europe have roughly the same level of technical expertise in the field of metallurgy. Over the past century, the lead of one region over the other in various aspects of metallurgy has changed hands numerous times. A new technical development tends to give one or the other region a temporary advantage, which is dissipated as the technical knowledge is diffused across the Atlantic.

In iron- and steelmaking, for instance, there is now almost universal knowledge about the most efficient techniques of production; and large plants tend to use similar equipment and processes, regardless of country or location.

Since the end of the Second World War, Europe has made technical improvements of worldwide importance, such as the basic oxygen furnace, first commercially utilized in Austria, and has contributed to the development of continuous casting of steel and vacuum degassing. The basic oxygen furnace has revolutionized the world steel industry, both by reducing production costs and by turning out steel in less than one hour, compared with six-eight hours under the older, open-hearth method. The Netherlands and Japan promptly installed this more efficient furnace at a rapid pace. The U.S., and to a lesser extent Britain and Germany, had invested heavily in openhearth furnaces and thus were reluctant to scrap their equipment for the sake of modernization. As a result, there was an 11-year lag (from 1952 to 1963) between the time that a basic oxygen furnace was successfully operating in the U.S. and the time it began operating in Austria. For Britain and Germany, the time lag was eight years. The original reluctance of the U.S. steel industry to adopt the technically more advanced steelmaking process— which has recently been reversed—is an important factor behind the large increase in U.S. steel imports in recent years, especially from Japan. Table 8.55 lists a number of processes of foreign derivation now used by the American steel industry and related industries.

Europe has also pioneered in the continuous casting of aluminum (Italy) and of copper (Germany), while the U.S. remains ahead in other aspects of metallurgy, such as in refractory metals technology; this reflects the requirements of the U.S. defense and space activities for exotic metals. (It is worth noting, however, that the basic process for the production of titanium, involving the reduction of titanium tetrachloride with molten magnesium, was invented in 1936 in Luxembourg by Kroll who later went to the U.S.A. Some further examples of innovation in metallurgical technology, particularly in the nonferrous metals field, are given in Table 8.56.

All in all, then, neither region has a commanding lead in metallurgical technology as a whole. This partly reflects the fact that there is no overall lag in scientific knowledge about metallurgy between the U.S. and Europe, with both sides making important contributions in solid-state metallurgy, electrochemistry, and dislocation theory.

Some Important Metallurgical Discoveries[19]

(a) Continuous Casting of Steel (1949, Germany)

The economic potentialities of this process encouraged inventors to persist in the face of failures which made the steel industry in general skeptical of its practicability. Credit for the successful introduction of the casting of steel thus belongs chiefly to men working outside the steel companies. The expenses of experimenting with these processes, and the fact that much of the work resembled development more than invention, make it surprising that this should have been so. The steel companies seem to have shown a serious interest in the process after the continuous casting of nonferrous alloys had become established; though they have contributed to subsequent development work, it was the persistence and ingenuity of a comparatively small number of individuals, notably Dr. Junghaus, which made the continuous casting of steel a reality.

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[19] Jewker, Sawers, and Stillinger, The Sources of Invention, Second Edition, Norton, New York City, 1969.

Table 8.55 Processes of Foreign Derivation used by the American Steel Industry and Related Industries*

Type of Operation	Derivation of Process
Pelletizing and Heat Hardening	Original process was developed by O.G.Lellup in Germany in 1920–1940 period, and applied to cement processing.
Cold Hardening of Pellets	Development by British-Swedish team.
Direct Reduction	Krupp-Renn process developed in Germany, was first D.R. plant to be operated commercially.
Basic Oxygen Steel-making (L-D Process)	Pilot scale development and reduction to commercial practice was German & Austrian development. Most recent variations are: Bottem Oxygen Blowing Process (Q-BOP) —Canada and Germany. Submerged Injection Process (SIP) —United Kingdom Creusot-Loire, Wendel-Sidelor (LWS) —France
Continuous Casting	Primarily developed prior to 1960 by: 1) A Russian group (Tsniichermet Laboratories in Moscow). 2) Mannesmann/Bohler group based on Siegfried Junghan's work. 3) BISRA group, U.K. 4) Rossi/Barrow/Concast group in the U.K.
Rolling	Major developments have been by Schloemann (German), ASEA (Swedish) and other European concerns.
Electroslag Melting	Essentially developed by Russia as a welding process. Further adapted by U.K. as primary melting process. Vast majority of research is Russina.
Spray Steelmaking	BISRA development—U.K.
Vacuum Degassing	R-H, D-H & ASEA process developed in Europe.
Continuous Steelmaking (Not yet practiced in the U.S.)	Rio Tinto (Australia) and IRSID (France are closest to commercial reality.

*From Metallurgical Engineering in the United States—A Status Report, by W.H.Dresher, University of Arizona, October 1973.

Table 8.56 Some Innovations in Metallurgical Processes

Description of Innovation		Country of First Successful Commercial Exploitation
Aluminum Fabrication		
1.	Direct casting methods	
	—Properzi	Italy
	—Hunter Douglas	U.S.
	—Hazelett	U.S.
2.	Oscillating Mould Process (Tessman)	U.S.
3.	Oscillating Mould Process (Crossing)	U.K.
4.	Joining Methods (Koldweld)	U.K.
Copper Fabrication		
Continuous Casting Methods		
	—Junghaus	Germany
	—ASARCO	U.S.
Titanium Manufacture and Fabrication		U.S.
Metal Working Processes		
1.	Application of resin bonded shell moulding and core-making	Germany
2.	The Shaw process	U.K.
3.	The CO_2 process in foundries	U.K.
4.	Electro-slag welding	U.S.S.R. U.K. Belgium
5.	Electro-gas welding	U.S.
6.	Electron-beam welding	Germany U.S.S.R. France
7.	Automated powder metallurgy	U.K. Germany
8.	Numerical control for machine tools	U.S. U.S.S.R.
9.	High energy-rate forming	U.S.
10.	Hydrostatic extrusion of metals	Sweden
11.	Electro-milling	U.S.
12.	Vertical roll forging	Switzerland Austria

(b) Shell Molding (1941, Germany)

This casting process was invented by J.Croning, a foundry proprietor, who had been seeking a simple method of producing accurate castings, as had many other firms and individuals for a considerable period. It is probable that Croning received some assistance from resin manufacturers concerning his use of powdered resins for metal casting in ways somewhat analogous to methods used for producing refractory and clay bricks.

(c) Tungsten Carbide (~1920, Germany)

Successful cemented tungsten carbide was discovered during a search for a substitute for diamonds for dies in the drawing of tungsten wire. Other inventors had mixed various metals with tungsten carbide but Schroeter was the first to produce a hard, tough, practical material and to develop a commercial production process. The inventor, a research worker in an electric lamp firm, had no idea when he started his experiments of the potentialities of his discovery in the machine-tool industry. Krupps carried out development work on the material and commercialized it, and some American firms, principally General Electric, contributed to later technical and commercial development.

(d) Oxygen Steel Making (~1948 Germany, Switzerland, Austria)

Though the idea of using pure oxygen in steelmaking can be traced to Henry Bessemer, the present commercial oxygen top-blowing process stemmed from the experiments of Dr. R.Durrer, a metallurgist who advocated employing pure oxygen in steelmaking from 1929 when a professor in Germany, and who tested his ideas in the late 1940's while associated with a Swiss steel firm. Dr. Suess and his staff at the Austrain steelmaker, VOEST, learned of Durrer's findings, and building on this foundation, perfected the necessary operating conditions. In this case, individuals at small European steel firms, one a former professor, all experimenting on a modest scale, were the prime movers in the invention and initial commercial development.

Remarks on Nonferrous Metals Technology

(a) Aluminum

From an analysis of patents in the aluminum field between 1854 and 1958, by and large the U.S. has performed as effectively as any other country. Over this period, the U.S. has collected 24.5% of the patents; France 26.1%; the U.K., 14.1%; Germany 13.6%; Norway 7.5%; Italy 6.7%; Switzerland 6.1%; and other countries, 1.4%. An interesting sidelight to these figures is that in the U.S. only one patent out of 194 is attributed to an individual inventor and none to universities. (This includes not only aluminum alloys but joining, finishing, and fabricating processes as well.) Instead, the main technical innovations for primary aluminum came from R&D carried out by domestic primary aluminum producers. There seem to be no major new production processes for primary aluminum resulting from foreign R&D.

In Canada, innovations arise from R&D in the domestic aluminum industry and by use of imported technology. Canadian knowledge and experience in the field is considerable and is exported or exchanged with international associates with the aim of increasing the usage, and hence the market, for Canadian aluminum. Nevertheless, it is surprising that Canada does not figure strongly in patent statistics—most of its technical "know-how" seems to reflect incremental process improvements rather than major innovative steps.

The position of France in aluminum production is particularly strong, largely as a result of the R&D pursued by the Pechiney Company. For the production of primary aluminum alone efforts consist of (a) an R&D laboratory of 65 research workers on the electrolytic process, (b) 65 people working in a pilot plant on a direct-reduction process, (c) 150 persons on an AlN dissociation process, and (d) a research station with 250 people specializing in casting and metallurgical applications. The results of this effort have, overall, put France in a strong licensing position relative to other countries (particularly as regards Soderberg Pots) including Japan, Spain, Formosa, Cameroon, Canada, Poland, some of the smaller U.S. companies, Greece, Rumania.

Germany also conducts extensive R&D on aluminum, leading to many economic and technical contacts with other countries. Fabricating processes in Germany, such as continuous casting, are nowadays in common use in the whole world. On the other hand, technical innovations, such as the Properzi wire process, have been introduced into Germany from abroad.

Very few original innovations on aluminum have been carried out in Japan. This technology is primarily imported through licensing and immitation.

(b) Copper

Canada has contributed to the technology of copper production primarily by incremental process improvements and by adopting technology from elsewhere. On the other hand, although Norwegian primary-copper production is small, it has contributed some important process improvements such as the Hybinette process and the Orbla process. Similarly, France has contributed the thermic-refining process and, at the semi-fabricating stage, mills for hot-roughing brass sheets and the production of copper tubes by press extrusion and cold rolling on a triple reducer. As in the case of aluminum, Japan mostly imports its copper technology, though it has contributed one major innovation—the oxygen smelting process (Momoda process).

(c) Nickel

The main technical innovations in the nickel industry in the U.S. have come from R&D carried out principally by The International Nickel Company, Inc. Its research has been directed toward solution of operating problems, i.e., the character of the ores from the mine as it affects the smelting rates, more than the development of new products. Important technological contributions have been made also as a result of R&D conducted by consumers of nickel, particularly those in the steel industry and in the special-metals producing areas. The U.S. Bureau of Mines, in its research laboratories, has been conducting programs for a number of years directed toward improving the supply of nickel, particularly with regard to the treatment of lateritic ores and the recovery of nickel from scrap.

Technological development in the nickel industry has been paralleled by a significant increase in the number of related patents and licensing agreements. During 1961–65, approximately 150 patents were issued in the

U.S. relating to mining, smelting, and refining of primary nickel, new nickel-containing products, and other new uses for nickel. During the same period over 100 licenses under these patents covering nickel-containing materials and other products or processes relating to the use of nickel were issued by companies in the nickel industry.

The majority of research work done in Canada relates to the fields of extractive metallurgy and mining methods since most semi-fabricated forms are produced outside Canada. At the present time, approximately 250 people are employed full-time in research projects by the three major Canadian nickel producers. This research staff also carries out projects on closely related metals such as copper. Most research work is done in the fields of extractive metallurgy and mining engineering. In the field of extractive metallurgy, considerable government-sponsored or partially sponsored programs have been undertaken.

Recent developments in Canada have related to slow matte cooling, direct electrolysis of nickel matte, and bulk oxygen in reverberatory and blast furnaces. The Sherritt Gordon ammonia pressure leach, hydrogen-reduction process is a Canadian development and enables a variety of metals, including both copper and nickel, to be produced in powder form. Sherrit Gordon has done much work in the field of dispersion-strengthened nickel and nickel alloys following the lead of Dupont.

The recovery of nickel and iron oxide from nickeliferrous pyrrhotite is a Canadian development as is the direct electrolysis of matte for the production of nickel, and the utilization of slow cooling for the separation of copper-nickel mattes.

In France, Societe LE NICKEL developed new processes (in mining, ore dressing, smelting, and metal refining) in the Le Havre pilot-plant, distinct from the processing plant, in connection with associated official laboratories of Montpellier University, IRSID, and PENNAROYA. A new electrolytic-refining process of 90% ferro-nickel has been developed as well as a new high-speed electroplating process.

Furthermore, recovery and metallurgy of nickel in lateritic ores has been investigated by various other companies, such as Ugine-Kuhlmann and the Bureau de Recherches Geologiques et Minieres. These efforts toward the selective reduction of nickel in oxide ores have led to a precise definition of the physical conditions for reduction before electric-furnace smelting, and enable these companies to select the best process to be used as a function of the characteristics of the ores to be treated.

Whereas nickel-silver was until recently cold rolled with successive reductions, hot extrusion has now been introduced with finishing by cold rolling (Societe Ferro-Nickel). At the Bornel Works (CLAL), efficiency in the rolling of nickel-silver has been considerably improved by converting to semi-continuous casting.

(d) General Remarks on Nonferrous Metals

The strong position of the North American firms in the production of primary major metals (aluminum, copper, and nickel) is clearly matched by a strong, though not preemptive, innovative performance, particularly in product technology (see Table 8.57). On the other hand, the growth of production and consumption and the growth of trade surplus is generally

Table 8.57 Patents Issued in the Nonferrous Metals Sector in Selected Countries

	United States	Austria	Belgium	Japan
1960	85	65	91	19
1961	74	68	90	27
1962	88	55	122	22
1963	62	64	118	16
1964	85	57	n.a.	40
1965	83	72	n.a.	34

higher in both Europe and Japan than in the U.S. and Canada, in spite of the absence of a spectacular innovative performance in most cases.

With respect to the commercial application of the newer metals, the U.S. lead is undeniable; this situation is certainly linked to a technological lead in the industries producing these newer metals, although other factors—particularly the size of markets—play a significant role in the manifestation of this gap.

Because the major primary-metal producers operate internationally, they can provide a vehicle for the dissemination of technological innovations in their own field. Thus, these companies might exercise a powerful gap-closing influence. On the other hand, it is possible that this internationalization of nonferrous metals production can lead to a concentration of the R&D activities in specific areas that may in certain cases be detrimental to the interests of some countries. Some data on the distribution of R&D activities in nonferrous metals are given in Table 8.58.

There tends to be a minimum critical size of R&D facilities before effective research and development can take place. Besides physical size, diversification of interests also enables the larger laboratories to profitably utilize a broader spectrum of ideas. On the other hand, it appears that a country's innovation performance is not entirely dependent on its R&D efforts. Some nations have been able to move ahead on the foundation of purchased technological know-how.

With respect to the spread of technology, metals such as copper, zinc, and lead, which participate in international cooperative research programs, have an advantageous position in comparison with metals whose development depends on domestic R&D efforts.

Relative to the newer metals, the fact that a country does not produce such metals (e.g., titanium and lanthanum) does not in itself imply a technological lead or lag. The reason is linked rather to the size of domestic markets for such products in general and in particular, to the size of governmental programs like defense and space.

Other Recent Progress Abroad in Metallurgical Process Technology

(a) Steel

The Japanese have obtained the best steelmaking technology from all over the world, coupled this with their own R&D, and as a result have some of the finest steel-production facilities in the world. Their plants are new, have the most modern equipment, and produce quality steel products with a minimum of labor. The Japanese do not necessarily lead in steel technology but their industry-and-government cooperation including financing has allowed them to incorporate modern advances into practice very efficiently.

(b) Plasma Melting

The U.S. is lagting in this type of melting. U.S.S.R. and Japan are using the process for the melting of superalloys and titanium. Several U.S.S.R. papers claim improved properties from plasma melting due to its speed and the occurrence of additional refining during melting. There have been

Table 8.58 Location of R&D Activities in the Nonferrous Metals Sector Around 1956

	R&D in Industrial Laboratories	Governmental Laboratories	Universities	Nonprofit Research Institutes	Others
United States	93%	5%	5%	2%	
Canada	65%	25%	10%		
Norway	40%	10%	31%	30%	10%
Germany	39%	20%	–	6%	4%
Spain	–	100%	100%	–	–
Turkey	–	–		–	–
Yugoslavia (1967)	60%	–	40%	–	–

Table 8.59 Orientation of R&D Activities in the Nonferrous Metals Sector Around 1963/64 (Percent of Total)

	Basic Research		Applied Research	Development
Canada	10.2		8.3	81.5
Norway	4.1	27.6	68.3	
United States	3.8	43.6	52.6	
United Kingdom	3.0	48.0	49.0	
France		39.0		61.0
Italy	–		72.2	22.8
Belgium	–	1.9	98.1	
Yugoslavia (1967)	10.0	60.0	30.0	
Japan (1965)	11.0	31.0	58.0	

several attempts in this country to use plasmas for steelmelting. These efforts seem to have failed, but specific information is difficult to obtain. Some effort is being conducted in this country to evaluate plasma melting for superalloys and titanium and to determine if the process is as good as claimed by the U.S.S.R. The Japanese have the capability to feed in titanium sponge and produce slab titanium in one operation with their plasma equipment. The slabs are reported to be 40 inches wide, 8 inches thick, and up to 10 feet in length. This plasma capability is also used for other structural metals. However, the Japanese appear to lag behind the U.S. in superalloy technology.

(c) Foundry Automation

The U.S.S.R. has done extensive work in the automation and mechanization of investment-casting foundries. One such foundry is completely automated through mold-making, pouring, shakeout, and cut-off of the casting from the sprue. Several U.S. foundries have mechanization or automation in some areas; however, none compare with the U.S.S.R. facility. The investment casting foundries are usually producers of high-temperature alloys such as stainless and superalloys. Their products are typically directed toward gasturbine engine application.

Rolls Royce, Ltd. has an excellent automated investment foundry for the production of engine blades and vanes. The bulk-melting furnace can cast up to 48 molds in rapid succession under full vacuum conditions. The 48 molds can be processed in about 2–1/2 hours or almost 20 molds per hour. There appears to be no equal to this facility in the U.S. for producing gasturbine engine hardware.

(d) Rotary Forging Machine

The GFM Rotary Forging Machine was developed in Austria and has been in production since about 1960, with greatest application on gun barrels up to four inches in diameter. It is not widely used in the U.S., but there is some application. This machine provides rapid production rates and basically utilizes a mandrel inside the tube during simultaneous forging of the part. The U.S. uses essentially a number of swaging operations to achieve final dimensions.

(e) Glass Lubricants for Hot Extrusions

The use of glass as a lubricant for hot extrusion of steels was originally developed approximately 30 years ago by Sejournet of France. The process involves glass similar to window glass, surrounding the billet to be extruded and glass pads which melt into the die. This is the only commercial process for hot extrusions in the 2200ºF range. There are now about ten licenses in the U.S. including the International Nickel Company, H.M.Harper Company, and U.S. Steel.

(f) Screw Presses

Screw presses have been employed in Europe for almost 40 years but have been slow to be adopted in the U.S. It is considered to be more precise than the hammer or hydraulic presses and, in Europe, have about a 3500-ton nominal capacity and a 7500-ton maximum capacity. TRW in the U.S. has bought one for making turbine blades where precision is critical. Westinghouse had one built in West Germany for installation in 1972, to have an 8000-ton nominal and 16000-ton maximum capacity.

(g) Electroslag Remelting (ESR)

The U.S. has made much progress in the area of ESR. In 1965 one company was using this process. Today fifteen to twenty companies are melting via ESR. Many steels, including structural, tool, bearing, and stainless, are being produced. In addition, many of the nickel-based superalloys are being melted by ESR. The Stellite Company melts all of its Hastalloy X by this process. However, the U.S. does not have the capacity for this type of melting that exists in the U.S.S.R.; nor do we have the large ingot capacity they claim, i.e., ingots of 200 tons and 100 inches in diameter. Yet it is not evident that either U.S.S.R. or Japan has any commercial advantage over the U.S. in this sector. Both the Japanese (with help from U.S.S.R.) and the Germans are building large ESR units.

(h) Titanium-Carbide Cutting Tools

The use of cemented carbide inserts coated with titanium carbide was developed in Sweden in 1968 by the Sandvik Steel Company and subsequently adopted in the U.S. A tungsten carbide substrate coated with titanium carbide improves the tool life by 50 to 100% depending upon the specific operation. In addition, closer tolerance can be maintained and long finishing cuts accomplished. There are now several users and producers of these inserts in the U.S. These include such companies as General Electric, Kennemetal, and Excello Corporation.

(i) Weldbond-Joining Process

The weldbond process, which combines resistance spot welding and adhesive bonding in the fabrication of structural panels called “glue welding,” was developed by Russia. It is used extensively in the fabrication of Soviet transport aircraft to replace riveted panels, with a subsequent weight reduction and estimated 20% increase in fatigue life. Continuing Soviet development on process control, automation, and better adhesives is reported.

By comparison, weldbonding is not used to any degree in the U.S. on production aircraft. Recent efforts are:

(i) Manufacturing process developments for weldbond have been sponsored by the AFML/LT with Lockheed, Georgia. Current activities involve process optimization, structural design and engineering data, structural tests of full scale components for C130E aircraft, installation on aircraft, and the conducting of flight demonstrations;
(ii) Sikorski has installed a weldbonded fuselage panel on the S-1;
(iii) An aluminized, corrugated sheet for large missile shrouds is being weldbonded.

Increased use of weldbonding in the U.S. is forecast based on its potential for increased fatigue life over both riveted and adhesive-bonded construction, the reduction in weight and costs over mechanical fastening, and simplified tooling.

(j) Fine Blanking

Fine blanking is used on sheet materials for insuring fine finishing and squaring of edges. It was developed in Switzerland and appears to be a relatively simple process which consists of a back pressure on the under part of the sheet being blanked reacting against the force of the press. This eliminates deformation in the center of the sheet and due to the stresses established eliminates cupping of the edges. The U.S. has adopted this method extensively for sheet materials in applications requiring precision of parts.

(k) Graphite Fibers

There are five graphite filament manufacturers in Japan, viz., Kureha (capacity 10 tons/year), Toray (12 tons/year), Tokai (1 ton/year), Nippon Carbon (10 tons/year), and Nippon Kayaku. Toray is in a joint venture with Union Carbide and Tokai with Rolls Royce. Toray appears to be the leader technically. Their fiber processing, tape processing, test methods, etc., all follow the technology developed in U.K. and U.S. Applications of composites are being explored for aircraft by Mitsubishi Heavy Industries, and for sports equipment by Toray. But the Japanese manufacturers are very much concerned over when and where large volume usage will emerge. The quality of the products by Toray is high. Their price is comparable with that of the U.S. Low price filaments are not yet available.

(1) Additional Foreign Developments

The following foreign developments were subsequently used by the U.S.

(i) Plastic Mold Processing (Crossing) of aluminum, developed in U.K.
(ii) Solid-State Bonding (Recrystallization Welding) —Koldweld of the U.K.
(iii) Hydrostatic Extrusion—Sweden
(iv) Vertical-Roll Forging—Switzerland and Austria

Ceramics and Glass

European countries have long had technical strength in the venerable technologies of ceramics and glass. Germany is noted for its glass industry, particularly the development of various high-quality and specialty glasses for optical instruments and scientific uses. Japan also has traditional skills in ceramics and has recently gained a corresponding reputation in the glass sector, especially for electronic components such as television and camera tubes, optics and glass-fiber waveguides.

Broadly, ceramics can be divided into two classes—those used in large volumes for structural and household purposes, and the specialty ceramics of interest principally to the electronics industry. The latter include, for example, ferrites for magnetic core memories and magnetic tapes, highpermeability ferrites for inductors and transformers, ferroelectrics for ultrasonic transducers, and certain high-quality alumina ceramics for integrated circuit materials.

The U.S. has been very successful with innovations in the structural and household ceramics, less so in specialty ceramics. Particularly noteworthy in the former class is Pyroceram, the ceramic out of which the well-known Corning Ware is made, but the work which led to this material was very much stimulated by the need to find ablators, or heat shields, to allow re-entry of manned spacecraft. Regarding specialty ceramics, both Europe and Japan have made significant contributions—ferrites for magnetic devices owe much to the R&D work carried on at Phillips in the Netherlands, while some of the most important magnetic ceramics for inductors and transformers have come in recent years from the research work carried on at Tohoku University in Japan.

As for glass, there does not seem to be any overall technological gap between the U.S. and other countries. However, no discussion of key innovations in glass technology would be complete without mention of the float-glass process, a method for producing flat glass directly without polishing and grinding (see below). This development by Pilkington's in England put that company in an exceedingly strong licensing position over the last 15 years — the process has been licensed to many of the major plate-glass producers in the world.

Float glass (~1958, England)

The float-glass process is an outstanding case of successful invention and development by a large company which already had a dominant position in its home market, but which recognized that large rewards awaited any discoverer of a method for producing high-quality plate glass without grinding and polishing. The basic idea of floating molten glass over molten tin was patented in the U.S. at the beginning of the century but remained unexploited. It seems certain that, in any case, its successful commercial development would have had to wait upon later technical advance in glass-making. Nevertheless, it may seem strange that the idea was not taken up much earlier by one or other of the glass manufacturers in the world. Evidently, only a large company with ample resources could have succeeded in this. One such, company had the imagination and the courage, and the unexpected good fortune, which enabled it to take the lead.

Plastics Technology

General Remarks: Europe has a strong tradition of research in chemistry and chemical technology, and is unsurpassed in much of its chemical manufactures, synthetic fibers, and organic chemicals. Germany, in particular, has made a strong contribution in this field, especially the HoechstWatcher process for the palladium-catalyzed oxidation of ethylene to acetaldehyde, the Siemens process for producing high-purity silicon from trichlorosilane, and a process for making vinyl acetate. Because the U.S. is the dominant producer of petrochemicals, it has created many new products in this field; however, Europe is not without its own contributions— cellophone, terylene, and crease-resistant fabrics. Also, the Ziegler-Natta process for the production of high-density polyethylene was one of the most important innovations in the development of plastics in recent decades and earned a Nobel Prize for its discoveries. Moreover, the European chemical industry is currently undergoing a period of rapid technological change, with many firms substantially expanding their capacities. And Europe appears to be far ahead of the U.S. in the utilization of plastics in construction activities such as flooring, pipes, and doors.

Between 1945 and 1955, U.S. firms and European firms each originated 3 major innovations. Since 1955, however, U.S. companies have originated 12 innovations, and European 4. Most of the innovations originated in the U.S. since 1955 have been in specialized plastics related to defense and space needs, but with no other important application so far. Whether further development of these plastics durinf the next decade will show the existence of a gap between the U.S. and Europe is something to be watched. But, in any case, these new materials will most probably not influence the production and consumption of bulk plastics. In what have now come to be called the “bulk plastics,” i.e. those introduced mainly before 1955, the European—and especially the German—position appears to be strong.

Since 1954, the pattern of invention and fundamental work in plastics has been diffuse. Important contributions have been made by large companies in a number of countries. Furthermore, the contributions of outstanding European individuals such as Natta and Zeigler have been exploited first within Europe. Only rarely does fundamental and inventive work in Europe get first exploited commercially in the U.S.—polybutene and penton, for which the fundamental work took place in Germany, Italy, and the United Kingdom, are such examples.

Specific Examples: The American and German lead in plastics innovation is evident from Table 8.60. Until 1960, Germany and the U.S. had each been leaders in commercial production of 14 polymeric materials. Britain had been responsible for two (high-pressure polyethylene and urea-formaldehyde), and France (cellophone), Italy (polypropylene), and Switzerland (epoxy resins) for one each.

Another point to be made is that usually a few large firms dominate the industry, so that even when they are not the world’s first producers of a material, they are frequently the first imitators or developers of new processes. This reflects the relative technical advance of these companies in various countries. Thus, when a significant new discovery is made in one country, other large firms are often able to imitate it quickly. The basic

Table 8.60 Countries of First Commercial Exploitation of Some New Plastics Since 1945

Plastic		Invention Country	Exploration	
Year	Country			
1.	Epoxy	Switzerland	1947	Switzerland
2.	Acrylonitrile Butadiene—Styrene	U.S.	1946	U.S.
3.	Acetal	U.S.	1953	U.S.
4.	Polyethylene	U.S., Italy, Germany	1954	Italy
			1955	Germany
5.	Polypropylene	Italy, Germany	1957	Italy, Germany, U.S.
6.	Polycarbonate	U.S., Germany	1957	U.S., Germany
7.	Polyvinyl—Fluoride	U.S.	1962	U.S.
8.	Polyvinilidene—fluoride	U.S.	1964	U.S.
9.	Penton (fluorinated Polyethers)	U.K.	1956	U.S.
10.	Polysulphone	U.S.	1965	U.S.
11.	Polyphenyl oxide	U.S.	1964	U.S.
12.	TPX—Methylpentene	U.K.	1967	U.K.
13.	Ionomer resins	U.S.	1962	U.S.
14.	Phenoxy resins	U.S.	1967	U.S.
15.	Polybutene	Italy, Germany		U.S.
16.	Parylene	U.S.	1965	U.S.
17.	Polyconide	U.S.	1963	U.S.

chemistry is generally straightforward and the technical ability already developed. Patent protection can, therefore, be crucial for the innovating firm. Larger companies sometimes make mutual agreements for the exchange of know-how.

Most important innovation stems from the R&D performed by the industry concerned. In the U.S., the greatest number of innovations has arisen from domestic R&D. In Canada, by contrast, only a small proportion, namely 10–15 percent has arisen out of R&D by native firms, while the rest is imported. There are some useful examples, however, of native Canadian R&D effort, such as the invention of resins derived from vinylacetate in the 1930's. In the 1950's a new acrylic-based resin was developed for the protective-coating industry. In the late 1950's, Dupont of Canada Ltd. came up with a method for producing a range of polyethylene densities. In the same period, Union Carbide Canada Ltd. evolved a process for making high-density polyethylene. In the mid-1960's, C.I.L. developed a new, still confidential high-polymer product. The majority of these advances were mainly adaptations and/or modifications of already-existing processes, such as would be involved in producing a new grade of vinyl resin by adjusting temperature and pressure conditions in the autoclave, and by finding, partly through trial-and-error methods, new means to control the performance of the product.

Japan received most of her post-war plastics know-how from abroad. In the last ten years, most of this technology originated in the U.S., and was transmitted through licensing agreements with foreign firms having the-property rights in the new processes.

In Germany the majority of important innovations originated in the industry itself. These new developments were mainly due to R&D efforts undertaken at the production and fabrication levels. Significant progress has also been recorded in the plastics-equipment field, where Germany plays an important part.

A trend similar to that in Germany took place in France, where most of the innovations during the last ten years resulted from research in the domestic-plastics industry. Here, as in Germany, an essential part of the innovation was contributed by equipment manufacturers.

All the innovations credited to the plastics industry in Belgium were the work of private enterprise. The sectors covered by these innovations were P.V.C., polyethylene, polyester, and cellulose plastics.

In the Netherlands, plastics R&D is expected to play an important part in technological innovation. In several diversified firms, there is a direct connection between the production of raw materials and the production of finished goods.

The majority of technical innovations in Sweden are imported from other countries. The Swedish plastics industry performs R&D mainly for short-range product developments and does not yet go into basic plastics research. Governmental research in this field is also relatively minor.

Most of the innovations in the U.K. as well as in Italy, have come from industrial R&D.

Some Important Chemical Discoveries[20]

(a) Catalytic Cracking of Petroleum (~1930, France) An individual (E.J.Houdry), trained as an engineer, who had no immediate connection with the oil industry, made feasible the first commercial catalytic-cracking process by solving the critical problem of regenerating the catalyst. One large oil company developed his ideas after another had decided the process would never be practical. Other large oil firms, which had simultaneously been studying catalytic techniques, later introduced much improved processes.

(b) Cellophone (~1910, France) The crucial “Cellophane” inventions were those of an individual experimenter, Brandenberger, a Swiss-born French chemist. A large French textile firm backed him and, with its help, “Cellophane” was further developed. One of the largest American companies then took up the basic idea, carried on the development and discovered in its own laboratories a new and valuable type of “Cellophone.”

(c) Crease-Resisting Fabrics (~1926, England) This is probably the major nonmechanical advance conceived of, and fully exploited within, the textile industry proper in this century. The process had no extensive scientific background. It has continued to hold the field since its discovery. The inventing company was the first to seize upon the problem and then to pursue its researches stubbornly to a cussessful conclusion. It was the achievement of a research group of physicists and chemists without special knowledge of the cotton industry, but working in close contact with the normal routine testing carried on by the company. The work of the scientists was “directed” in that a specific problem was set before them. Their successful solution of the problem had unexpected dividends: it could be used to increase the tensile strength of rayon, making rayon useful as a dress fabric.

(d) Methyl Methacrylate Polymers: Perspex, Lucite, etc. (~1930, Germany, Canada, England) Nineteenth-century scientists first observed that methacrylic acid would polymerize. The exploitation of the products derived from the acrylates can be attributed to Dr. Röhm (Germany) and the firm of Röhm and Haas. In making use of the methacrylates, a postgraduate research-worker, Dr. Chalmers (Canada), was the first to discover that they polymerized into a plastic glass. Imperial Chemical Industries (England), as a result of a research team under Dr. Rowland Hill, were granted the first patent on the use of polymerized methyl methacrylate, while Röhm and Haas were the first to commence production of this plastic glass.

(e) Polyethylene (1935, England; 1950, Germany) The story of this discovery provides an unusually clear-cut instance of the unexpected results that may come from research and of the importance of chance in such work. The general purpose of the program at I.C.I, was to investigate the effect of pressure on chemical reactions in the hope of finding ways to avoid the use of catalysts. In 1933 an experiment involving ethylene and benzaldehyde yielded a while waxy solid which was presumed to be a polymer of ethylene, but ethylene subjected to somewhat higher pressures caused an explosion, so the

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[20] Ibid.

work was discontinued. In 1935, with improved facilities for pursuing pressure experiments, the experiment was tried again. But there was a defect in the apparatus, the pressure dropped, and a small amount of white powder was discovered when the apparatus was dismantled.

Some fifteen years later, Dr. Ziegler and his team at the nonprofit Max Planck Institute in Mülheim discovered ways for making polyethylene at normal temperatures and pressures by utilizing catalysts. Ziegler explains that his discovery was not the direct outcome of attempts to solve a given problem; he had set himself a broad course of study in which "my only guide was initially just the desire to do something which gave me pleasure."

(f) Terylene Polyester Fiber (Dacron) (1941, England) Terylene was discovered by two research workers, one a chemistry graduate, at the Calico Printers' Association. The crucial idea came to the inventors from a study of the work of Carothers, the inventor of nylon, but who had failed to produce fiber from polyesters. The idea was fundamentally a simple one. The invention stage was carried through with the simplest devices in a research laboratory of modest size in a firm with no direct interest in this branch of research by inventors who were able to devote only a limited amount of time to the task. The inventors reached their results long before Dupont, the company in which nylon had been discovered and which had very much larger resources for research.

(g) Polypropylene (1954, Italy) (OECD Gaps in Technology Plastics) The polymerization of olefines starting from ethylene should normally have continued with higher homologues. Unfortunately, the polymerization of propylene, the homologue just above ethylene, did not give the expected results. This was because the polymer obtained was amorphous (atactic) and possessed very few of the physical properties needed for use either as a plastic or as a synthetic textile fibre. It was not until 1954, with Professor Natta's discovery of stereospecific catalysis, that a satisfactory solution was found for the polymerization of propylene. Professor Natta and his colleagues at the Milan Institute of Technology, working in collaboration with Montecatini, used new catalysts to orient the polymerization reaction towards highly crystalline structures which gave the polymer good mechanical properties. Thus, isotactic polypropylene was born. It still took a number of years for all the technical problems to be resolved (stabilization, constant quality, dyeing of fibers, etc.) and for production to be undertaken on an industrial scale. Technical difficulties slowed down the growth of this polymer during the initial stage of its introduction on the market. However, most of these difficulties have since been overcome and polypropylene would seem to have a good future, both in the field of synthetic fibers and as a plastic for molding and for films.

Materials Science and Engineering in Electronics

Introduction—U.S. Leadership: The field of electronics and electronic equipment depends on a hardware base of electronic components. These include an increasingly-wide range of solid-state devices together with tube devices and various other traditional items. Solid-state devices, particularly the integrated circuit, represent probably by far the most sophisticated achievement yet in any sector of MSE. The integrated circuit represents the combination of the very highest skills and knowledge of physicists, metallurgists, chemists, electrical and mechanical engineers. Indeed, it often seems that the term "solid-state electronics" has become almost synonymous with "solidstate physics," with electronic materials, and even with the title "materials science and engineering" itself.

Since its beginning, with the discovery of the transistor in 1948, the technology of solid-state electronics has been completely dominated by U.S. companies. According to "Gaps in Technology," of 13 major component innovations, only one occurred abroad (the tunnel diode in Japan) and likewise only 3 out of 12 major process innovations (III–V compounds in Germany, ion implantation in Denmark and Great Britain, and electron-beam writing in Great Britain). The U.S. lead in consumer electronics has been seriously challenged recently by Japan but the U.S. still maintains an exceptionally strong dominance of the computer field, telecommunications equipment, and satellite communications. It is, therefore, of interest to discuss in this chapter on international activities not so much what other countries have been doing, but why the U.S. has established such leadership in this field and why, with the exception to some extent of Japan, other countries have not.

The dominance of the U.S. in electronic components is illustrated in Tables 8.61A and 8.61B. These tables raise a significant point: although an important amount of work on semiconductors had been going on in European firms both during World War II and after (the only exception being Germany, where all activities on semiconductors had to be discontinued for a few years after 1945), few far-reaching developments seem to have been made, and the impact on the world scene of new European technologies appears to have been relatively small when compared with those of the leading American companies.

In certain cases, R&D efforts have been misdirected (as they have been in many American companies). However, it must be stressed that an R&D effort is not always geared to the development of new products but is often used as a sort of insurance policy or means of creating a particular capability in a field which may prove extremely important. As an illustration, it can be mentioned that Philips, which had been undertaking work on semiconductors at the time the transistor was developed by Bell Telephone, managed to produce a working transistor within a week of the announcement by Bell in 1948. Philips sole source of information then was the American daily press! Had it not been for their substantial previous work, such a feat would not have been possible. Their subsequent success in germanium transistors only confirms the point.

In assessing the capability of a country or a firm, the "assimilative capability" must, therefore, be taken into account as well as the more conventional innovative or technological capability. As far as countries are concerned, Japan seems to be a good example of how R&D can be used to assimilate and improve upon new technologies developed abroad.

The best yardstick with which to measure innovative performance over a long period is the market share of various companies. This yardstick is especially useful in the case of a fast-changing industry like electronic

Table 8.61A Major Product Innovations in the Semiconductor Industry, 1951–68* (From John E. Tilton, "International Diffusion of Technology: The Case of Semiconductors," Brookings Institution, Washington, D.C., 1971).

Innovation	Principal Firm Responsible	First Commercial Production	Importance
Point contact transistor	Western Electric	1951	First solid state amplifier. More efficient in power consumption, and eventually less costly, more reliable and smaller than tubes.
Grown junction transistor	Western Electric	1951	Increased production yield, thus lowering costs. Less electrical noise and greater resistance to shock.
Alloy junction transistor	General Electric RCA	1952	Greatly improved transistor capability to perform digital (switching) operations. Encouraged development of second-generation computers.
Surface barrier transistor	Philco	1954	Increased transistor frequency range and switching speeds; useful in computer development.
Silicon junction transistor	Texas Instruments	1954	First transistor not made from germanium. Silicon increased temperature range of operation, thus opening up military market. Also increased frequency range.

* From 1963 to 1968, important advances in semiconductor technology were concentrated in the integrated circuit field. These innovations are considered further developments of integrated circuit technology and are not separately identified here.

Innovation	Principal Firm Responsible	First Commercial Production	Importance
Diffused transistor	Western Electric Texas Instruments	1956	Lower production costs; increased reliability and frequency range.
Silicon controlled rectifier	General Electric	1956	Valve allowing electric current to flow in one direction only, at same time controlling the flow. Can replace thyratron tubes for control and switching functions.
Tunnel diode[#]	Sony (Japan)	1957	Can replace special purpose tubes for amplification and oscillation at very high frequencies. Very fast, but so far too expensive: though a major technical development, commercial use is limited.
Planar transistor	Fairchild	1960	Batch production possible, lowering costs. Improved performance and reliability.
Epitaxial transistor	Western Electric	1960	Increased switching speed; lower production costs.

[#] Company and date indicated are for the first laboratory model rather than the first commercial production

Innovation	Principal Firm Responsible	First Commercial Production	Importance
Integrated circuit	Texas Instruments Fairchild	1961	First semiconductor device with two or more elements within a silicon substrate. Incorporated bigger segment of circuit into one device, making increased reliability, faster switching speeds, lower costs, and greater miniaturization feasible.
MOS transistor	Fairchild	1962	Cheaper slow-speed switch. Easy to integrate into circuit designs. Fewer steps in production process.
Gunn diode[#]	International Business Machines	1963	Gallium arsenide device, can replace klystron and magnetron tubes for generation and oscillation in microwave range. Still in experimental and development stage.

[#] Company and date indicated are for the first laboratory model rather than the first commercial production.

Table 8.61B Major Process Innovations in the Semiconductor Industry, 1950–68* (From John E. Tilton, "International Diffusion of Technology: The Case of Semiconductors," Brookings Institution, Washington, D.C., 1971).

Innovation	Principal Firm Responsible	Date of Development	Associated Product Innovation[#]	Importance
Single crystal growing	Western Electric	1950	Grown junction transistor	Method of growing and doping germanium crystals. Bell Laboratories (an affiliate of Western Electric) achieved same innovation for silicon crystals in 1952, leading to silicon junction transistor.
Zone refining	Western Electric	1950		Produced Extremely pure germanium and silicon crystals. Also improved doping process.
Alloy process	General Electric	1952	Alloy junction transistor	New method for forming junctions, leading to transistors with superior switching capabilities.
3–5 compounds	Siemens (Germany)	1952		Semiconductor materials made from combinations of elements in third and fifth groups of periodic table, such as gallium arsenide. Later used in the Gunn diode.

*From 1964 to 1968, important advances in semiconductor technology were concentrated in the integrated circuit field. These innovations are considered further developments of integrated circuit technology and are not separately identified here.

[#] When the new process led directly to one of the new semiconductor products listed in Table 8.61A this column indicates the product.

Innovation	Principal Firm Responsible	Date of Development	Associated Product Innovation[#]	Importance
Jet etching	Philco	1953	Surface barrier transistor	Process for producing transistors with increased frequency and switching properties.
Oxide masking and diffusion[+]	Western Electric	1955	Diffused transistor	Improved method for forming junctions. Batch production possible, reducing production costs. Also improved quality control; increased power and frequency capabilities of transistors, diodes, and rectifiers.
Planar process	Fairchild	1960	Planar transistor	Development on oxide masking and diffusion process that lowered production costs and improved performance characteristics; of great importance for economical production of integrated circuits.

[#] When the new process led directly to one of the new semiconductor products listed in Table 8.61A this column indicates the product.

[+] Up to this point, diffusion has referred to the transfer or dissemination of technology. The term is also used in this study, as it is here, to identify a specific process used in semiconductor production. The meaning intended is apparent from the context.

Innovation	Principal Firm Responsible	Date of Development	Associated Product Innovation[#]	Importance
Epitaxial process	Western Electric	1960	Epitaxial transistor	Technique for junction forming whereby one type of crystal structure is grown on another. Used with planar process, it reduces production costs and increases performance characteristics, particularly frequency range, of transistors and integrated circuits.
Plastic encapsulation	General Electric	1963[†]		Inexpensive method of protecting transistors and integrated circuits from contamination when reliability is not crucial. Though important commercially, not a major technical advance.
Beam lead	Western Electric	1964		Reduces encapsulation costs for highly reliable semiconductor devices. Permits air isolation of integrated circuit elements, and facilitates mixing of semiconductor and thin-film technologies in hybrid integrated circuits .

[#] When the new process led directly to one of the new semiconductor products listed in Table 8.61A this column indicates the product.

[†] Plastic encapsulation was known in the 1950's but was not practical for commercial use.

components, since new products create new products create new markets, and the market share of a firm is built up from practically nothing. In contrast, the market share in a slowly changing industry largely reflects past quantitative commitments in production facilities rather than recent successful innovation.

Market-share estimates for the semiconductor industry show that few foreign firms have succeeded in penetrating the American market, and that none holds a leading position. On the other hand, many American companies, either through direct manufacturing investments or exports, have captured a substantial share of the semiconductor markets in other countries. Since the U.S. accounts for approximately 60% of the world's electronic markets, a leading commercial position in the U.S. will almost necessarily mean a leading position on the world markets.

Evolution of Electronics: The transistor's major achievement was not simply to replace the vacuum tube but to open up a vast number of new fields of application which until then had remained unexplored because of the tube's inherent limitations. The integrated circuit also contributed in the same way to opening up the area of applications—witness the hand calculator.

In contrast to the more mature industries (where it must be stressed, new product and process development and innovation are equally important), technological change in electronics, and in particular in components contributes to the creation of new markets and new applications for the products of the industry. In the solid-state electronics industry, replacing existing products is only a subsidiary aim of innovation whereas in the more mature industries, this substitution function is often the main aim.

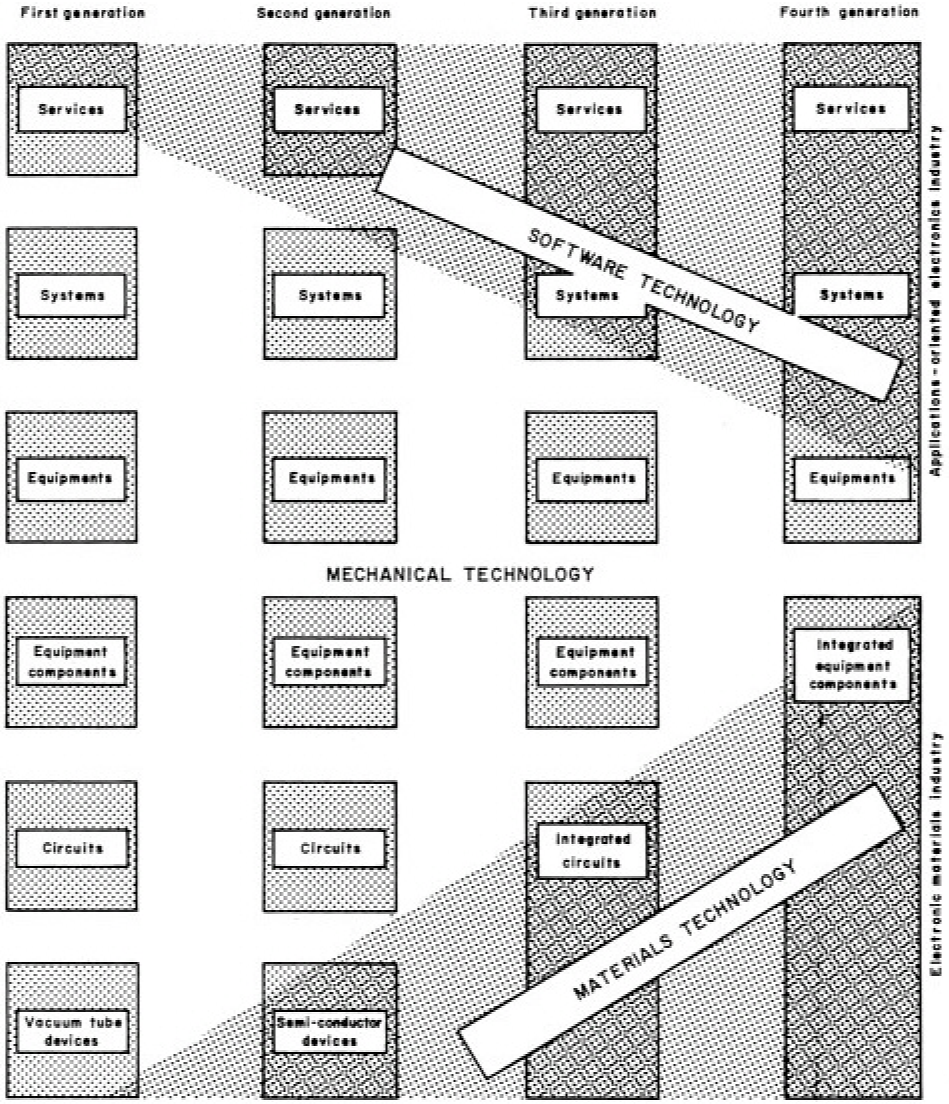
The increasing need for close cooperation between the component manufacturer and the equipment manufacturers is best understood in the light of the evolution of the electronics industry as a whole. The accompanying chart (Figure 8.4) attempts to summarize the evolution of the electronics industry. Two important factors emerge;

(a) The difference between circuits and devices is disappearing with the advent of integrated circuits. As a result of this evolution of technology, the distinction between components and subsystems is becoming increasingly blurred. The component manufacturers are, in a way, invading the other sectors of the electronics industry, and their main weapon is their capability in materials technology (physics, chemistry, microphotography, etc.).

(b) The equipment manufacturers are tending to sell services, rather than products. This is the case for the computer industry; what the customer often buys is not a machine, but a service provided by the machine. The same principle can be seen in telecommunications.

Governmental Markets and Support of Electronics: In some countries, the government has supplied large markets for electronics in defence, in communications and broadcasting, but not for consumer electronics.

FIGURE 8.4
STRUCTURE OF THE ELECTRONICS INDUSTRY



Source: Technological Foundations and Future Directions of Large Scale Integrated Electronics by Richard L.Poritz. Taxas Instruments, Dallas, 1966, Page 50.

The considerable size of governmental markets for electronics can be attributed to the particular nature of electronics, to the changing role of governmental influence, and to prestige and political considerations. A great number of the industry's products have potential military applications. The military market has created a demand and provided a market for a wide variety of new electronic products.

The industry grew up at a time when the range of governmental activity was being considerably extended both in the U.S. and in West European countries. By contrast, the pharmaceutical industry grew up long before Social Security and public welfare were invented.

With its high growth rates, its technological sophistication, and its pervasive influence on other industries, the electronics industry has a prestige value to which governments have not remained insensitive, the image of the industry often being equated with the image of the country. This is the case for computers, color TV, and telecommunications, as well as for industries using a high quantity of electronic equipment like aircraft.

The components industry is an intermediary industry, and the governmental support from which it benefited was in fact largely directed towards the equipment industries. The military customer, as a rule, does not buy components as such, but buys specific pieces of hardware or systems such as missiles, radar networks, computers, or satellites.

In the case of the transistor, most of the inventions and major technological breakthroughs were made in companies with private money, at least at the beginning of the industry (1946–1953 approximately). Around 1953, governmental contracts were given to study specific problems; even if they did not result in major inventions and breakthroughs, they did contribute to developing the state-of-the-art and, in some cases, provided a big boost to the small companies who were unable to channel large sums of money into R&D. This is particularly true of the newer companies operating solely in the semiconductor sector and having no other divisions to provide the funds for such a type of activity. In a newly-created industry, governmental support can be viewed largely as a means of developing the state-of-the-art and providing R&D risk capital to the newer firms.

In the case of the integrated circuit industry, the picture which emerges is somewhat different from that of the transistor industry, in that the main ideas and basic inventions were concomitant with a specific military need for a fundamental revolution in electronics technology.

In the development phase, governmental support was largely directed towards the generation of various pieces of equipment using integrated circuits (IC's). The primary aim of these programs was not to create equipment directly usable by the military customer, but rather to gain a thorough knowledge of how IC's could be put to work in electronic systems and to convince companies and other governmental agencies that these new systems were more reliable and much less cumbersome than their predecessors.

Although this program proved extremely useful to the Department of Defense and to the companies involved (mainly Texas Instruments and Westinghouse), it is doubtful whether IC's would have led to such a far-reaching revolution had they remained confined to the military market, or to certain very specialized applications in the industrial sector. From an economic point of view, the real impact of IC's was to come only a few years later, with mass production, lower prices, and consequently, an increasing pervasiveness of electronics in the whole fabric of the economy.

The major step in this breakthrough was made in 1960–61 with the invention of the planar process by Fairchild's three-year-old semiconductor division. The planar process, developed without any federal support, and subsequently adopted by all IC manufacturers, paved the way to mass production.

The creation of large governmental markets for entirely new products like transistors or IC's is of considerable importance in that it provided a strong incentive for the firms involved to develop their technologies and allowed them to overcome within a relatively short period the cost barrier which prices these new products out of the civilian market.

If a typical cost curve for IC's or transistors is considered, it will be found that in the first years these new products are far too expensive to be sold on the industrial market, let alone on the consumer market. Only when the technology has been fully mastered can these products be widely adopted by industry; this can take a number of years. However, if governments can create a reasonably wide market at the stage when these products are still very expensive, the subsequent drop in prices can be more rapid and the penetration of the new products into the economy greatly accelerated.

To conclude, the hypothesis that the semiconductor and integrated circuit industries owed their development to federal support can be accepted with the two following major reservations: first, most of the basic discoveries and ideas came from the civilian sector using private funds; secondly, although the impact of governmental support was largely concentrated on the development stage, the real significance of these two revolutions, namely their overall influence on the economy through the increasing pervasiveness of electronics, was largely the result of company strategies and private management.

The rapid development of the integrated circuit industry in the U.S. poses the question: why did an equivalent development not take place in the U.K.? The technology available to, and the capability of, the British firms and governmental research establishments were acknowledged by all experts to be as good as those of the U.S. Moreover, there was a considerable national interest in the electronic components industry, with two authorities in charge of the development of components for military purposes: one organized by the Admiralty for active components, and the other by the Ministry of Aviation for passive components. In the early 1960's, the U.S. was deeply engaged in the development of missiles, which were to be the first large-scale markets for IC's. During the same time, the U.K. was following the opposite policy and abandoning the development of a national deterrent (as exemplified by the cancellation of the Black Knight program). However, even if the British policy at the time had been different, the market for microelectronics would at any rate have been much smaller than in the U.S., and the impact on the electronic industries as a whole would not have been as far-reaching as it was to be in the U.S. Nevertheless, one can speculate about what might have happened had the British policy been different.

The organization and structure of governmental support plays an extremely important part. Part of the success of the U.S. lies precisely in the structure of this support. Most of the work done on IC's was performed in private companies, which had an incentive to expand on the commercial market. In the U.K., most of the work was concentrated in governmental establishments and universities, few of which could be in close contact with the market. It is worth noting, though, that owing to the absence of any significant military market for IC's, most of the work in the U.K. was concentrated on techniques rather than on the creation of devices.

One of the key factors influencing innovation in the military field appears to be a clearly expressed need. Companies can respond rapidly to the demand because it is easily identifiable. In a sense, this is what can be called "tailor-made innovation."

The problem facing companies in a fast-changing industry like electronics, where innovation is all-important, is to identify future demand, and come out at the right moment with the right type of new product. On the military market, the requirements of the customer are readily identifiable through the bidding process; on the civilian market the requirements are much more difficult to assess, particularly in the case of consumer products.

Once a market has been clearly delineated, three other factors of key importance for the success of an organization are (a) a clear understanding of its goal or mission, (b) a source of ideas and knowledge, and (c) available resources.

Stimuli for Innovation—Organizational Purposes and Long-Term Goals; A clear and reasonably-wide definition of a company's purposes can have a tremendous impact on its growth and development and in particular on its innovative activities. A good example of a bad definition of purposes, or rather the absence thereof, can be found in some of the U.S. railway companies; seldom was it considered that the aim of the industry was to provide public transportation and not just to run railways. Had the broader aim of public service been kept in mind rather than the narrow allegiance to one specific means of transportation, it is probable that these firms would have been more receptive to innovation and to an improvement of their services, and would not have been so dramatically superseded by more service-minded aircraft transportation companies.

In the electronic components industry, the same type of mistake was made in some companies manufacturing vacuum tubes. The purpose having been to produce such tubes, too little attention was paid to the emergence of the transistor which, although completely different in structure from the tube, was nevertheless capable of performing similar amplifying functions. Had company purposes been defined more broadly—for instance to provide products capable of performing certain types of electrical functions, rather than just to manufacture tubes—it is probable that the necessary transition to the new transistor technology would have taken place more rapidly.

The definition of a company's purpose can be made with reference to the firm's present activities; however, the main benefit will come from looking at the future activities: what are the objectives for the next 5–10 years? What are the longer-term purposes? These questions are all-important, in that the reply given to them will determine in what directions the R&D effort should be pushed, and what the overall commercial strategy will be (e.g. what types of acquisitions and takeovers can be envisaged? What new markets must be explored?). A clear answer will not prevent mistakes, but can contribute very substantially to avoid wastages and dispersion of efforts.

Admitting that company purposes have been defined, it is possible to set a number of more specific goals which will then fit into the company's general purposes. This process of goal-setting is necessary for companies in the electronic components industry—but it is also relevant to countries.

Goal setting by governmental authorities can have a tremendous effect on the development of industry, and can contribute to creating a positive scientific climate. Two illustrations can be given: the first was President Kennedy's committing the U.S. to reach the moon by 1970, and the second was the French government's commitment to the "force de frappe."

Technological and economic disparities are largely the manifestation of differences in innovative capability and performance. Innovation can succeed if there is a need, more or less clearly expressed, for new products. In the U.S., and to some extent in Japan, there has been a generally much more receptive attitude towards innovation than in Europe: customers seem to be more willing to try out new products, to experiment with, novelty.

Structure of the Electronics Industry: In the U.S. one sees four classes of electronics firms:

(a) Bell Telephone, which has been a major source of inventions and new technologies;
(b) The major electrical and electronics companies, such as General Electric, Sylvania, Westinghouse;
(c) Energetic newcomers specializing in solid-state electronics, such as Texas Instruments, Fairchild, Motorola;
(d) A host of small, entrepreneurial companies.

Bell Telephone, and more recently to a similar extent, IBM, belong in a class on their own—fully integrated companies whose activities range all the way from original R&D through component and equipment manufacturers to the provision of services directly to the customer. They are superbly equipped to perform the whole innovative process efficiently and effectively. It is important to note, however, that at least In the case of Bell Telephone, the component and equipment manufacturers do not enjoy a captive market—the service organizations i.e. the telephone companies, are free to purchase their equipment from any manufacturer, in-house or outside (including foreign sources), who can meet the specifications, thus ensuring competitiveness.

The second group of companies all started in solid-state electronics at the same time, 1952, when Bell Labs made its transistor know-how freely available, but for the most part they have faded out of the components picture (though not out of equipment manufacture); probably the prime cause was lack of vertical integration and their heavy investment in earlier product lines.

The third group of companies had much less in heavy prior commitments. They were free to seize on whatever new ideas and techniques looked most promising and exploit them through vigorous management often aided by effective governmental contract support.

The fourth group, the entrepreneurs, have tended to be very small companies clustered in and thriving on the major electronics industrial areas, such as Route 128 around Boston and the San Francisco peninsula.

There are some interesting national parallels with this industrial structure. In Europe most of the established electronics companies, Siemens, Phillips, AEI, would compare with those in the second group and, likewise, they have not seemed able to adapt as readily to the new solid-state technology, particularly because of the reluctance of banks to put up risk capital and because of traditionally restrictive attitudes towards patents and cross-licensing. Similarly, these factors served to thwart the entry of newcomers that would compare with the third and fourth categories. Consequently, much of the market in Europe has been captured by U.S. branches and subsidiaries, such as Texas Instruments in components and IBM in computers. The European companies in the electronics field at first thought mainly of solid-state components and later, IC's, as of marginal value to electronics as a whole, perhaps confined mostly to the military sphere. When they realized otherwise, other firms (U.S. subsidiaries) and other countries (Japan) had moved ahead.

Mobility of scientific manpower can greatly enhance the diffusion of technology and the rate of creation of new companies. Such mobility has been a significant factor in the development of the U.S. semiconductor industry. On the other hand, Japan has traditionally very low mobility. There are some advantages, too, to low mobility; it enables companies to have a pool of readily-accessible and hard-won relevant experience on tap—experience which, often can not be documented but resides in the "know-how" of individuals familiar with the broad needs and interests of the company.

Other Factors Affecting Pace of Innovation: Differences in innovative capability stem from both internal and external factors. A key internal factor is the quality of the firm's management, which manifests itself for instance by a clear identification of the market needs, an efficient organization of the company's scientific and technological resources, and a strict control of the financial aspects of production. Among the external factors accounting for differences in innovative capability, one can mention the sophistication of the customers (private or public), the overall quality of the environment in which the firm is operating, and the scale of governmental support.

In the semiconductor industry, the innovation aspect has been of considerable importance, precisely because this industrial sector is new and because the technology has been evolving very rapidly. Firms which, for some reason (internal or external) have not been very innovative have suffered both in terms of profitability and market position. The same is true of some countries, with the difference that the lower performance in innovation has resulted in a considerable inflow of foreign investment, coming from the more innovative firms and countries.

Innovation has been a central factor in the semiconductor industry. This is not to say, however, that it will remain so in the future: the development of large semiconductor industries in many countries besides the U.S., all based on the same technology, and a stabilization of the pace of technological change will become more dependent on other factors such as production technology, marketing, and lower labor costs.

European Reaction to U.S. Dominance in Electronics[21] American technology is now vital for the future success of the European electronics industry. Texas Instruments is the world's largest manufacturer of integrated circuits; U.S. companies now hold well over 40% of the European semiconductor market; IBM has a grip on 70% of the world computer market. In IC's, the key component technology for the future which will leave no industry untouched and no area of life unaffected, Europe is realizing it is much too totally reliant on U.S. know-how. As in the aircraft, nuclear power, and heavy electrical industries, mergers have been occurring in the electronics and computer sectors, e.g., Sescosem in France and ICL in Britain, though so far no viable computer industry seems to have emerged in France or Germany.

But in IC's, national mergers may not be enough—the need for the widest possible market base stems from the peculiar properties of the integrated circuit. The "value-added" to the material costs are enormous, the latter representing perhaps only 2% of the finished cost. (It is worth, noting that most of this value added is due to materials processing even if it is very often performed by physicists and electronic engineers). These value-added costs can be minimized by the economies of scale. In the U.S., Motorola, Texas Instruments, and Fairchild together hold almost 60% of the U.S. market which, in turn, is about half the world market. The U.K. market, on the other hand, is only about 5% of the world market and no totally British-owned company has more than 10% of that. Thus, the signs point to international collaboration and mergers within Europe, the principal example so far being the Phillips group. Other mergers can be expected. For example, in Britain there is a fairly full range of expertise in IC's, but it is fragmented among such companies as GEC Semiconductors, Gerranti, and Plessey. In the crucial area of computer-aided design, for example, all three companies are now pooling their software design programs and a very real software capability has resulted. This pooled CAD program resulted from a five million pound grant from the Ministry of Technology, one condition of which was that there should be collaborative research where possible. Other areas selected for collaboration were piece parts (e.g. ceramic bases, lead frames, hermetic packages) and production machinery.

In almost every case, materials work is intertwined with device or equipment development and is not subject to any policy in its own right. In this field, material R&D tends to be inexpensive compared with the work on its applications and is rarely recognized as a separate field. Rather, it is generally handled within each company that carries out device development.

(a) A Success Story—A Mini-Consortium: A fairly systematic effort was

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[21] Based on "Making Sense of Electronic Components," K.Smith, Science Journal, Vol. 6, 00, 1970.

made in the U.K. to coordinate R&D in the field of semiconductor III-V compounds—notably GaAs, GaP and GaAsP. This effort was based on the following considerations:

Advanced components for defense depend on the exploitation of new phenomena observed in these compounds. Examples are microwave generators, detectors, mixers, etc., emitters of infrared and of visible light, domain-scattering devices, and so on.

Several companies and governmental establishments in the U.K. might be expected to become involved in developing these devices and would, therefore, need supplies of compounds in a form not available commercially. In particular, requirements on purity, uniformity of carrier concentration, mobility, thickness control in layered structures, etc. are so severe in sophisticated devices that outside suppliers are not capable of meeting the demands. (The situation is further complicated when the supplier is in another country and is itself involved in device development. The material buyer always has the suspicion that the vendor keeps the best material for himself, gives the next-best to his major domestic customer, and exports what remains!)

Because of the delays and other difficulties in buying material from commercial sources—and often it is just not available—the device development teams find it increasingly necessary to prepare their own material. (In fact, it is general experience that each device team must have, under its own control, an appropriate material preparation and evaluation group, working towards the common (device) objective. The feedback from material-user to material-maker should be continuous, rapid, and unambiguous, and unified control seems the best way of ensuring this. The practical difficulties of having several material preparation groups working at once, each as a part of a different device team, are solved by physically co-locating the groups so that common use is made of clean rooms, fume cupboards, measurement gear, etc.

A comprehensive military R&D program in advanced electronic devices thus inevitably leads to the appearance of numerous groups in diverse companies and governmental establishments, all trying to prepare compounds. Clearly some form of close collaboration is necessary to avoid duplication of efforts, repetition of errors, and loss of useful information.

One way to handle this is to form a consortium of those engaged in this work. The consortium meets regularly and members exchange information, interchange samples, visit each others' facilities, compare results on reagents, containers, measurement sets, etc.

Conditions for successful operation of the consortium appear to be—

(i) Clearly shown need for cooperation,
(ii) Demonstratable benefits to all taking part,
(iii) Existence of strong, knowledgeable chairman,
(iv) Use of contract funding to exert effective pressure where necessary.

In addition, the question of timing is important. A consortium can be effective in the early days of the R&D before commercial exploitation is a reality. As soon as commercial sales become significant, then normal competitive considerations make cooperation more difficult.

It seems evident that the U.K. consortium activities on compound semiconductors have been successful. The status of device performance is at least as advanced as that anywhere in the world and is ahead in some areas.

(b) A Not-So-Successful Story—Silicon Technology: In the case of silicon, things have not turned out so well. At present, the U.K. relies largely on imports, except for two local manufacturers who are both subsidiaries of foreign firms (Monsanto and Texas Instruments). Although there was some very good early progress in pure silicon research in the U.K. (indeed one company licensed DuPont to make pure silicon from silane), rather little work has been done more recently. Problems here are numerous. First, without a local manufacturing base, it is not easy to see how any R&D results would be applied. Secondly, the development of advanced devices in silicon is fairly limited (microwave generators and detectors, electro-optic devices). Finally, the commercial conditions in IC's (the biggest user of silicon) make it very difficult to formulate a coherent policy. (An example is the irrational price structure of IC's where selling price often falls below manufacturing cost, overcapacity is rife, charges of dumping abound, etc.)

(c) An Example of Government-Industry Cooperation: The British Post Office has long been concerned with the development of high-reliability components for deep-water cable systems. Originally, repeaters involved tube amplifiers with long life and stable performance. Recent cable installations are based upon semiconductor amplifiers. The development pattern has been the same. Original development, including materials engineering, has been carried out in the BPO laboratories until the desired performance has appeared certainly attainable. The material development has involved long-life oxide cathodes, purification of electrode materials and process development for the electron tubes, and semiconductor-materials refinement for the transistors.

When the required performance appeared within range, industrial firms were sponsored to complete product development and ultimately to undertake production. Information interchange was carried out between the companies under the direction of the Post Office laboratory management to assure complete availability of all technology developed by any of the groups involved.

Through this pattern, the Post Office has concentrated upon the key component necessary for the system success and has assured its availability and quality. The results have been highly successful cable systems, on schedule. The most recent example is the first 1860 channel cable, at a cost below competing systems in other countries.

(d) National Strategies for Electronics: A small country in a large world has the same problems, essentially, as a small company in a large industry— in order to make a significant contribution to knowledge, to progress, or to prosperity, it must be selective. The U.K. has selected III-V compounds as an area where it planned to do something worthwhile. For the future it has to choose other areas where it has a good chance of contributing in a similar way. The first step is to survey scientific fields and draw conclusions on which areas should be tackled and at what level of effort. A country, just like a firm, cannot be first at everything! But it has to be first at something (to attract and keep its creative people). It will consciously decide to be a 'good second' at a selected list of things and, again consciously, accept it can do nothing at all in others. Thus, it appears that the U.K. decided it would be first in civil use of nuclear energy and supersonic civilian aircraft (jointly here because of cost), a good second in telecommunications and computers, and not complete in space technology.

The means of selection are many but one source of valuable input information is represented by the studies carried out by the Science Research Council (SRC) into various fields of physics "to establish whether the subject, scientifically and technologically, merits the special encouragement." Reports issued so far cover:

The Physics of Surfaces

The Physics of Amorphous Materials

Ion Implantation

Parenthetically, France appears to have no clear policy regarding development of electronic fields or materials science and engineering. Some years ago, the government undertook to concentrate on computer technology, and a consortium of companies was organized and funded. The output was not very successful.

A similar attempt was made in the components field. One move in support of this action was the establishment of a regulation against the use of foreign semiconductor components in French equipment.

Electronic Materials in the U.S.S.R.: It has long been apparent from the U.S.S.R. scientific literature, and it is confirmed by visits to Russian laboratories, that by Western standards there are very large numbers of scientists who concentrate on preparing samples or growing crystals of electronic materials of various compositions and catalog their properties. This approach was championed by loffe. However, the specimens are not carefully characterized; vast numbers of dielectric, magnetic, and semiconducting compositions have been explored without any really important discoveries.

Two achievements in electronic materials should be mentioned, however; electroluminescent p-n junctions in silicon carbide crystals, and the world's first double-heterojunction containment injection laser operating continuously at room temperature. Both achievements represent real skill with materials, but it is important to observe that these achievements were stimulated and paced by applied physicists and engineers who had definite device objectives. Both advances occurred in the loffe Physical-Technical Institute at Leningrad where there is relatively good coupling between science and engineering.

On the other hand, there are many research institutes exclusively devoted to various materials: to semiconductors, to thermoelectrics, to the growth of single cyrstals, to superhigh pressures, to superhard materials, and so on, which have no counterparts, at least with regard to size, in the U.S. Some of these have made impressive contributions, such as the Institute for Superhard Materials in Kiev, with its work on synthetic diamonds and, to a lesser extent, on boron nitride and other abrasion-resistant materials. The Institute of Crystallography is perhaps the largest center in the world devoted to this topic. Much of its earlier reputation was based on its heavy emphasis on quartz and the successful growth of synthetic quartz. It now has the facilities for tackling most crystal-growth problems and its research has expanded to various other dielectric and magnetic crystals such as sapphire and garnets. Again, it appears that the work suffers by not being in close contact with scientists and engineers who are concerned with the applications of the crystals.

Semiconductor R&D in the U.S.S.R. is regulated by a Semiconductor Council (chaired by Professor Vul of the Lebedev Institute). It is planned that future investigations will concentrate on microwave devices, optoelectronic systems, long-term computer memories, and large-scale integration. Understanding of semiconductor phenomena is regarded as sufficiently complete to allow for more sophisticated devices in the future. Curiously little has been published so far about Russian work on integrated circuits.

PATENTS AND PUBLICATIONS AROUND THE WORLD

Data on patent awards and trade are an indicator of inventiveness. But since the factors determining the granting of patents vary considerably among countries, more meaningful information can be obtained by comparing the number of patents awarded to nationals with those awarded to foreigners in each country (i.e. patents awarded to U.S. applicants by foreign countries minus patents awarded to foreign applicants by the U.S.). This yields an index which reflects the relative success of countries in developing products and processes of sufficient potential significance to warrant international patent protection.[22]

Over the period 1966 to 1970, the number of U.S. patents filed abroad has shown a steady decline; from about 32,500 to about 26,000. At the same time the number of foreign inventions filed in the U.S. has shown a slight rise; from about 9,000 to about 12,000. Thus, the net patent balance in favor of the U.S. has fallen from about +23,500 to about +14,000 over the five-year period.

On a country-by-country basis, the U.S. patent balance has been declining relative to Germany, Japan, France, and the U.K. In 1970 the “balances” were approximately: Germany, −1700; Japan, +2000; France, +4000; U.K., +9700.

In scientific and engineering publications, the U.S. share of the world literature is larger in 7 out of 8 fields than for any other country; the field of chemistry and metallurgy is the one exception. Some data are given in Table 8.62. The definition used for “quality” is the number of literature citations per publication. Overall, the U.S. literature had the highest “quality” index in most fields, followed by the U.K.

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[22] See Science Indicators 1972, National Science Foundation, Washington, D.C., 1973.

Table 8.62 Quantity (A) and Quality (B) Rankings of Scientific Literature in Selected Fields (From Science Indicators—1972; NSF)

	U.S.		U.S.S.R.		U.K.		Japan		Germany		France	
	A	B	A	B	A	B	A	B	A	B	A	B
Physics, Geophysics	1 (40%)	1	2 (15%)	4	3	2	4	5	5	3	6	6
Chemistry & Metallurgy	2 (24%)	1	1 (29%)	6	3	2	6	4	4	3	5	4
Molecular Biology	1 (50%)	1	6	5	2 (9%)	2	4	3	4	4	2 (9%)	6
Systematic Biology	1 (30%)	3	3		2	1	6	4	4	2	4	5
Mathematics	1	2	2	5	6	1	3	4	4	3	5	6
Engineering	1 (50%)	1	2 (12%)	6	3 (10%)	2	5	3	4	4	6	5
Psychology	1	1	?		2	2	4		3		5	
Economics	1		5		3		6		4		2	

COSMAT undertook a detailed study of publications and patents in the field of MSE. The survey was based in large part on Chemical Abstracts (CA). This abstracting journal is known to have comprehensive coverage in MSE. Approximately 125,000 articles were abstracted by CA during 1970 in areas designated by the COSMAT survey as MSE. The percentage of CA abstracts in this materials area increased from 35% in 1950 to 45% in 1970 (Table 8.63) indicating a more rapid growth in MSE than in CA as a whole. Examination of Ulrich's International Periodicals Directory (Table 8.64) indicated that there were many more articles than this published in the materials field in journals not abstracted as part of the scientific literature. These consist of semitechnical papers in trade journals and house organs which deal with MSE, but which do not constitute part of the "scientific" literature.

The relative growth of MSE publications is illustrated in the following figures, which compare the average annual growth rate of CA and the materials abstracts in CA during the past two decades.

	Chemical Abstracts	Materials
1950–60	8.8%	9.2%
1960–70	6.7%	9.2%

The growth rate of the materials abstracts has remained constant over the past two decades (on average) at 9.2%, whereas the overall growth rate of CA has dropped from 8.8% to 6.7% per year. For comparison, the following numbers have been obtained by other investigators: the physics literature, based on Phys. Abstr. (Rep. Prog. Phys. 32, 709 (1969)) doubles every 8 years for a growth rate of 9.1% per year, the mathematics literature (Mazo, K.O., Science 154, 1672–3, (1966)) has grown at 2.5% (since 1880); the semiconductor physics literature has been growing at a rate of 13.4% (from 1963 to 1968) (Oliver, M.R., J. Doc. 27(1), 1–10 (1971)). Studies which cover a long period of time (from 1900 or so) show lower growth rates. This can be seen in the study of C.C.Holt and W.E.Schrank (Amer. Doc. 19, 18–26 (1968)) as summarized by the following growth rates in publications:

Field	Years	Growth Rate (percent per year)	Source
Biology	1927–64	4.4	Biological Abstr.
Economics	1886–1959	5.5	Index to Econ. Journals
Electrical Eng'g.	1903–62	3.5	Sci. Abstr. B.
Physics	1903–64	3.7	Sci. Abstr. A.
Psychology	1927–64	2.9	Psych. Abstr.

Table 8.63 Chemical Abstracts (in thousands)

	Total Abstracts	Materials Abstracts	Percent of Total
1946	42.8	15.5	36.2
1950	62.2	21.8	35.0
1955	91.9	25.9	28.2
1960	144.7	52.7	36.4
1965	199.7	78.2	39.1
1970	276.7	126.7	45.7

Table 8.64 Ulrich's International Periodicals Directory—Materials

	No. Materials Journals	Annual Percentage Growth	Estimated No. Articles per Journal	Annual Percentage Growth	Total Articles (thousands)	Annual Percentage Growth
1959 (9th Ed)	1150		174		200	
1965–6 (11th Ed)	1570	5.3	209	3.1	328	8.4
1969–70 (13th Ed)	1946	4.4	244	3.1	475	7.7

D.B.Baker (Chem. Eng'g. News 39, 78 (1961)) points out that the overall growth rate of CA was about 3.8% from 1907 to 1960, and that the years since 1945 (the period covered by COSMAT) represent a period of rapid growth following a decline during WW II. A similar period of decline was observed during WW I, followed by a period of rapid growth which lasted into the early 1930's.

How long the current rapid growth (9% per year) of the materials literature will continue clearly depends on world events. Extrapolation of the long-term 4% annual growth rate of such literature indicates a reversal, or at very least a decrease in the growth rate from the present level. But there is no real indication of this decrease yet.

The growth rate of the literature in various categories is illustrated in the following charts and tables. Several points are apparent. The U.S., which held a good lead in publication rate over all other countries throughout the late 1940's and early 1950's, had almost no growth during this period and lost the lead in the late 1950's to U.S.S.R. (Figure 8.5). U.S.S.R. is now publishing papers in the materials area at a greater rate than the U.S., and in recent years has been widening the gap (hereinafter referred to as the "paper gap"). Germany, Japan, United Kingdom and France are the next most prolific countries. They are all roughly comparable in current publishing rate, but a factor of five to six less than U.S.S.R. and the U.S. The four taken together are slightly below the U.S., and slightly above the total of "all other" countries.

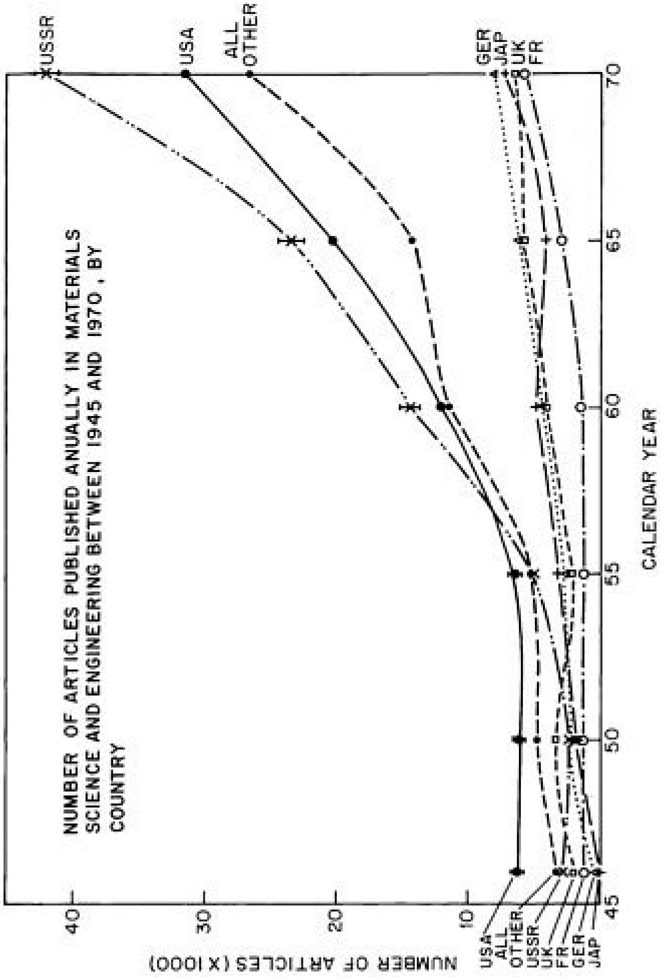
During the years 1946–1970, the materials literature from the U.S.S.R. has increased at an average annual rate of 12%, while that from the U.S. has increased at an average annual rate of 7% during this period. This 7% growth rate for U.S. literature can be divided into two periods: 1946 to 1955 when almost no growth occurred, and 1955 to 1970 when the growth rate was 11.3% (see Figure 8.5).

A similar decline in the percentage of total CA abstracts from the U.S. and an increase in those from the U.S.S.R. is reported by D.B.Baker (op cit) up to 1960. The U.S. still had a confortable lead in the total abstracts in 1960:27.1% for the U.S. as compared to 19.1% for the U.S.S.R., but Baker noted an increased growth rate from the U.S.S.R., and predicted a crossover in 1965. Our data indicate a crossover in materials literature somewhat earlier (1957).

Within the U.S. (Figure 8.6), the most remarkable change is the post World War II growth of papers from educational institutions.

A sampling of 1970 papers indicates that the U.S.S.R. leads in publication rate in the categories of Elastomers, including Natural Rubber; Cellulose, Lignin, Paper, etc.; Mineralogy and Geological Chemistry; Extractive Metallurgy; Ferrous Metallurgy and Alloys; Cement and Concrete Products; Phase Equilibria and Chemical Equilibria. In each of these areas, it publishes at a rate at least twice that of the U.S., and accounts for about half of the total. These categories are concentrated in the "heavy industry" sectors. There are several categories in which the U.S. has a significant lead, such as Synthetic High Polymers; Plastics; General Physical Chemistry; Crystallization and Crystal Structure; Electric and Magnetic Phenomena; Spectroscopy; and Nuclear Technology. These tend to be concentrated in the "high technology" sectors. But the U.S.S.R. and other countries are also publishing strongly in these areas.

FIGURE 8.5



NUMBER OF ARTICLES PUBLISHED ANUALLY IN MATERIALS SCIENCE AND ENGINEERING BETWEEN 1945 AND 1970, BY COUNTRY

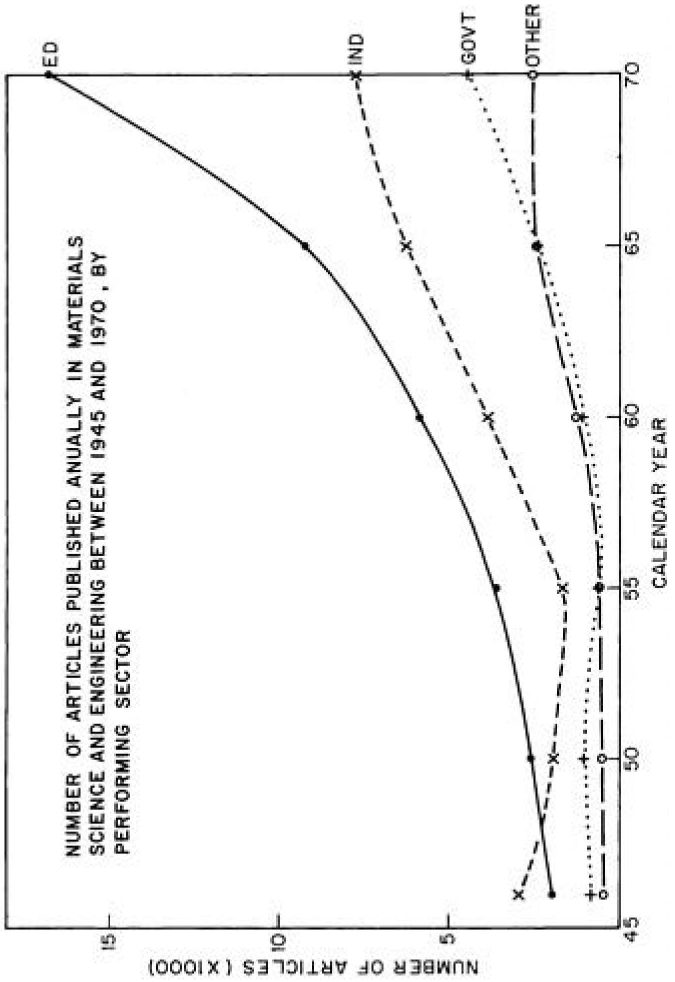

NUMBER OF ARTICLES PUBLISHED ANUALLY IN MATERIALS SCIENCE AND ENGINEERING BETWEEN 1945 AND 1970, BY PERFORMING SECTOR
ED
IND
GOVT
OTHER
NUMBER OF ARTICLES (X1000)
15
10
5
CALENDAR YEAR
45
50
55
60
65
70

FIGURE 8.6

The difference in emphasis between the U.S.S.R. and the U.S. in the "heavy industry" and "high technology" sectors respectively, raises the following point: close track of the foreign literature is kept in the high— technology areas, but one wonders whether the same close track is kept of the heavy-industry foreign literature from which, judging from the publishing rates, the U.S. has relatively more to learn.

Because the Chemical Abstracts patent coverage is not comprehensive, it does not represent an unbiased cross section of world-wide patent activity. For example, direct comparison of the U.S. and U.S.S.R. patent activity based on CA is risky. Nevertheless, some conclusions may be drawn concerning the distribution of materials patent effort within a particular country. Areas in which patents are generated strongly in the U.S., such as plastics, electric phenomena, and radiation chemistry, are also areas in which papers from the U.S. are published at a comparatively high rate. Japan, Germany and the U.K. have relatively high patent rates in the categories of polymers, plastics, and textiles. Japan also has a relatively high patent rate in the category of electric phenomena.

It is worth mentioning that in the U.S. very few patents are filed by institutions in the educational, governmental or "other" classes.

The growth rate of the materials literature is rapid and represents a significant and expanding man-power investment. The categories of strong publication seem to reflect the areas of strong industrial activity in various countries.

INTERNATIONAL COOPERATION

Philosophical Background

Science and technology are international exchange currencies. Science in particular, which in its purest forms is based on universal truths, is generally regarded as transcending geographical, political, ideological, and cultural boundaries. It is a natural vehicle for promoting international cooperation. Quoting G.P.Miller, Chairman of the House Committee on Science and Astronautics, in 1965:

"I believe that one of the most important characteristics of science is that it can be, and usually is, outside the realm of politics. It has provided us areas of peaceful dialogue and cooperation between ourselves, our friends and our potential enemies that have hardly been possible in any other field of activity. The International Geophysical Year Programs were great testimony to this fact."

Glenn T.Seaborg, Chairman of the U.S. Atomic Energy Commission, said in 1966 that the "essential internationalism of science…may ultimately be mankind's greatest blessing". Continuing, he gave two reasons:

"The first, and more obvious, is that international cooperation in science will accelerate those advances of mankind which, if applied wisely and equally around the world, will help to eliminate the causes of political and economic strife.

"The second idea is that internationality in science extends the national processes of science to other human activities in all countries, and that the ascendancy of scientists within their respective countries will influence national leaders and their people to deal with problems in a more rational and hence more peaceful and productive way…. If we view science in its broadest terms, that is, as a highly organized and penetrating pursuit of knowledge and truth, some good is going to come by having the attitudes and approaches of science applied to other areas."

However, the limitations of science and scientists should also be recognized. While the lingua franca of science can help remove barriers between societies, as Secretary of State Dean Rusk said: "But the burden is not all on one side. Scientists and engineers must, of course, recognize very real progress in many fields outside their own specialties, and they should be conscious of the difference between the values of society and the verifiable truths of the natural sciences."

And as V.A.Ambartsumian, Chairman of the International Council of Scientific Union, has said: "It will be wise, when we (scientists) consider that we don't understand anything in politics, and yet I know that many scientists are very critical of politicians. But nobody had proved that scientists can be better politicians than the real politicians themselves."

It is pertinent to to include a number of observations that were made by Herman Pollack in summarizing the proceedings of a meeting on International Science Policy of the Panel on Science and Technology of the House Committee on Science and Astronautics in 1971. Pollack notes the following recurring themes in discussions of international science policy:

"(a) The importance of insulating science from the imperatives of parochial politics.
(b) The habit of cooperation, which is fostered by scientific relationships, in itself is of high value and a justification for the relationship.
(c) The importance of more effective use of science and technology in support of the developmental aspiration of the poorer countries of the world.
(d) The importance of the free movement of scientific information among the countries of the world.
(e) The necessity of employing science and technology more effectively in the achievement of the great social aims of this age."

Elaborating on some of these points, Pollack went on: "international scientific relationships must be insulated from transitory political considerations and they have possibly unique capabilities of transcending political differences." But, "the absence of political agreement, frequently occasioned by national ambitions or concerns regarding soverignty, is an effective barrier to many necessary endeavours in science and technology which can be accomplished only by international cooperation…We may sometimes unbalance our perspective by overly emphasizing the necessity to free science from political considerations…(but) we have not emphasized nearly enough the importance of obtaining the political agreement which will be the necessary precedent to the multilateral undertaking of major scientific and especially technological ventures such as those that are foreseeable, for example, in the use of outer space and in the management of international environmental problems."

More Tangible Incentives for International Cooperation

J.-J.Solomon, in an article in Minerva in 1964 entitled "International Science Policy" stated that:

"Experience has shown that governments will not undertake large-scale combined action and set up scientific organizations (or extend the compliance of some existing organization to cover scientific questions) except when prompted by one or more of the four following motives—only the first of which is purely scientific:

1. The research is to be devoted to an essentially extra-national subject (meteorology, oceanography, etc.).
2. It requires expenditure which no country could meet from its own resources (nuclear research, space research, etc.).
3. The scientific activities in question are believed to contribute to some wider economic, or military project for which the countries are pooling their efforts.
4. Participation in this form of scientific cooperation is likely to enhance or maintain the international prestige of the individual countries."

Quoting Pollack again: "The overall objective of governments in fostering international cooperation in science and technology is to advance their national interests and to strengthen their international relationship… Inherent in all such cooperation is the d-sire to extend, improve, or expedite the acquisition and diffusion of knowledge. Such cooperation, furthermore, is often activated or motivated by humanitairan, political, or economic considerations.

"From this cooperation, each government expects to obtain particular benefits, direct or indirect. In some cases, these will be tangible and of an economic nature. Others will be less tangible, such as improvement of health, safety, the quality of life, and the advancement of science, the thread which binds the entire enterprise.

"These goals and benefits are not unilateral. Cooperation would not be possible or meaningful if the goals sought were not mutually compatible and the benefits derived did not flow to each nation involved…. (Studies show that there are) many instances of direct economic benefit: through sharing with other nations the costs of essential research; through the incorporation into key U.S. research programs of instrumentation, techniques, and essential data generated in programs supported by other nations; and through opportunities for U.S. scientists to utilize unique research facilities created by and financed by other nations."

Many examples of indirect economic benefits accruing from international cooperation in science and technology have also been identified. Thus, there are the new markets for U.S.-manufactured scientific instruments which result from international cooperation in research, the adoption by U.S. producers of economically important new technologies developed abroad and brought to our attention as a result of cooperative programs, and the ability to avoid unproductive, and expensive, directions for our research efforts or to “leapfrog” in our research planning on the basis of results coming to us through international cooperation.

International Science Policy

While the value of international cooperation in science and technology is widely recognized, the instances of it, with only a few exceptions, have tended to arise on an uncoordinated, ad hoc basis. But the extent of these disjointed though often lively activities raises the question of whether some form of international science policy can take, or is taking, shape. James E.Webb (in the meeting already referred to) has pointed up some of the issues that can underlie such an evolution:

“Have we learned enough about the conditions essential for advancement of science and the gathering of its benefits to propose a joint or cooperative policy of a deliberate fostering of those conditions which produces scientific advancement by many nations within their own economic, political and social structures and patterns of life?

“Is there a common set of criteria by which the leaders of the nation can guide themselves in doing those things which they can reasonably expect to lead to scientific advance and without which they are not likely to get it?

“Could a major international policy goal be to substantially increase throughout the world the amount of effort dedicated to scientific research in an area where every nation needs to know more than is known today?

“Can we build on our experience in the International Geophysical Year and the International Year of the Quiet Sun so as to evolve an international policy related to further study of the sun under which all subscribing nations could justify national investments and the undertaking of a commitment to follow the agreed international policy through the level of sophistication was very different in each of the countries?

“Could one goal of an international scientific policy be to increase the ability of all nations to use the scientific method itself in approaching their own national problems and thus increase, on an international basis, the total effect of the values to be derived from the scientific method?

“Is it possible that under some form of international science policy, a steady increase in the competence of scientists in all nations could be made available to the political leaders of those nations so that each nation would have leaders and diplomats in a better position to negotiate those international arrangements most condusive to the achievement of its national objectives?

“Is it possible to approach this problem of defining goals for an international science policy by assuming that for a particular nation the state of scientific inquiry and its relationships to education and technology can be assessed and understood within the forces at work in the total of the economic, social and political system of that nation?"

Webb goes on to propose some concepts that might be starting points from which an international science policy could evolve:

(a) The use of the power of nations together over the forces of nature for the benefit of mankind.

(b) Make clear in policy statements and relevant actions the value that the competent scientist and researcher has in areas beyond the extension of scientific or theoretical knowledge—that is his value to his own national leaders in their international relationships, his value to engineers and others who are working in the developmental areas to determine that boundary beyond which scientific knowledge at that time and place does not permit the reliable or safe operation of machines, equipment and systems—in technology assessment.

(c) Advances in the education of future generations is directly linked to the existence and participation of scientists in a country, particularly at the graduate level.

(d) We need a policy statement and commitment that investments in basic research will yield important economic returns.

(e) We need to make clear through policy or experience that when a nation moves from the area of scientific research, and then the advance of knowledge to engineering design and to organized use of resources, there is a competence in the area of organization and administration that is necessary for successful cooperation between nations in these related fields.

Themes for Cooperation in the Materials Field

The "international commons" of the oceans, the air, and space appear manifestly appropriate for international cooperation in relevant science and engineering. The environment and its protection concerns everyone and every country. Any undesirable actions at one part of the globe can spread across the whole world. Pollution of air and water by effluents and other agents, and disturbance of the upper atmosphere by terrestrially-released gases or high-flying aircraft can lead, if unchecked, to disastrous consequences for all mankind. Enough has been written on this subject of environmental hazards elsewhere to make it unnecessary to elaborate these dangers further.

With the appearance of technologies of global impact and influence, the question of international regulation begins to be asked (The Evolution of International Technology, Congressional Research Service, December 1970):

"As technology has made the world more a "village world", there has been a growing tendency since the foundation of the United Nations for international bodies to concern themselves with matters…which were formerly held to be the exclusive province of a nation-state. It is in the fields of science and technology that this need for international rather than national action is most strongly felt, and for many reasons."

These reasons are: the traditionally international character of science, the need for international cooperation in inherently global activities such as civil aviation, the need for control of dangerous technologies like atomic energy, and the regulation of global dissemination of pollutants. With respect to the last item:

"Combating pollution will inevitably require international rather than national regulation as its starting point. First, pollution originating in a single nation-state might well spread, through one of the components of the environment such as the air or oceans, into the territories of other nation-states. Secondly, in the context of current patterns for modernization of economics by the export from the most advanced countries of capital equipment for technological manufacturing, a plant which fails to contain adequate anti-polluting equipment will spread pollution by the very fact of its export. Thirdly, the measures to combat pollution need to be internationally prescribed and enforced for they will undoubtedly affect costs, and states which fail to observe them will gain a competitive advantage over those who do."

The point to be emphasized here is that aside from regulation there might be no better area for international technical cooperation than these environmental problems.

There is a need for a global effort to identify sources of existing pollution, to monitor pollution levels in air and water, and to arrive at internationally-agreed standards for air and water quality. At the same time, developing technology has to minimize or eliminate pollution as far as is practicable. Much of this bears directly on the materials field. Mineral and industrial operations with materials are major sources of pollutants as are the chemical reactions that occur in such industrial products as internal combustion engines.

There are two major hindrances to cooperation in developing pollution-control technology: (a) a company or country that succeeds in developing a suitable product or process might feel that this gives it a competitive advantage over others who have not succeeded, and (b) developing countries, for example, may be willing to accept some dirty processes in return for the economic improvements that they bring. These are both legitimate objections in contemporary terms but ones which can be got around, and will have to be, by making equitable international arrangements.

Besides stimulating improvement of the existing environment, another matter for international cooperation is technology assessment. There is need for such an activity to foresee, as far as possible, the effects that new technological developments would have on the environment, public health, and the quality of life, generally.

The oceans also pose problems of territorial rights. These will become all the more aggravated as they and the coean-floor are exploited in the future as sources of various raw materials. There will be need for international agreements on the winning of these resources and the ways of so doing in order not to cause unacceptable environmental harm. Ocean technology may well become another arena for international cooperation.

Increasing concern over future supplys of minerals suggests another area for international cooperation, namely, geological mapping and prospecting. This could cover not only the field work itself, but also the development of improved geophysical and geochemical techniques. Such programs could be of particular value to the developing countries. An ancillary need is for a global geological information center.

Space technology has led to earth resource satellites for surveys of global resources of agricultural and mineral wealth, and for the management of these resources. Possible applications of satellite data include: geologic mapping; mineral resource investigation; thermal activity in connection with volcanic eruptions; observations of magnetic and gravity fields on a global basis; tectonic analysis of earthquake belts; data useful in planning site selection for large engineering works; continuous mapping of subaqueous deposition, channel-filling, and excavation; and effects of floods and other natural changes in large coastal deltas. The international nature of space technology makes it one in which it is appropriate to seek various modes of international cooperation. One such mode is the cooperation in joint experiments that has been agreed to by the U.S. and the U.S.S.R., the only nations thus far with a space-technology capability.

The last example underscores another aspect of international cooperation. As technologies grow in size, cost, complexity, sophistication, and range of effects, they may tax the willingness (if not indeed the physical means) of individual nations to support such developments. This effect has already been observed in the case of the Concorde supersonic transport aircraft, whose development is currently being shared by France with the U.K. As Basiuk notes[23]—

"First, confronted by rising costs and problems of increasing scale, even the superpowers individually may lack the capability of taking advantage of the full potential of future technology. This factor will increasingly generate pressure for international cooperation among the middle-rank powers (e.g., Britain, France, Germany, Japan), between the superpowers and the Western European powers and Japan—and perhaps between the superpowers themselves. Second, some forms of future technology such as large-scale climate modification, will require international cooperation not so much because of the costs involved but because more than one geographic region will be affected and the participation of those concerned will be essential."

Energy-generation and distribution technology will increasingly offer occasions and needs for international cooperation. This will be particularly true of the newer or longer-range methods of power generation including thermonuclear fusion, solar, and geothermal energy. These are likely to be less sensitive areas than the more current technologies, suck as fossil-fuel and conventional nuclear technologies, which are already very much in the commercial phase. As European experience with EURATOM has shown, the conflects that arise when a government is supporting an international effort to develop nuclear technology at the same time as it is fostering its own nuclear

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[23] Basiuk, "Technology and World Power," Foreign Policy Association, Headline Series, page 16, April 1970.

industry may lead to failure. Perhaps somewhat more assured of success would be a cooperative program aimed at developing the technology of energy conservation—more efficient use of space-heating and air-conditioning, solar-heating of buildings, more energy-efficient industrial processes, and so on.

Europe provides some interesting lessons in international cooperation in technology. In the late 1960's, the Common Market countries undertook a study, headed by P.Aigrain, which considered seventy-one projects proposed for international cooperation. The Aigrain study resulted in seven being endorsed: data processing; telecommunications; pollution and noise; meteorology and oceanography; new means of transport; and metallurgy.

Data processing produced an early casualty—the development of a large European computer was viewed as much too costly and the European computer industry felt there would be little market for it. On the other hand, a much less costly venture—the development of a European data-transmission network— was given the go-ahead. A proposal to create a European Institute for Data Processing and Technology—to provide training—was not pursued, but the setting up of a European computer-program library was considered further. The telecommunications proposal was adopted more or less in full.

The pollution proposals received fairly general acceptance and several countries declared they would coordinate parts of their national research efforts in this field. They also declared that relevant laws in the European Economic Community (EEC) should be harmonized, as should methods of management. Many people felt, however, that the program was nowhere near bold enough.

It is interesting that the Aigrain group settled on metallurgy as an area ripe for development on a European basis, particularly work on materials for gas turbines and for desalination plants.

Since making its proposals for technical projects, the Aigrain group has been looking into the problems of interchanging scientific information, comparing the national research programs of the various EEC countries, and singling out areas of radical research which might be suitable for European collaboration.

Returning to materials areas which seem generally appropriate for international collaboration, the matter of international standards and testing methods would seem high on the list. As was proposed in Nature (231, 222, 1973) in a European context, "this is one field, at least, in which it could be expected that the present work of six (national) laboratories, or ten perhaps, could either be concentrated in one or two or, more realistically, could be shared out much more efficiently than at present among standards laboratories specializing in the kind of work which they do best."

Organizations and Institutions

While there are numerous international organizations and institutions concerned with science and technology, very few are in existence specifically for the materials field or MSE. As in so many other spheres, materials activities tend to be subsumed into organizations with broader activities. Prominent among these are the following:

United Nations

Many of the activities in the U.N. that relate to the materials field come under the environmental category. The U.N. has convened international congresses (e.g. at Stockholm in 1972) and committees with the aim of developing international agreements on such matters as air and water quality and quality standards. A persistent question is how to reconcile the aspirations of the developing countries to build up their basic materials industries in the face of pressures to invest in cleaner processes—developing nations may prefer to accept the pollution problems in return for the economic benefits of industrialization.

Another pertinent activity that was organized by the U.N. was the International Geophysical Year in which various nations generated and pooled basic information about the planet, earth. Further such exercises in international cooperation would seem timely, particularly in generating more detailed and calibrated information about mineral resources.

The area of statistics and information in general is one which could well be usefully conducted unver the auspices of the U.N. as could efforts to evolve internationally-agreed materials standards.

An increasingly urgent problem for the U.N. is to foster international agreements on sharing the resources of the international "commons" of the oceans and Antarctica.

Overall, the U.N. is seen as the most global and international of agencies and, therefore, one which should have a strengthened role in trying to bring about international agreements on the sharing of resources and the diffusion of knowledge. The minerals and environmental sectors deserve particularly urgent attention. In this connection an intriguing suggestion is the sponsorship of an International Technology Assessment Agency.[24] The basis for such a proposal is that (a) there is already a considerable assessment activity in international bodies, (b) adverse secondary consequences of technology are often international in their impacts, and (c) assessment of technology is important to developing countries with respect to their own policies in the adoption of technology, in evaluation of imported technology, and in evaluating technological trends and their social consequences in the developed countries. Such an agency could (i) contract out specific technology-assessment studies, (ii) provide liason and foster cooperation among national technology assessment bodies, (iii) insure annual reports on the use of science and technology for mankind, and (iv) provide fact-finding and mediation services.

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[24] Dennis Livingston, "International Technology Assessment and the United Nations System," Am. J. of Int. Law, Vol. 64, pages 163–172, September 1970.

Organization for Economic Cooperation and Development (OECD)

This organization serves the more advanced nations. It generates valuable comparative information concerning such topics as national economies and trade, national science policies, and a host of technical and educational matters. However, its efforts specifically directed at the materials field have, to date, been rather meager. In a previous group, now disestablished, subjects such as education, national policies for materials, technological forecasting, and biomaterials were investigated. The OECD should be well placed to serve the materials field and it is to be hoped that a more vigorous role in various aspects of the materials cycle, including materials, energy, and environmental conservation, will evolve.

North Atlantic Treaty Organization (NATO)

This is a regional organization, born out of a military pact, which also tends to be concerned with the affairs of the more advanced North American and West European nations. NATO tends to be oriented towards high technology and the related basic and applied sciences. Nevertheless, its role in science and technology has been broadening, based on Article 2 of the NATO treaty— “the Parties will contribute toward the future development of peaceful and friendly international relations by strengthening their free institutions, by bringing about a better understanding of the principles upon which those institutions are founded, and by promoting conditions of stability and well-being”. NATO has implemented this policy, among other ways, by awarding NATO Fellowships to enable scientists to spend periods working abroad, by aiding scientific publications and libraries, and by sponsoring international conferences and winter and summer schools on a wide range of topics. On the while, NATO serves science and technology, including materials technology, usefully. However, inasmuch as many of its activities result in funds from donor countries essentially being returned to the donor countries minus the “overhead costs”, some may regard NATO as an excess bureaucratic mechanism for the purposes under discussion here.

European Economic Community (EEC)

Slowly, Europe seems to be fashioning a community of nations that have agreed to abide by common policies in various commercial sectors—food, agriculture, energy, etc. —as well as more general principles of cooperation. In the technical area, some of its earliest major efforts were concentrated in the energy sector, mainly through EURATOM, a joint effort to harness nuclear energy for certain purposes. This program has had indifferent success, not purprisingly, because of the inevitable conflicts between the commercial interests and desires of individual member nations who wish to build up their own nuclear energy industries. There have been difficulties also with ELDO (development of satellite launching rockets) and ESRO (organization for space research). Conflicts of interest are partly responsible, but so are poorly defined charters for these organizations.

In spite of inauspicious beginnings with EURATOM and other activities, the role of science and technology in EEC is likely to grow stronger. It is to be expected that common science and research policies will evolve as well as cooperation in the environmental sphere. One suggestion is the formation of a European Council in R&D. So far materials technology has not figured very prominently in the EEC other than through the Aigrain proposals described earlier, although this situation is likely to change.

There is also motion towards greater cooperation in scientific affairs through the creation of a European Science Foundation. A prime concern of ESF would be, like the NSF, the “health of science.”

Other topics likely to receive increasing attention within the EEC are technology assessment, and the mobility of scientists and engineers. The latter area is one in which already much has been done by the various scientific academies and equivalent organizations in the various countries.

Some lessons that might be learned about international cooperation in scientific institutions from European experience so far appear to be: (a) No purpose is served by the development of common institutions for tasks which are unnecessary; (b) common institutions are most valuable when they can be seen, especially by those who contribute to the cost, to be credible substitutes for national institutions already in existence; (c) the development of common institutions should not be regarded as a means of safeguarding the interest of individual countries in maintaining, perhaps uneconomically, a stake in some technical field that should be abandoned.

It is hard to see why industrial enterprises by themselves should not be driven by purely commercial considerations to form consortia to perform technological tasks perceived to be internationally appropriate. On the whole, the best subjects for formal common institutions are those in which the public interest is predominant. And the materials field, along with energy and the environment, will increasingly offer such opportunities. It is likely that nations will increasingly acquire the habit of working together not because of some philosophical rationale of the virtues of collaboration, but because it will become steadily more apparent that they cannot all “go it alone” and that they are interdependent.

European Center for Nuclear Research (CERN)

CERN appears to be invariably regarded as a success. Located in Geneva, Switzerland, it provides scientists from many countries with large accelerator facilities for basic research on the fundamental particles and forces of nature. No doubt, a major factor in its success as a venture in international cooperation is that its field of endeavor is generally regarded as far removed from commercial and nationalistic interests. This is not a feature that the materials field can so easily exhibit.

Scientific Societies

Europe displays evidence of increasing collaboration among scientific societies in various countries. Perhaps the most notable recent development is the formation of a European Physical Society. This exercise in cooperation will bear watching. Some of the most obvious activities that joint activity by national societies, or transnational ones, can undertake include: coordination of conferences, promotion of international exchanges of scientists and engineers, and more rationalized approaches to the publication of scientific periodicals.

On a more global scale there are the International Unions of Pure and Applied Physics (IUPAP) and Pure and Applied Chemistry (IUPAC), principally active in the planning and coordination of conferences. There seems no reason why more scientific societies in the materials field could not undertake more such activities.

U.S.—U.S.S.R. Cooperation

In a special category are the opportunities for scientific and technological cooperation between the U.S. and the U.S.S.R. In recent months, agreements have been reached to cooperate in 25 project areas. Of these, the topics that have a substantial component of materials technology are: chemical catalysis, electrometallurgy, forestry, metrology, standardization, environment, water resources, space, health, atomic energy, oceans, artificial heart, energy, transportation, and housing. Under this program there is an exchange of scientists for periods ranging up to six months and joint seminars are being planned.

Some Further Possibilities

This brief review of some of the existing programs and mechanisms of scientific and technological collaboration, with examples shown mostly from Europe, raises the question of what further could be done in this direction, particularly on a more global scale and involving the U.S.? Progressional societies in the U.S. might try to form stronger links, for instance, with their counterparts abroad. And why not, under the U.N. for example, start exploring the prospects for an International Science Policy Council, an International Science Foundation, and even a World University concerned primarily with the technological problems that confront society as a whole? An International Materials Year has also been suggested.

Cooperation with Developing Countries

The materials field forces attention on cooperation between the advanced countries (AC's) and the less developed countries (LDC's). As the LDC's occupy a much larger fraction of the planet's land area than do the AC's, then by the nature of things, they can be expected to own the major fraction of the world's mineral (and fuel) resources so needed by the AC's. It is often as if the supply side of the materials cycle lies in the LDC's while the use side lies in the AC's.

But the LDC's, almost by definition aspire to and move towards raising their own level of technology. Justifiably they are not content to remain material suppliers but wish to embrace progressively more and more stages around the materials cycle. Thus, there is an almost inevitable sequence of technology transfer, by various mechanisms, from the AC's to the LDC's. For example, from the beginning as a straightforward supplier of raw materials, an LDC may wish to acquire process and refining capabilities. From there, it may move on to invest in transport systems and often ancillary industries. Then comes broadening of the industrial base into other bulk-material industries. The next step is local manufacture and assembly of somewhat simple products but this leads eventually to more sophisticated manufacturing industries. In time, the LDC will want to strengthen its technology by engaging more and more in the appropriate R&D. And in concert with this build-up of its technological fabric, the LDC will likely develop appropriate administrative and financial institutions. Thus, there are many levels at which technology transfer occurs, depending on the stage of development of the LDC.

A particularly potent instrument for this technology transfer and international cooperation in technology is the multinational corporation. Quoting Walter Orr Roberts:[25] "I am much impressed with the important technology transfer that sometimes materializes, under favorable circumstances, when multinational corporations take up the task of establishing industrial plants in developing regions. In areas where the prints of advanced technology are to be brought to a poor area, the sophistication to install environmentally-sound plants, the skill to integrate local managements, and to develop local markets in concord with local mores—these things seem often to be especially well done by multinational corporations, and at small public cost." (See also next section.)

Pursuing this theme, Emilio Daddario[26] foresees much broader, even "mandatory", cooperation in future among sovereign nation-states. "For today, we possess the technological and organizational capabilities to begin not only to manage human affairs on a worldwide scale, but to feed, clothe, educate and otherwise care for all those who wish it. On the economic plane we have already begun to see evidence of this kind of capability in the form of large-scale private multinational corporations whose activities span many different sovereign and market boundaries. I believe that we could begin to do the same if man would only express his will to do so."

Continuing, Daddario notes, however, that before there will be any real global cooperation, there must be far greater consensus on its purposes and priorities among, say, enhancement of material well-being, intellectual

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[25] International Science Policy Meeting, loc. cit., p. 29.
[26] loc. cit. p. 74.

development, economic growth, education, arms control, peace-keeping, health care, or housing, etc. He explores the area of exploitation of natural resources, observing the consumption rates by the AC's, the finiteness of the earth's resources, and the political sensitivities of the LDC's. "And yet, most of us in the developed world are still unwilling to restrict our own activities, to restrain our voracious appetites to consume, and to contemplace seriously the long-term implications of present-day action. We prefer, rather, to go it alone as nations, exploiting and competing for these resources. We favor the near-term material benefit to the potential long-term loss, with only minor consideration of the real and present social costs, both to international political stability and to the developing countries, themselves."

As to more specific mechanisms of cooperation Harrison S.Brown[27] has concluded that "expanded transfers of capital from the rich countries to the poor are essential if development is to be accelerated. It is doubtful, however, that a really major increase in capital flow (a factor of two, for example) could be effectively absorbed at the present time for the reason that there simply are not enough trained persons in the poorer countries who are able to make the decisions which must be made and to solve the problems which must be solved if development is to take place. Nor is there adequate organizational structure which would permit decisions to be transformed effectively into action or which would permit development problems to be solved systematically. Nor are there adequate numbers of technically-trained persons who can carry out the multiplicity of tasks which are essential in even a quasi-technological society. Indeed, this appears to be a really basic limiting factor to the rate of development."

Of equal importance to capital transfer is scientific and technical assistance. This is needed for "the solution of national development problems and for the building of the organizational structure which will make this possible. The basic aim of technical assistance should be to help a developing nation select, adapt, and develop technologies which will help to achieve its social and economic objectives…Research, analysis and problem-solving are major keys to development…and here the United States, with the highest technological problem-solving capacity in the world, can play a major role." Ways of implementing policies to strengthen local scientific-technological problem-solving competence are for governments and their agencies in the AC's and their counterparts in LDC's to engage in joint technology programs, to create research councils and institutes to help modify educational approaches, and to develop guidelines for industrial research which will be cognizant not only of technical and economic considerations but also of the long-term effects of the proposed technology on the society as a whole.

A sound R&D infrastructure is an essential element, particularly for the transfer of the more sophisticated technologies. Consulting engineers, university staff and other specialists can play important roles in aiding such transfer, although again it is worth emphasizing the importance of choosing appropriate technologies, taking into account the potential local markets, uses, skills, and knowledge.

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[27] loc. cit. p. 127.

In general, broadly-based incentives designed to encourage transfer may often result in the transfer of irrelevant or inappropriate technology. Incentive programs need to be carefully and specifically framed so as to achieve the desired results. Other elements in facilitating technology transfer are to foster cooperative industrial research, business management training, international standardization and quality control.

However, underlying all technical cooperation and technological transfer is an adequate level of education and training. The U.S. and its agencies can help considerably in this sphere, by the education of foreign nationals in appropriate materials technologies at universities in this country, by cooperative programs between U.S. and LDC universities, and by facilitating personal contact and experience between the AC's and the LDC's.

Finally, in addition to capital transfer and technical assistance, much will depend on legislative and fiscal measures which influence the terms of trade, both in the donor and the recipient countries. Factors that can have these significant effects, positive and negative, include patent agreements, inventor and licensee protection, export and import restrictions and taxes, and local tax laws and regulations.

Much of the above discussion is reinforced by recommendations made recently in an O.E.C.D. publication.[28] They apply as much to the materials field as to science more broadly.

"The needs of the developing countries for science and technology are undoubtedly different from those of the developed countries. National science and technology policies within the developed countries should therefore be formulated with attention to the particular situation of those countries." It was recommended that "problems relating to science, technology, and underdevelopment be considered (by the AC's) as an integral part of their national science and technology policies". As a first step, it was proposed that an inventory should be made of science and technology activities in the AC's that are relevant to the LDC's. It was also proposed that the AC's, "as a matter of conscious and explicit policy, devote a certain fraction of their R&D activities to problems relevant to underdevelopment"… "Policies should be developed in two directions: (a) fostering in the LDC's the development of indigenous capability in science and technology relevant to the socioeconomic situation of those countries, and (b) formulating research programs in favor of the LDC's in the laboratories of the AC's, as a part of science policy.

"Only by creating institutions in the LDC's themselves does it seem possible, on the one hand, to become sufficiently close to the prevailing economic and social environments to respond to their real research and development needs." They recommended a pooling of AC resources with this aim in view, and stressed the value of centralizing knowledge of these actions to ensure that, so far as possible, they fit in with an overall plan of international action for the installation of centers of research and advanced studies in the developing countries.

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[28] Science, Growth and Society, O.E.C.D., page 106, Paris, 1971.

The study proposed further ways to facilitate international cooperation and technology transfer including: (a) aid in creating in the LDC's technical information-evaluation centers manned and organized by specialists capable of informing themselves of technological development abroad and of advising on the importation of technologies, (b) fostering within the LDC's information banks for research on the 'Third World', and (c) availability of training assignments and visits by specialists from the LDC's to centers of excellence in their own disciplines in the AC's, to assure them of frequent consultation, without thereby inducing them to quit their own countries.

The report concluded by recommending that "governments organize formal arrangements permitting scientists and engineers from AC's to spend periods of time in LDC's both to provide technical assistance and education, in situ, and to familiarize themselves with problems and conditions".

Interactions with LDC's Particularly Concerning Materials

Almost all relationships in the materials field with LDC's involve ownership of mineral resources and involve issues related to the degree of integration from ore to manufactured products. Except for stone, clay, and glass products, which can be produced and consumed locally, discovery and exploitation of natural resources are dependent on high-grade ore supplies needed by resource-limited industrial nations, notably in Western Europe. A strong impetus for late 19th-century imperialism and colonial empires rested upon the search for an assured supply of basic metals to feed the fabricating and manufacturing industries of the mineral-poor European countries. Because of the Monroe Doctrine, Latin America escaped direct colonialism, but the rich mineral resources of Chile and Peru were developed for the benefit of European and American consumers. Following World War II and its accompanying breakup of colonial empires, distinct national strategies were established regarding the exploitation of indigenous natural resources, and discernible patterns have emerged with particular minerals and in different mineral regions. These will be examined in more detail in the following paragraphs. Common to all national strategies is the assertion of ownership of local resources by the country possessing them.

After wood, stone, clay, and glass products, all of which are globally abundant and necessary to preindustrial societies, development of domestic iron and steel resources was given major priority in a large number of developing nations. While iron ore and limestone, both necessary raw materials, are widely distributed, sources of coking coal are less abundant. In addition, supplies of scrap were relatively low. In spite of these drawbacks, however, large integrated steel mills were constructed in the early post-war years in a number of Latin American countries as well as in some parts of Africa and India. Products were mostly simple carbon-steel shapes (reinforcing bars, structural sections, rails, etc.) all necessary for construction projects. Alloy and other specialty steels were imported, as well as flat-rolled products necessary for consumer-oriented products such as appliances and automobiles. In some areas, electric power projects instigated electric-furnace steel plants. Technology was derived from the U.S. and Western

Europe, with capital supplied by U.S. Foreign Aid programs. Technical management was often supplied by foreign nationals, although local universities eventually provided trained technical management.

In contrast to iron and steel, almost all other metal-producing projects depended on supplies of high-grade, readily-exploitable mineral deposits, whose economic viability depended on demand by industrialized nations. Copper deposits in South America and Africa were developed, owned, and operated by foreign capital and manpower. Forward integration was limited to production of blister copper, the primary output of the smelting process, although a few electrolytic refineries were built in areas where power projects provided cheap electricity (particularly in Africa). Similarly, aluminum projects were based on exploitation of local supplies of rich bauxite. Nickel and ferroalloy projects (manganese and chromium) likewise were developed as sources of raw materials. In almost all cases, local manpower provided only a source of cheap labor, with supervision and management remaining the province of the educated foreign engineer.

With increasing political independence, national strategies started taking form, primarily centered in the political demand for (a) local management, and (b) forward integration, in order to add value to the exported products. Two types of tactics were commonly employed—first, granting of special incentives to invite investment in forward-integration projects; and second, threatening loss of control of the ore body unless further investments were made. In either case, the exported products provided foreign exchange useful for other sectors of local development, either industrial or social.

In almost all countries with an advantageous natural-resource position, this strategy has been successful in shifting the interface of product transfer from a simple upgraded mineral to a more sophisticated semifinished product. Efforts to develop local fabricating and product manufacturing facilities have been less successful, largely due to lack of local demand (or funds); moreover, metal industries are often capital intensive with relatively low manpower requirements. Process equipment, design and construction equipment are almost invariably provided by foreign sources. Thus, the plant owners are almost completely dependent on foreign technical innovation for process equipment. As a result of these factors, opportunities for employment of technically-trained people are limited to operating and management positions. Some countries have created scientific research institutes, and creditable technical university research is conducted, but the lack of infrastructure represented by equipment and process-design capabilities severely limits the development of a complete MSE structure. Since most innovation in metals production has been in the area of process conception and design, the lack of matching capital-goods industries slows down the widespread transfer of technology by means other than importing process equipment from highly-developed countries.

The trend in extractive industries based in LDC's is toward increasing local autonomy in ownership, management, and technical supervision. Process equipment is almost exclusively supplied by well developed nations. Design and construction of facilities (with the exception of process and control equipment) now tend to be provided from local resources. Despite strong efforts to forward integrate, most resource-based products are exported to consuming countries in a relatively simple form. Until a satisfactory local demand develops, this situation is likely to continue; thus, one of the principal sectors for MSE is growing only slowly in the developing countries. Absence of a major capital-goods manufacturing sector also limits the needs and opportunities for MSE. Finally, governmental financial policies which direct foreign exchange derived from raw-material exports towards other sectors of the economy, have also inhibited technical development in the LDC's.

With respect to commodities, iron and steel production have reached the highest level of development, followed by aluminum, copper, ferroalloy ores (particularly manganese and chromium), lead, zinc, tin and minor metals. Emphasis on particular raw materials is almost exclusively determined by the availability of local raw materials.

Educational and research facilities tend to reflect the state of product integration achieved in a given country. Hence, the evolution of an identifiable MSE educational and R&D community depends to a large extent on the nature and course of future economic developments in the particular LDC.

Technological Interactions with LDC's—Example of India

The standard of living in a country is, to a considerable degree, linked to the level of technological sophistication achieved in the means of producing industrial, consumer, and agricultural products. The technological gulf between the AC's and the LDC's is widening steadily and the question we are facing is how to bridge it. The immensity of this problem becomes apparent when one reflects upon the principal reason advanced for expanding the membership of the European Common Market: by pooling the technological resources of its members, it may be possible to achieve technical parity with the U.S.

In the following paragraphs, attention is given to the steps taken, in collaboration with the developed countries, for the development of technical education facilities in India and the relevance of this education to the present phase of industrialization. Some additional alternatives for achieving the desired objective are then examined.

During the past twenty years, five advanced technological institutes have been established in cooperation with the U.S., U.K., U.S.S.R., and West Germany; these collaborations were arranged under the auspices of UNESCO. In this scheme, the AC has provided the laboratory equipment and other accessories and also pays for the visiting faculty members. These specialists are responsible for evolving the technical curricula in consultation with their Indian counterparts and nurturing the institute through its infancy. These appointments are initially for one year, but are extendable. In the past the basic difficulty has been in attracting best-qualified foreign personnel to this scheme. The problem stems from the fact that an active research scientist usually does not want to disrupt his research program for a period as long as a year; this is particularly true for the experimentalists. In order to rectify the situation, the following steps have been taken: (a) the visiting faculty members are now appointed in consultation with, the department concerned; and (b) appointments for shorter durations are also now possible.

The primary objective of such institutes of technology is to impart technical education in the following disciplines: (a) Engineering (Electrical, Mechanical, Civil, Aeronautical, Architecture, Naval, Metallurgy and Ceramics, and Chemical); (b) Science (Physics, Chemistry, and Mathematics). The departments are organized along the traditional disciplinary lines rather than on an interdisciplinary basis. These departments are also actively engaged in research, and are authorized by the University Grants Commission to confer advanced research degrees, such as the M.S. and Ph.D.

For a B.S. degree in a particular discipline, a student has to complete the prescribed curriculum, which includes courses from various other related disciplines. However, he has little choice in the selection of these courses; this organizational aspect is more in line with the British pattern than with the American. Consequently, there is no opportunity for him to evaluate whether or not he has chosen the discipline compatible with his interests.

In these institutes, the education facilities are extremely good and the quality of education compares very favorably to that of the good schools in the technologically-advanced countries. However, the education may have little relevance to the technical needs of the present phase of industrialization. This point will be illustrated by taking specific examples. (a) Presently the metallurgically-oriented industry needs well-trained extractive metallurgists and engineers familiar with the fabrication of metals and alloys, whereas the current educational trend is towards physical metallurgy. A student will be well versed in such esoteric areas as dislocation theory, electron optics and electron microscopy, deformation behavior of single crystals, experimental methods in physical metallurgy, metal physics, phase transformations in solids, etc., but may not know the fundamentals of ore dressing, recovery of ferrous and nonferrous metals from their ores, fabrication of metals and alloys, nuclear metallurgy, and corrosion-protection of metals. (b) In electrical engineering, the emphasis is shifting towards solid-state electronics, but the need for engineers who can design and build better vacuum tubes, electrical motors, generators, etc., is still there, (c) In aeronautical engineering, the students learn about supersonic planes, but there is hardly any real opportunities for these engineers in the country. All this is in contrast to more essential engineers who can man hydroelectric power plants, chemical fertilizer plants, steel plants, as well as design and build roads and dams efficiently.

The Indian faculty members are largely responsible for the aforementioned unbalance. This could stem from the fact that there is little coupling between these institutes and the industries they are meant to serve. It is very likely, of course, that redressing of this imbalance will lead to less comprehension of the new technical developments in the AC’s, but a possible solution may be to offer only to some fraction of a class the choice between research and industrially-oriented curricula, whereas the rest would study the latter.

The technical collaboration on a purely commercial basis with industry in the developed countries can be a very effective avenue for the transfer of technology to a developing country. This could include: (a) obtaining technical information and machinery through a licensing agreement; (b) providing expert guidance in the creation of indigenous industries; (c) setting up of applied R&D laboratories.

In developing certain basic industries, such as steelmaking, machine tools, etc., in an LDC, the advantages to an AC are relatively short term. Nevertheless, the establishment of labor-intensive industries can offer long-term benefits to both participants: (a) cheaper finished products to export to the AC; (b) a possible market for other industrial products; (c) increased opportunities of employment in the LDC.

Advantages to an AC in participating in the aforementioned schemes are the following: (a) development of mutual understanding and opening of communication channels; (b) cheaper finished products; (c) increased opportunities for trade. There can also be an undesirable gain in the osmosis of talent, i.e., the “brain drain” from the LDC to the AC.

Korean Institute for Science and Technology—Example of U.S. Aid

This Institute can be examined as a possible model for LDC’s, especially those which are poor in conventional natural resources, South Korea is one of the world’s most rapidly developing nations, having at present relatively low labor rates and thereby encouraging industrial activity as Japan did earlier. Playing a part in this evolving picture is the Korean Institute for Science and Technology (KIST), an organization that was established with U.S. financial and technical assistance during the latter 1960’s. Its subsequent development has been guided by Battelle Memorial Institute. Modern laboratory facilities have been built, talented staff recruited from among Korean expatriates, and contract research for government and industry has started.

The aim of KIST is to bring science and technology to Korea quickly, to spur economic development by applying science to local industrial needs, and to reverse the “brain drain”. KIST is attempting to fill what would otherwise be a scientific vacuum in the country; to help industry select and adapt technologies already developed abroad; to improve production methods; to determine the best areas for investment; to find new ways for using local materials; to upgrade the quality of exports; and to produce important products that must now be imported such as machine tools and mechanical equipment. KIST also holds training sessions for scientists, technicians, and managers from industry, universities, and government. The President of KIST is a metallurgical engineer who received his higher education in the U.S.

KIST is an autonomous, not-for-profit institute which serves the needs of government and industry without being subject to the political control of either. A special law was enacted to allow the government to donate money to KIST without exerting power over its plans and operations. Another law has encouraged industry to use KIST by providing special tax incentives.

KIST succeeded in attracting a very competent staff; it mounted a determined recruiting drive, offered relatively high salaries, excellent fringe benefits, and fine research facilities. It also offered skilled Koreans an opportunity to use their talents in the service of their country— “You have to be interested in solving our industrial problems rather than building up your academic reputation. If you’re after a Nobel Prize you’d better stay in the United States.”

Joint KIST-Batelle teams surveyed 18 industrial sectors to determine what had to be done to improve Korean industry. Scores of research contracts have followed. KIST has, for example, developed a recovery process for automobile lubricating oils, and devised a means for extracting titanium and zirconium oxides (important for making paints and ceramics) from heavy sand.

The principal divisions of KIST are: Materials Science and Metallurgical Engineering; Chemistry and Chemical Engineering; Electronics Engineering; Mechanical Engineering; Food Technology; Economics and Construction. Fields of investigation under Materials Science and Metallurgical Engineering include: Properties of Solids; Ceramic Materials; Semiconductor Materials; High Temperature Materials; Electronic and Magnetic Materials; Corrosion and Surface Treatment; Metal Working; Nonferrous Metals; Physical Metallurgy; Chemical Metallurgy; Iron and Steel (Making, Shaping, Treating); Smelting and Refining; Foundry Technology and Materials; and Powder Metallurgy. Some of the fields in the other divisions include: Polymers, Plastics, Lubricants, Catalysis, Surface Chemistry, and Mechanical and Plastic Working of Metals.

MULTINATIONAL CORPORATIONS

Types of Multinational Corporations

Multinational corporations (MC's) are enterprises that see the world, or a goodly portion of it, as their market and act to make the most of their opportunities on a supranational basis. Some MC's have a truly multinational flavor, others carry the stamp of their headquarters country wherever they operate. There is no generally-accepted definition of an MC, but as far as MSE is concerned it seems that such corporations can be broadly classified into two types:

(a) The high-technology MC (HTMC) which confines most of its operations to the advanced countries, and
(b) The vertically-integrated MC (VIMC), the operations of which usually embrace raw-material-producing countries, often in developing countries, as well as manufacturing in advanced countries.

Examples of the HTMC's occur in the electronics and semiconductor industry, pharmaceuticals, and the automotive industry. Examples of the VIMC's include oil companies, mining and metallurgical companies, and food industries. A third type of MC is the conglomerate; while a particular industrial theme may provide the backbone to a particular conglomerate its overall enterprise resists simple categorization into technological fields.

Over half (528) out of the 1000 companies on Fortune's first and second "500 largest" lists operate abroad. In a study of 267 of these companies, roughly 24% are in automotive, machinery, tools, and related industries; 24% are in chemicals, oil, drugs, and similar undertakings; 20% in aerospace, electrical, electronic, and other high-technology areas; 12% in mining, metals, building materials, and construction industries; and the remaining 20% are in consumer products such as food, apparel, tobacco, paper, glass, books, etc. Most such companies expect their overseas operations to grow much faster than their domestic activities.

Of a gross world product (GWP) of $3 trillion, approximately 1/3 is produced in the U.S., 1/3 in the industrial nations of Europe, Canada, Japan, and Australia, and the remaining 1/3 in Russia, Eastern Europe, China, and the developing countries. About 15%, or $450 billion, is accounted for by multinational enterprises; $200 billion of this by U.S.-based companies; $100 billion by foreign-based companies which also operate in the U.S.; and $150 billion by interproduction in other countries. The proportion contributed by MC's is growing at the rate of 10% per year. At this rate, MC's will generate 1/2 or more of the GWP in less than 30 years.

Statements For and Against MC's

The recorded operating results of MC's support the statement of N.R. Danielian, President, International Economic Policy Association, "There is no other instrumentality with the same flexibility, inventiveness, initiative, and effectiveness as the multinational corporation in undertaking the extraction, fabrication, transportation, and marketing (of the world's) resources. No armies, no governments, no foreign aid, no international institutions can match this achievement."

Representative Hale Boggs, July 27, 1970, on the other hand said: "While business leaders have viewed (direct investment) abroad as a means of distributing the fruits of technology and managerial expertise more rapidly throughout the globe, spokesmen for organized labor have viewed the MC's as institutions exporting thousands of jobs. The U.S. government has also become concerned that American firms might be able to avoid administrative regulations by permitting their branches abroad to engage in activities that would not be permitted here. On the other hand, some other governments have considered the attempt to impose U.S. antitrust statutes, balance of payments guidelines, and trade regulations on foreign subsidiaries of American firms as an unjustified extension of U.S. sovereignty."

Danielian describes the conflicting pressures on MC's: "They are confronted with a diversity of political motivations—some of emotional origin, such as nationalism; others ideological, such as consumerism; and some even humanitarian, as in the case of welfarism—which subject them to a multiplicity of restrictions and taxation of varying levels in different countries. They have to do business in a variety of environments; the nation, state, common markets, free-trade areas, preference systems, state trading blocs, and democracies of varying degree of popular representation…. They have to cope with controls over imports and exports, tariffs, nontariff barriers, diversity of tax systems and tax rates, different welfare schemes, a variety of employment policies, exchange controls, antitrust rules, and threats to nationalization and expropriation."

Thus, on one hand the MC is regarded as having an equalizing effect on the world; as a world unifier, it speeds up the spread of new products, new technologies and new skills; it can be a powerful agent for cultural change, tending to equalize attitudes towards work, authority, and life itself in the countries it penetrates. On the other hand, critics claim that MC's add to managerial and economic inequalities because they concentrate more and more business decision-making into vast managerial pyramids which operate according to directions issued from central control towers in home countries; they are thereby creating cleavages and inequalities both inside the U.S. and in the foreign circuit—charges of neocolonialism from the developing countries; charges of exporting jobs from organized labor; charges of unfair foreign competition from businessmen in host countries; charges of unfair advantages to the MC's in U.S. from small businessmen; charges that the way of life in other countries will be engulfed. Even within the MC's, there are differences between "freer trade" and "buy American" groups; there are antitrust dilemmas for the Justice Department; the Treasury worries about the effect of MC's on the balance of payments; Congress is concerned about finding ways to tax domestic and foreign earnings equitably.

Labor, Management and Government Attitudes: Not surprisingly, organized labor is trying to develop counterforces, such as by international associations of labor unions. Labor sees two prime "dangers": (a) the cost of MC's in terms of American jobs, and exports, and (b) the growth of the "foreign satellite plant concept" to take advantage of lower labor rates. Labor representatives urge easier public access to corporate records; tight tax rules to reduce opportunities for tax avoidance; more effective labor policy; mandatory union recognition under international conventions; tighter regulation of export of capital, tighter labeling (country of origin) requirements; uniform accounting standards; taxation of exported capital; and in the case of inventions stemming from government-subsidized research, direct royalty payments to the U.S. Treasury instead of to the corporation conducting the research.

Management representatives recommend simplification and harmonization of the antitrust, tax, and securities regulations, a rationalization and perhaps internationalization of patent law, and standardizing of weights and measures.

The Peterson Report[29] (Presidential Task Force on International Development) noted that developing countries are now setting their own priorities for development, mobilizing funds for investment, educating and using more well-trained professional personnel. International agencies such as the World Bank are gaining influence. The traditional exports of developing countries have limited growth potential—they will be forced to export more manufactured goods. The debt burden of developing countries is now a serious problem. The above Task Force supported continued reduction of tariffs globally, the grant of preferential tariffs to certain countries, and regional market-economy concepts to achieve economies of scale. They recommended that U.S.-based MC's grant more responsibility to local national employees, create improved working conditions, and encourage widespread local ownership of their corporations. They also supported some form of guarantee against expropriation, multinational joint ventures, tax incentives, and an international program to provide technical assistance, research, population control, personnel training, agricultural improvements, and debt rescheduling.

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[29] "The United States in the Changing World Economy," U.S. Govt. Printing Office, Stock No. 4000–0271, Washington, D.C., 1971.

Host Country Attitudes

Nationalism presents the most critical constraint on overseas investment and MC operations, most dramatically in the developing countries where MC's are sometimes regarded as neocolonialism. But even advanced countries, such as Europe, particularly France, and Canada have shown concern over the extent of the American business penetration. Japan until now has resisted such penetration. Societies, however, will continue to demand services and goods from abroad but they are going to insist that the inflows be achieved in ways more compatible with their national interests. Host countries are increasingly likely to insist on two preconditions to new foreign business activity:

(a) The needed skills and products must be acquired without the host society having to surrender ownership and control to foreigners.
(b) The needed skills and products must be acquired without the host society having to commit itself to the continued pay-out of foreign exchange after the unique skill or resource that was originally required from overseas becomes available locally.

MC's may well find it difficult to accommodate these attitudes. Even though MC's can take many steps to alleviate the more obvious irritations, e.g. by use of local nationals in management, use of local capital, etc., the external ties remain so significant that the conflict with nationalism remained unabated. Truly multinational corporations, not identified with any major advanced countries in particular, are likely to be more appealing to most developing countries but such MC's will still be regarded as outsiders from the viewpoint of narrow nationalism. New contractual arrangements within the MC's may be an answer—e.g. where the Western firm will supply management skills and technical knowledge without the equity participation and direct control of overseas operations that have been the essence of traditional foreign investment. This compares with the familiar licensing arrangements. The selling of technical and managerial services abroad may become the main profit-earning activity for the advanced country, with local groups making the major capital commitments and assuming actual ownership. Such methods may enable advanced countries to maintain some operations in the developing countries in the face of nationalism; they may provide more desirable combinations of return maximization and risk minimization.

Developing countries are wont to attack MC's when searching for explanations of their countries' compound miseries, and so MC's have learned the importance of being good corporate citizens in the countries where they operate. The trend of new investments towards manufacturing and away from extractive industries and public utilities may help to lessen tensions. Probably the more self-confident developing countries will provide the best overall investment climate in the future as, for example, in the past did Israel, Mexico, and Japan.

Among the advanced countries, there is also fear of becoming branch-plant countries in relation to the U.S. (Canada and France have particularly expressed this concern). Such countries are aware that the MC has a national address and a national (often American) character as well. U.S. investments in Europe, though relatively smaller than in Canada, tend to be in the science-based industries and Europeans worry that they may have lost control over such industries as computers upon which they believe their future development depends. On the other hand, U.S. firms perform well in Europe; they thereby help to speed modernization and to improve productivity.

Prospects for Multinational Corporations

The MC seems here to stay; the prospects for its continued growth seem favorable though complex; the "interdisciplinary" nature of the MC leads to flexibility and adaptability enabling it to surmount the tangle of obstacles that may be placed in its path. The MC is rich and, within its sphere, powerful. Its management is able to circumvent many governmental barriers because business has gone international while governments have not. The MC surrounds itself with an aura of the future; it attracts excellent personnel, including managerial talent, R&D brains, tax specialists, and public-relations experts.

MC's can operate across national boundaries, counting on national governments to maintain reasonably stable price levels, trade barriers, and exchange rates.

However rich and powerful the MC's are, they are private profit-making enterprises that cannot be expected to pacify the world, let alone unify it. They are instruments of material progress, not tools of foreign policy. And since the U.S. is the home-base of most MC's, the spotlight is on the U.S. as well as on the MC. The U.S. has devised a number of specific policies to deal with particular MC problems as they arise, but usually on an ad hoc basis. What is needed is an internationally-coordinated approach to the MC and its problems.

It has been suggested that some of the problems requiring attention are the establishment of more uniform tax laws; common guidelines for setting intracorporate transfer prices; the coordination of national policies for preserving competition; a tribunal for resolving problems of conflicting jurisdictions; clarifications of the conditions on how far a home country government can enforce its laws against subsidiary companies in foreign countries; and the role of private foreign direct investment in the extractive industries.

The developed countries could coordinate policies through the O.E.C.D. more than at present, but no start seems to have been made yet on the more pressing problems concerning the developing countries. More could be done in this sector through U.S. organizations.

Research, Development, and Flow of Technical Information In a High-Technology Multinational Corporation

An MC faces a dual requirement for assuring that technical information will flow as needed between those units which can make use of it and for avoiding duplication of effort in various locations. This requirement poses a large and urgent problem of communications.

Each company which operates in this environment will have its own policies and procedures for handling this problem, which will differ in detail but which must be capable of satisfying the dual requirement.

In a typical MC, there are subsidiary units in several countries engaged in the same basic business field, but with specific constraints dictated by local conditions. These units may or may not report organizationally to a common group management. If they do the communications problem is simplified, but if they do not they are still tied together closely through commonality of market and product requirements. These units generally will have strengths and capabilities which vary and which will duplicate in some areas and be complementary in others. Each of these units will have its own technical staff reporting to a local technical management and engaged in the development of products to meet the local-market specifications, and in the development and control of production processes.

Although each separate unit will have its own technical staff, in most instances these staffs will not carry out the function of research or exploratory development which will normally be undertaken by central laboratories, staffed at the appropriate level. This is a necessary step to optimize efficiency since the diversified staff required for effective research and exploratory development cannot be supported by individual units. The central laboratories will be charged with the responsibility for carrying out the advanced programs which can underlie product development in various locations, and then with supplying the necessary information to those locations.

The overall technical coordination and control rests upon a general technical director and his corporate technical staff. This technical director is held responsible for all of the funds spent for RD&E and for the quality of each of the technical programs which are undertaken, either in the centr al laboratories or by the engineering staffs of the various company units.

The corporate technical staff undertakes, on a continuous basis, to monitor the programs which are being carried out at the various locations. Such monitoring is done by means of reports generated at the locations, by review meetings between corporate and local staffs and by periodic visits to review individual programs in depth. Through this continuous contact, the corporate staff is cognizant of all the work which is being done within the corporation and with the progress and status of each individual program. The requirements for information which may arise in any individual location can thus be reviewed by the staff, which should know in detail where the required information can be found and can take the necessary steps to see that the information flows.

As an example, when an individual company unit is seeking new products to supplement or expand its present product line, discussion with the corporate technical staff will often reveal work being done in other units which will serve as the basis for new products and of which the seeking unit may be totally unaware. Characteristically, discussions with technical staff will suggest new directions in which the existing technology in one or another of the units can be exploited. It is in this way that the major requirement for fostering flow of technical information is discharged.

The other aspect of the dual requirement is that of minimizing the duplication of technical effort in various parts of the MC. This requirement is satisfied by the control program which is exercised by the corporate technical staff. It is the objective of this staff to establish and monitor an optimum number of parallel development programs. Because of the diverse demands of the various national governments, designs produced in a single central laboratory could never meet the local constraints. One of these demands is typically that the companies supplying the requirements in a particular country have a technical capability in its own staff which can respond to specifications drawn up for it. This is why each company must have its own technical staff, but it also imposes the need to control the number of parallel developments in order to avoid undue duplication

The process by which this control is exercised is based upon the procedure for funding the programs. Each manufacturing unit is required to contribute to a central development fund on the basis of a percentage of its sales. This fund is used to support the central laboratories and to provide for the refunding of a portion of the payment to each of the units. This allocation is carried out on the basis of review and approval of proposals for development programs, initiated usually on an annual basis but also, when appropriate, at other times. The amount of funding will depend on a number of aspects of any particular program. Funding may be larger for a development in a new field and, of course, for programs where the commercial prospect appears particularly attractive.

Proposals for developments are generated and are supported by market forecasts, which will indicate the payback that can be expected from the expenditure requested. The various programs proposed in any period of time are reviewed by appropriate groups to insure that the direction proposed for the program meets the requirements of the largest number of potential beneficiaries and that parallel programs are combined or redirected so as to achieve the maximum return with the minimun of duplication. After several reviews of this nature, an overall program will have been refined and the component parts of it can be approved for funding for a specified period of time. The final approval of such funds rests with the corporate technical staff which thus has a mechanism for control of the program.

By a procedure such as this, coordination and cross-fertilization among all of the various company units is assured. Information flow between the units in various countries is facilitated by this process, and the information and technology available to the engineering staff at any given location is optimized.

Technology Diffusion via High-Technology Multinational Corporations in the Electronics Field[30]

In Europe, foreign subsidiaries have assured the swift diffusion of new

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[30] From John E.Tilton, The International Diffusion of Technology, Brookings Institute, 1971.

technology when the established industry leaders have faltered. More specifically, in the 1960's, when the European receiving-tube firms, which like their American counterparts, are large, diversified companies, delayed too long in providing devices made with the planar silicon technology, American semiconductor firms set up subsidiaries in Europe and concentrated on the new devices neglected by the domestic leaders. As a result, the U.S. MC's captured a substantial share of the European market which, in turn, stimulated the European receiving-tube firms to adopt the new technology.

It appears that the newer American subsidiaries have been much more effective at diffusing semiconductor technology in Europe than the older established American subsidiaries, the latter tending to perform more like their European counterparts. This suggests that the new subsidiaries may receive more help from their parent companies in the form of R&D results, know-how from production experience, specialists, and from other professional personnel, and, if necessary, venture capital.

In Japan, the established receiving-tube firms were better able to re-establish themselves in semiconductors, perhaps because foreign subsidiaries were barred as a matter of governmental policy.

Thus, new foreign subsidiaries of MC's provide an alternative to large established firms for quickly transferring new technology from the innovating to the immitating countries. The MC subsidiaries are not hampered by learning economies as are new domestic firms because they have special access to the technology of the innovating country. Moreover, as a result of their special ties, they can often acquire new technology from abroad as fast or faster than the large independent firms, even though the latter may have licenses and technical assistance agreements with major foreign producers.

Despite such advantages, there is considerable reluctance on the part of many countries to allow subsidiaries controlled by foreign interests to dominate the strategic and prestigious research-intensive industries. This, they feel, undermines national sovereignty. Moreover, it is stated in a modern version of the infant-industry argument, domestic firms will never become competitive unless they have the opportunity to acquire production experience and, in turn, the benefits of learning economies. For such reasons, some imitating countries have limited the activities of foreign subsidiaries.

The experience of Japan suggests that it is possible to ban foreign-controlled firms and still acquire new technology quickly from abroad. However, restricting foreign subsidiaries entails certain risks. Such firms, as European experience demonstrates, provide insurance that new technology will quickly disseminate in the imitating country when indigenous firms fail to respond as rapidly as desirable.

The risks involved in barring foreign subsidiaries are reduced when the established firms are exposed to other forms of discipline. This may come from new domestic firms if entry barriers are low, from other established firms if competition for the domestic market is vigorous, or from foreign firms if overseas markets are important. While the risks may be reduced, they cannot be completely eliminated, for in barring new foreign subsidiaries an imitating country cuts off a potential diffusion channel that just may be needed. Of course, this disadvantage may be offset by other considerations. This is a political decision that involves weighing competing national goals.

Technology Transfer via Vertically-Integrated, Multinational Corporations to Developing Countries

Those companies whose operations span both advanced (AC) and developing (LDC) countries often find themselves transferring technology from the AC to the LDC. This is only likely to continue, though selectively, and perhaps even accelerate in the future as LDC's raise their standards of living. But the ability of an LDC to absorb successfully foreign technology depends not only on the transfer of technical knowledge and methods, but also on the ability to introduce new and foreign developments in those administrative, financial, and social fields which constitute the infrastructure of industrial activities. Another factor of concern to a VIMC is that those LDC's seeking to emulate Japan's meteoric economic rise may note that Japan successfully absorbed foreign technology while essentially barring foreign subsidiaries. However, compared with most LDC's, Japan was already quite advanced technologically and educationally. It seems more likely that an LDC in its early stages of development will profit more from the operation of an MC, especially in those situations where centralized control is the only means by which a technology, particularly an advanced technology, can be effectively transferred. As the scale, complexity, and pervasiveness of the technology increase, governments in LDC's become more and more involved. This involvement is obviously greatest in the defense industry and in the basic and service industries such as iron and steel, electricity supply, and telecommunications.

An important point is that the level of technology which is transferable depends very strongly on the level of technological sophistication of the receiving country. The two levels should be matched. But the trend is everywhere upwards; as the level of educational, technological, and social sophistication rises in a country, so will the level of technology it can absorb. This is simply another corollary of the fact that today's high technology in an AC becomes its low technology as LDC's acquire the capability of absorbing it. For example, the manufacture of automobiles, once confined to only a few technologically-advanced countries, is being carried on in a number of LDC's which have acquired the necessary industrial and management skills. On the other hand, these LDC's are mostly not at the stage in their development where they can carry out much independent R&D concerning automotive transportation. It is the AC's who can investigate new forms of motive power, sophisticated safety devices, and traffic-control systems at the present time. Yet in due course, these technologies will join the procession to the LDC's.

The old picture of an LDC being regarded as simply a source of raw materials for which they are paid in cash or manufactured goods from the AC is no longer valid—it represents only the first stage in the development of a country. The payment nowadays has often to be in the form of exports of technological and managerial capabilities, a function which the VIMC is in an excellent position to perform. But the message is clear. For that part of the MC operating in the AC to remain viable, it has to keep generating new technology. Otherwise, the LDC part of the MC becomes increasingly self-sufficient, the operation in the AC sees a shrinking market, jobs are lost, R&D declines, and the downward spiral leads to a relative lowering of the standard of living. It is a difficult but exhilarating endeavour for a country, or a company, to become the leader, technologically, but it is even more difficult for it to remain on top. To do so must also become a continuing exhilarating enterprise.

The stages and methods by which technology transfer to LDC's take place within an MC are varied. The transfer may occur by direct investment, i.e. by the setting up of local manufacturing subsidiaries; or by licensing and patent agreements; by the transfer of managerial personnel; or by the setting up of local R&D facilities, usually at a later stage of sophistication. But the actual transfer of information and experience can be improved by direct action to raise the level of education, training, and competence of individuals in both technical and managerial knowledge.

It is necessary to regard the transfer of technology as part of an interacting system and to take a systems approach to it. Lack of such systems planning, for example, can lead to the introduction of large raw materials plants before the secondary processing industry is ready to absorb the output. Again, the wrong choice of a research project may cause difficulties in the absorption of the technology for countries which have not appreciated how the results of these research projects will affect their own developing technologies. To an increasing extent, industry in the AC's is being forced to plan on a world scale in order to secure the success of their particular technology in the widest possible market. Otherwise, societies may find themselves compelled to accpet a given technology even when it is not in their best interests to do so. Urban pollution and congestion could be changed by alternative approaches to the technology of transportation and building construction, but it is extremely unlikely that any developing society can at this time resist the growth of the conventional motor vehicle and its associated highways. Also, new technologies may result in an LDC having its economy based on the wrong raw materials—for example, the rise of the synthetic fiber industry has by-passed LDC's which were basing their economic growth on natural fibers. Thus LDC's have to recognize the importance of new technologies and the timing of their introduction.

The problem for an MC is not so much one of choosing between basic, intermediate, or advanced technologies but of selecting and encouraging compatible technologies with built-in opportunities for development to match world economic and productive trends. For example, instead of launching into large-scale basic production, it may be more effective to encourage programs of industrial development through the establishment of a final products industry using imported raw materials, and gradually build up the basic and integrated industries after a proper market size has been reached.

Role of Research and Development

There is evidence in some LDC's that a correlation exists between investment in indigenous R&D and importation of technology. The investment in R&D is not merely complementary to the importation of technology, but is a prerequisite for the absorption of the transferred technology into society. The Japanese regarded their own early R&D investment as the fertilizer which encouraged the "seeds" of new technologies to grow. The R&D activity should, therefore, be firmly based on fields where applied research is necessary to foster adaptation of the imported technology.

But while LDC's may see the need for more indigenous R&D, the MC's and the AC's may not. It is often felt that the creation of virtual monopoly conditions by foreign companies precludes the growth of R&D in the LDC. Besides these arguments it is often true that there is not sufficient qualified manpower in the LDC to carry out effective R&D.

R&D in the LDC is often regarded as a technical service backing up the adaptation and use of the imported technology and ensuring quality control. Arguments for investment in more fundamental research in the LDC have to be based on general premises, such as that improved understanding of structure-property relationships in materials is of importance in all forms of technology, or that science is a potential industrial strength because the quality of tomorrow's technology depends on the influence of the scientific effort today. Nevertheless, the mere accumulation of scientific research will not contribute very much to success in industrial development unless the results are actively exploited. Generally, it will be more effective if scientists and engineers in LDC's are employed in fairly well defined applied research and development coupled to industrial needs. However, applied research provides substantial scientific knowledge, and work in advanced technologies can create both the capability and desire to advance further in the relevant fields of basic science.

Where MC activity in an LDC involves only the manufacture of some components for inclusion in an assembly, most of which is imported from the parent company, there is no investment in R&D in the LDC. Likewise when the MC is forced into producing in the LDC because of tariffs or similar economic policies, the technology may be transferred simply from the parent country with minimum possible expenditure on adaptation or development. Only if really interested in the investment as a long-term proposition aimed at a market expected to expand, and in the potentiality of an export market, does the MC consider it worthwhile to set up an R&D unit in the LDC. Sometimes, though, MC's do have to establish local R&D units to adapt technology to meet local standards and regulations. These activities can be regarded as final development extensions of the R&D conducted by the MC in the home country. The latter R&D embraces longer-term research and is often carried out as a corporate activity in central research laboratories. Such laboratories can provide excellent training grounds for personnel who will subsequently return to the local R&D in the LDC. However, unless these subsidiary R&D units can offer reasonable facilities and career prospects, they may accentuate the brain drain from the LDC.

In dividing R&D effort between the parent country and the receiving country, the MC has to ensure that both activities are above critical size for effectiveness, otherwise the local R&D units are likely to confine their efforts to quality assurance and trouble-shooting. Another consequence of the critical-size requirement is that the final development work may be organized, instead, into geographically convenient units, with one unit serving several countries.

The justification for the transfer of foreign technology lies essentially in the reduction of lead time, coupled with enhanced commercial viability over the long term. The stages in the R&D transfer occur in parallel with the growth of the technology and its market in the LDC. During the early stages, R&D is mostly concerned with quality assurance, trouble-shooting, and customer-oriented service functions. Later, the R&D will be related to manufacturing and assembly processes, to be followed in some cases by R&D of an exploratory development or even a basic nature. Again the lesson for the AC is that when it sees a given technology, including increasingly sophisticated levels of R&D, slipping to the LDC, it must find new technologies to take its place.

Some Concluding Remarks Concerning Multinational Corporations[31]

The MC and its companion concept, the global market, are under attack at present. It is argued that MC's are responsible for exporting U.S. jobs, draining capital and technology, reducing exports, and acting as neocolonialists. Perhaps here and there and in the short run such arguments are justified; perhaps some jobs, capital and technology are siphoned off in areas where the U.S. is apparently non-competitive. And perhaps some MC's have naively been neocolonialist. But MC's also create jobs, trigger exports, earn revenue, allow U.S.-based firms to compete locally more effectively, and serve in some cases as a pipeline for a reverse flow of foreign technology to the U.S. For the foreign country they are a source of new products, needed know-how and technology, and a breeding ground for developing indigenous leadership. Furthermore, no firm acting as a neocolonialist will long be tolerated these days. Finally, it is apparent that if a "U.S." MC doesn't get the business, someone else's will.

There are also larger considerations. Trade and business help break down boundaries, oil the machinery of international relations, and bring people together at the grass roots. Commerce is a natural process, a system for redistributing resources, but one recurring element is protectionism, which seems to ebb and flow in concert with economic fortunes and geopolitical maneuvering. Protectionist measures almost invariably fail in the long run and perpetuate, instead of cure, the ills that caused them to be devised in the first place. Fortunately new natural processes arise to get around such obstacles, today's MC being a manifestation of one of these natural processes. They are well on their way to creating a supranational network for transferring ideas, technology, know-how, and well-being that bypasses official channels which are often cumbersome or ineffective.

TECHNOLOGICAL INNOVATION IN THE INTERNATIONAL SPHERE

International Comparisons of Technological Prowess

Much of the international information on innovations in this report came

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[31] Based on Patrick R.McCurdy, Chemical & Engineering News, 1, (Nov. 22, 1971).

from major studies of technological leads and lags between the U.S. and other countries undertaken by OECD in the mid-1960's and later. Their main conclusions for various industrial sectors are summarized in Table 8.65. Perhaps contrary to popular belief, the conclusion seems to be that for the civilian sectors studied very few large gaps appear except in solid-state electronics and computers. It should be noted that major industrial sectors not studied included, for example, military hardware, aircraft, ships, automobiles, ceramics, and wood products; services such as railways, telecommunications, and electricity; and industrial processes such as mining, extraction and refining. Thus, it would be dangerous to draw overall conclusions about U.S. leadership or lag in the mid-1960's from these data above. Instead, the data may be taken to show simply that the U.S. is in a competitive world, that others are technologically just as capable, that the U.S. does not have some inherent gift guaranteeing technological superiority, and that the U.S. cannot afford to relax its efforts to "stay in the race". Importantly, though, by whole-hearted commitment, the U.S. can hope to exert some influence on its direction, consistent with benefits for mankind.

Some of the conclusions and lessons for U.S. technology that might be drawn from the preceding technological comparisons are:

(a) It appears that by and large the results of R&D in MSE outside the U.S. have not been too impressive so far except in certain areas of processing technology. But it is this latter which is growing increasingly important if a country is to keep its competitive edge—the trend seems to be toward process innovations rather than product innovations.

Until recently, the U.S. has generally led in product innovation, particularly in the high-technology, frontier industries. It is all the more understandable, therefore, that other countries have moved to concentrate on process improvements—there is no sense in inventing the same product twice. If the tendency of the U.S. is to generate new products in order to meet the unique challenge of the U.S. market, the tendency of the Europeans and the Japanese may be to find ways of producing cheaper and better versions of those products.

(b) An impressive number of important chemical and metallurgical process have stemmed from Europe in recent years. For example, Italy's Natta technique and Germany's Ziegler process for producing polyethylene, also Germany's catalyzation processes, as well as her methods of producing high purity silicon, are all widely licensed. The list continues to grow and the world-wide import of these processes covering relatively conventional products tends to balance the export of frontier technologies from the U.S. The proclivity towards process innovation can be an asset, for process innovation is reflected sooner in the economic growth pattern than is the innovation resulting from exploration of the more distant frontiers of technology. It is therefore a more attractive basis of investment where R&D funds are limited. At the same time, this philosophy may not attract the more imaginative investigators, who generally prefer to work on the frontiers of technology where there will be a longer range pay-off.

Table 8.65 Performance in Originating Innovations (From Gaps in Technology—Review of situation to mid-1960's)

Electronic Computers
Europe effective at first. U.S. assumed leadership and gap has steadily widened since.
Semiconductors
U.S. has had strong lead from the start.*
Pharmaceutical Products
No great performance differences between countries though U.S. has slight edge.
Plastics
No important gap between countries in bulk plastics. U.S. has had clear lead in specialized plastics.
Iron and Steel
No fundamental disparities in technical know-how. Differences in rate of application of new technology for various reasons, but eventual convergence towards a standard appears to be the rule.
Machine Tools
No major technological gap between countries though varying gaps, plus and minus, for specific machine tools.
Nonferrous Metals
No gap in Al, Cu, Ni. U.S. leads in Ta and, to lesser extent, Ti.**
Scientific Instruments
No overall gaps in this diversified sector. Leadership in many countries. U.S. leads in electronic test and measuring equipment. Europe and Japan strong in nuclear, biomedical, process control.
Man-Made Fibers
No obvious gaps.

[*] In solid-state electronics, the U.S. has remained the technological leader, although its commercialization and marketing position in the field of consumer electronics has been particularly challenged by Japan in recent years. Virtually all the significant new devices and sophisticated processes for making them have emanated and are still emanating from private industry in the U.S.

[**] However, the following quote by W.H.Dresher in "Metallurgical Engineering in the United States—A Status Report," October 1973, is of interest: "The copper industry…has turned to foreign-developed processes for a large portion of its new capital investment. The nation's two newest copper smelters…are both based on European technology. (One) is exclusively European (with a Norwegian electric furnace, a Belgian siphon converter, and a German acid plant)…(the other) is based on a Finnish flash smelting process."

(c) The industrial effectiveness of a country seems to depend upon its capacity to draw on and utilize existing knowledge, wherever it has been generated, perhaps more so than on its ability to generate new knowledge itself. This still requires the availability of scientists and engineers who can absorb, use, and adapt scientific knowledge and new developments.

(d) If the Japanese had not been willing to buy their technology and had sought to generate it afresh, both their growth and their balance of payments would have been impaired. On the other hand, if they failed to move into innovative activities at some stage, the failure might also have been informative from an economic standpoint.

(e) Identification and understanding of market opportunities are critical for successful innovation. Innovation is stimulated by competition for a certain market.

Some General Characteristics of the Innovative System

The international data-gathering and comparisons made by the OECD in the mid-1960's led to some conclusions concerning factors that are important for successful innovation. These factors are as applicable today as they were then, even though objectives and markets are changing rapidly. They are summarized below:

Essential Components

Successful technological innovation is favored by: (a) scientific and technological capability, (b) market demand, and (c) industrial firms responding to the pressures and incentives of competition and profit.

"Technology-Push" versus "Demand-Pull"

The majority of innovations are initially stimulated by a clear definition of market needs. However, the remaining technology-stimulated innovations are generally more radical in nature and can then lead to many innovations of the market-oriented sort.

Differences Amongst Industries

In spite of R&D activities being concentrated in relatively few industrial sectors, many other sectors of the economy benefit through being suppliers or customers of the research-intensive industries. However, the latter are not particularly capital-intensive, nor are they relatively big consumers of raw materials.

Three factors suggested to explain variations in research-intensity among industrial sectors are: (a) variations in technological opportunity, (b) nature of management, and (c) market opportunities.

Technological advances in materials, automation, and informatics offer considerable opportunities for application in sectors which are not at present research-intensive. If managements in these sectors do not exploit these opportunities they may well be seized by the research-intensive industries.

Industrial Structures

Both large and small firms play essential roles in the process of technological innovation, and these roles are complementary, interdependent, and ever-changing.

They are complementary in that larger companies have tended to contribute most to innovation in areas requiring large-scale R&D, production or marketing resources, whereas smaller firms have tended to concentrate on the production of specialized but sophisticated components and equipment—often with large firms as customers. However, small companies have often made very major innovations, either because large firms have not had effective methods of evaluating and implementing radical proposals, or because major innovations often involve great uncertainties so that even the best managed of large firms may let important opportunities slip through their fingers.

The roles of large and small companies are interdependent because small firms are often started by scientists and engineers with previous experience in large firms. Sometimes the establishment of these “spin-off” companies has been actively encouraged by the large organizations. Sometimes it has happened by default. Small science-based firms flourished earlier in the U.S. than in other OECD countries, partly because of a more favorable market and financial environment and also a greater degree of personal mobility.

Finally, the roles of large and small companies are ever changing. As a technology matures in one sector, scale factors tend to become more important. But, as one technology matures, another enters a period of growth, thereby opening other and new opportunities for the smaller firms. Hence, there is a need for mobility and flexibility of innovative resources—and particularly skilled manpower and capital—in order to respond to the ever-changing opportunities and requirements of technological innovation.

Size of Markets

The size and sophistication of the U.S. market has been a key factor in its innovative strength. However, in several instances strong industries in small countries have been able to respond to demands for innovation on world markets.

Management of Innovation

Technological innovation poses many difficult and sometimes novel problems to management, given the uncertainties and long-time horizons involved, and given the need for communications across disciplinary and functional boundaries. Hence, a need arises for "entrepreneurial" organizational forms, with flexible definitions of responsibilities and large possibilities for lateral communication, capable of evaluating and responding to new—and often unforeseen—technical and market circumstances; hence, also, the need for commitment by top management to taking risks.

Study and teaching specifically related to the process of innovation may be particularly valuable—for both research workers and managers—given the difficulties of applying successfully many of the conventional management techniques. Furthermore, the increasingly worldwide competitive and market environment within which technological innovation takes place requires a careful definition of the role of R&D in achieving company objectives: specifically, the definition of the appropriate mix of "offensive", "defensive" and "absorptive" R&D and strategies.

Role of Fundamental Research

Universities play a vital role in enlarging the pool of basic knowledge and trained manpower on which industries can draw. Also, strong links exist between national potentials in fundamental research and national strengths in technology. The effective absorption of fundamental knowledge into industry requires fundamental research efforts in industry also, at the higher levels of technological development. The knowledge-transfer process is most effectively done through personal contact and mobility. Fundamental research at the universities is also stimulated by industrial strength in innovation.

Governmental Role in Creating a Climate Favorable to Technological Innovation

Three key characteristics are identified: (a) the outcome of innovative activities is uncertain, so that risk taking must be rewarded, and individuals and institutions must have the ability to adapt to new and unforeseen situations; (b) innovation often implies uncomfortable change, so that pressures must exist for change and its social costs reduced as far as possible; and (c) transfer of technological knowledge is mainly "person-embodied".

These characteristics suggest a number of objectives for government policy, such as:

- ensuring industrial competition, as the main pressure for technological innovation;
- ensuring equitable rewards for innovations, through the tax and patent systems;
- ensuring that regulations, codes, and standards take account of both the social costs and benefits of the innovative process, as well as the flexibility and pluralism required for successful innovation;
- having active regional and manpower policies to deal with the changes in industrial and skill patterns brought about by technological change;

- using government procurement to upgrade the technical level of industry, and to couple technology more effectively to overall social needs;
- encouraging the mobility of scientists and engineers, especially in and out of governmental laboratories;
- identifying policy measures to encourage science-based entrepreneurship;
- ensuring continued trade and capital liberalization, thereby heightening the pressures and incentives for technological innovation in all OECD countries, and maintaining a rapid, international spread of the benefits of new technology.

A Study of Success and Failure in Innovation

Although this in-depth study* has so far dealt only with the chemical and scientific instrument industries, its findings might prove to be of more general validity for the field of MSE.

Fundamental Features of the Approach

SAPPHO was originally conceived as a systematic attempt to test various hypotheses concerning the factors which lead to success in industrial innovation. Many such hypotheses have been advanced in the European and American literature, but few if any have been satisfactorily tested and some are mutually contradictory. A kind of "folk-wisdom" or "mythology" has grown up, which is supported by fragments of empirical work, but lacks a structured foundation. The SAPPHO project was designed to contribute towards the development of a more satisfactory basis for innovation studies by testing a variety of possible explanations, and hopefully eliminating some, while substantiating others. Perhaps the most important single feature of the method was the effort to measure a pattern or profile of successful innovation. Much earlier work had attempted to look at single factors held to be important. While not disregarding the importance of these single factors, the starting point here was the view that successful innovation was a complex process involving the interaction of many factors. The successful innovator needs to get many things right, not just one. In particular the validity of explanations exclusively in terms of either R&D power or market power was doubted. The "R&D" explanations were more fashionable in the 1950's, whereas the "market" explanations have become more prevalent recently. It was hypothesized that most successful innovators would have to perform relatively well in both and that the art of innovation management lay in matching the changing requirements of the market with the kaleidoscopic new technical possibilities emerging from scientific advance.

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*Carried out at the Science Policy Research Unit, University of Sussex, United Kingdom—Project SAPPHO.

Definitions of “Technical Innovator”, “Business Innovator”, and “Chief Executive”.

In the innovation literature, there is a great deal about the critical role of key individuals. Not only “heroic” theories of innovation but also more prosaic accounts emphasize the part played by entrepreneurs, managers, and inventors.

For the purpose of the SAPPHO investigation, therefore, an effort was made to distinguish between various key “roles” in the conduct of innovation. Although these roles have been recognized in much of the earlier innovation literature, they are not always identifiable from the formal titles used in firms. The job title may vary a good deal, but it was the role which an attempt was made to identify, defined as follows:

(a) “Technical innovator”. The individual who made the major contributions on the technical side to the development and/or design of the innovation. He would normally, but not necessarily, be a member of the innovating organization. He would sometimes, but not always, be the “inventor” of the new product or process.

(b) “Business innovator”. That individual who was actually responsible within the management structure for the overall progress of this project. He might sometimes be the same man as the “Technical Innovator.” He could be the Sales Director, or Chief Engineer. Occasionally, especially in smaller companies, he could be the chief executive for the organization as a whole.

(c) “Chief executive”. The individual who is formally the head of the executive structure of the innovating organization, usually but not necessarily with the job title of “Managing Director”.

In every case, there was an identifiable “chief executive”, but there was not always an identifiable “business innovator”, and quite often there was no identifiable “technical innovator”. No effort was made to force individuals to assume these roles if they were not readily identifiable, since one of the objectives of the inquiry was to assess the contribution of outstanding individuals. In order to clarify this, one other category or “role” was distinguished—“product champion” —which might sometimes be performed by the same individual as the technical innovator, or chief executive.

(d) “Product champion”. Any individual who made a decisive contribution to the innovation by actively and enthusiastically promoting its progress through critical stages.

Nationality of Innovating Organizations

Of the 27 innovations developed outside the U.K., 14 were successes and 13 failures. Of the 31 developed in the U.K., 15 were successes and 16 were failures.

Pairs Used

The results of the SAPPHO study apply to 29 paired comparisons of successful and unsuccessful attempts to innovate in two industries—chemicals and scientific instruments. Many characteristics of these 58 instances were systematically measured and compared in an endeavor to disclose the patterns of success and failure. The 29 pairs are listed as follows:

Scientific Instruments

1. Amlec Eddy-Current Crack Detector
2. Milk Analyzers
3. Foreign-Bodies-in-Bottles Detector
4. Roundness Measurement
5. Scanning Electron Microscope
6. X-Ray Microanalyzer
7. Digital Voltmeters
8. Optical Character Recognition
9. Atomic Absorption Spectrophotomer
10. Electromagnetic Blood Flowmeter
11. Electronic Checkweighing I
12. Electronic Checkweighing II

Chemicals

1. Acrylonitrile I
2. Acrylonitrile II
3. Caprolactam I
4. Caprolactam II
5. Ammonia Synthesis
6. Ductile Titanium
7. Extraction of Aromatics
8. Steam Naptha Reforming
9. Extraction of n. Paraffins
10. Urea Manufacture
11. Oxidation of Cyclohexane
12. Hydrogenation of Benzene to Cyclohexane
13. Phenol Synthesis

14. Accelerated Freeze-Drying of Food (Solid)
15. Methanol Synthesis
16. Acetic Acid Preparation
17. Acetylene From Natural Gas

Summary of Main Findings

(a) As expected, only a few of the 201 measures which were made for each pair differentiated between success and failure. Most would-be innovators share many characteristics in common, whether they fail or succeed. They almost all conduct organized R&D, form project teams, take out patents, attempt forecasts, and encounter bugs in development.

(b) Even where they differ, many of these differences show no consistent pattern. For example, differences in size, formal management techniques, publications policy, scale of R&D department, rate of growth, and incentives are apparently unrelated to success or failure in innovation.

(c) The clear-cut differences within pairs which do form a consistent pattern related to success and failure may be summarized as follows:

(i) Successful innovators have a much better understanding of user needs. They may acquire this superiority in a variety of different ways. Some may collaborate intimately with potential customers; others may do thorough market research or have the necessary experience of user requirements. But however required, this imaginative understanding is the hallmark of success.

(ii) Successful innovators pay much greater attention to marketing. Failures were sometimes characterized by neglect of market research, publicity, user education, and customer problems.

(iii) Successful innovators perform their development work more efficiently than the failure ones, but not necessarily more quickly. They get the bugs out of the product or process before it is launched, not after the user complains. They usually employ a larger development team on the project and spend more money on it. This applies even when the successful firm is smaller than the failure one.

(iv) Successful innovators make more effective use of outside technology and scientific advice, even though they perform more of the work in—house. They have better contacts with the scientific community in the specific area concerned (not necessarily in general).

(v) The responsible individuals in the successful cases are usually more senior and have greater authority than their counterparts who fail. In the instrument industry, they have more diverse experience including experience abroad. The greater power of the innovators in the successful instances facilitates the concentration of effort on the scale which is needed and also on the integration of R&D and marketing.

(d) An important limitation of the findings must be stressed. The SAPPHO investigators do not know the “universe” of innovations and therefore cannot say how far their sample is representative. They believe it to be so, for the two industrial sectors considered but cannot prove this. Moreover, 29 pairs is still rather a small number of cases from which to generalize. The results showed some differences between the two industries investigated and the pattern of successful innovation in other branches of industry may well differ in important respects.

A British View of U.S. Technological Leads and Lags

With a few notable exceptions, the British have not been especially aggressive or skillful in technology. An appraisal of the British position, vis-a-vis the U.S. and Western Europe, is presented in Christopher Layton’s study, “European Advanced Technology, A Programme for Integration,” (1969, PEP). Excerpts—

“—Pure research accounts for only 5–10 percent of the cost of inventing and developing a product to the production stage. The rest is accounted for by marketing and research and development;

— Larger American size, springing from a larger market, has conferred larger financial resources for marketing and research and development;

— Management skills, and training in them, are a second factor in America’s technological predominance;

— The dramatic growth of the U.S. Government’s spending on research and development…has been concentrated in two sectors—aerospace and electronics—where the ‘gap’ between America and Europe is most pronounced.

— The demand for advanced metals for the space and aircraft industries has advanced the whole science of metallurgy, and played a part in giving the U.S. steel industry—and even the gigantic, but long backward U.S. Steel Corporation—a new lease on life;

— Outside nuclear power, electronics, and aviation, the stimulus of the U.S. Government has been far smaller;

— A whole new range of management techniques—operations research, systems analysis, statistical quality control, and so on— …have…been developed in defence and space programmes, and increasingly applied elsewhere;

— Crucial to the dissemination of knowledge in Federal Government programmes has been its open patent policy;

— Perhaps the most decisive difference between U.S. and European practice is the allocation of 5 percent of all government contracts to cover company overheads and ‘independent research;’

— A government in which scientists and engineers have top jobs is far more likely to be creative and alert to new scientific ideas…’

— Mobility of people and ideas has conspired to produce such unique social institutions as Route 128 in Boston…;

— The initially small, but fast growing advanced technology firm is, indeed, as crucial to the U.S. ‘miracle’ as the established giant;

— If the small firm plays a key role in invention, the large is essential for mass marketing and production, for development in industries where plant is expensive, and for fast development on a broad front;

— The strength of America’s advanced technology industries lies in the remarkable dialectic between large and small companies, in a ring where the antitrust ringmaster is always promoting competition, and where there is a massive public as well as private market for advanced ideas;

— If the strength of America is its practical men, its skill in carrying out specific tasks, its weakness perhaps lies in the absence of a philosophy for policy. It has been called a reservoir of undirected power;

— What distinguishes American support for advanced technology is the pursuit of difficult goals, under competitive conditions, at high speed, and in an economy which already possesses a huge highly skilled labor force and powerful industrial firms;

— West European states spend only a quarter as much as America, and a smaller proportion of national income. Yet their efforts are still divided between 18 different policies and administrations.”

Views such as these seem to center on the proposition that although the U.S. has institutionalized change in the more exotic elements of technology, it has neglected to do so in the more prosaic areas which provide the underpinning of much of the nation’s economy, and which ultimately go to pay for the far-out exploits. Why is Japan surpassing us in steel? Poland in coal research? Yugoslavia in shipbuilding? England in plate glass? Sweden in housing construction? Germany in automobiles?

A U.S. View of U.S. Technological Leads and Lags

Up until about 1967 there was a general feeling that the U.S. had an unassailable technological lead over the rest of the world. Since 1967, this view has given way to almost the opposite, that the U.S. is lagging more and more in the technological field. These views have been put in perspective recently by H.Brooks;[32] this concluding section is based on his analysis of five propositions which are directly pertinent to the role of MSE as well as to the broader arena of science and engineering. These propositions are analyzed in terms of bygone perception, and the likely situation, as follows:

(a) The Technology Gap

Bygone Perception—There is a technology gap between Europe and the United States, and this gap is steadily widening to the latter's advantage.

Current Perception—Europe and, most visibly, Japan and overtaking us in the export of high-technology products, and many European and especially Japanese products are displacing their American counterparts in world markets. At the same time these nations are showing an even more evidently superior performance in low-technology industries, whose exports are taking over U.S. markets.

Likely Situation—It is clear that the technical and economic inferiority of Europe in the early post-World War II period was unnatural and was certain to be overcome when favorable social and economic conditions returned there.

What we are seeing, in fact, is the emergence of an increasingly international science, technology, and economic system in which the very concept of superiority and inferiority has less and less meaning.

Other industrialized nations most likely will continue to close the gap, but will approach a common asymptote with us—that is, reach the same approximate level—rather than pass us on a steeply rising curve.

(b) Space-Defense Spin-Off

Bygone Perception—The technology gap is primarily the result of large U.S. governmental expenditures for research and development in defense, space, and nuclear energy.

Current Perception—The concentration of our R&D effort in a narrow range of sophisticated technologies for defense and space has diverted innovative talent and energy as well as venture capital away from industry and from public needs other than defense and national prestige. (The spinoff effect has been greatly exaggerated.)

Likely Situation—The current diagnosis of the impact of space-defense R&D on innovation in the rest of the economy is probably essentially correct. The United States is long overdue for a period of "catch-up" in other areas, a change in priorities toward civilian technology.

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[32] Harvey Brooks, "What's happening to the U.S. lead in technology?", Harvard Business Review, Vol. 50, page 110, 1972.

(c) Support of Basic Research

Bygone Perceptions—The U.S. technological lead is accompanied by, and in part due to, its superior performance in virtually every significant field of basic science.

Current Perceptions—Although the U.S. still enjoys a lead in many areas of basic science, it is disappearing fast as the Federal Government withdraws its support of graduate training and research.

Likely Situation—In basic research we are dealing with an internationalized system, in which knowledge and talent move with ever-increasing freedom. Not surprisingly productivity in science correlates closely with GNP, and the U.S. contribution to world science will tend to decline proportionately as its share of world GNP declines.

(d) Graduate Education

Bygone Perceptions—A prime source of the lead in science is our superior system of graduate education combined with the system of graduate education combined with the system of research grant support of individual professors, in which projects are chosen on the basis of open, competitive evaluation by committees of scientific peers in the same or closely related fields. The project grant system has fostered a creative scientific entrepreneurship which stimulates greater originality in science and more rapid identification and exploitation of potential applications of basic science.

Current Perceptions—Both inside and outside academic ranks, there is serious disenchantment with the system of graduate training in science. Industry sees it as too narrow, too specialized, and too remote from the real-world problems with which technical people in industry must cope. Many students and the public see graduate education as irrelevant to the most pressing problems of the modern world and the system itself as self-serving and “elitist”, designed to exploit students and the public purse for the greater personal glory of professors.

Likely Situation—The superiority of U.S. graduate education over European has probably always been exaggerated. Despite the criticisms, the U.S. system is probably basically healthy. It is actually highly adaptable and is adapting to new priorities, but the time lag produces a feeling of crisis.

(e) Manpower Situation

Bygone Perceptions—The U.S. is experiencing a severe shortage of scientists and engineers in almost every category, leading to a continuing and even an accelerating immigration of foreign scientists, engineers, and doctors.

Current Perceptions—In almost all fields of science there is a surplus of Ph.D’s which the academic institutions should have foreseen. It will grow steadily worse throughout the 1970's unless drastic steps are taken to curtail graduate programs and discourage students from entering graduate work—or perhaps even higher education.

Likely situation—The present "surplus" of scientists and engineers in the U.S. is the product of the coincidence of several factors: the cutback in research-intensive space and defense activities, the economic recession, and the financial crisis of higher education. While there is little chance of a return to the shortages of the 1950's and 1960's, the present surplus will probably work itself out through expansion of the career opportunities considered appropriate for Ph.D's, stabilization or a slight contraction of the output of graduate schools, and a relative reduction of the salary levels of scientists and engineers to bring supply and demand into better balance. At the same time, the rapid expansion of European higher education is likely to lead to similar "surpluses" there within a few years.

H.Brooks' study is very relevant to the questions of civilian vs. defense R&D and of high technology vs. low technology. Quoting from the same article:

"There is considerable evidence in support of the notion that the deterioration of the U.S. trade balance reflects a comparative deterioration of the U.S. trade balance reflects a comparative deterioration in its technological performance, particularly in the more mature low-technology industries. Furthermore, this deterioration has been going on for some time.

"The U.S. government is beginning to act on this hypothesis, responding by a step-up and expansion of direct and indirect subsidy of industrial research. Then Secretary of Commerce, Maurice Stans made a clear statement of this new policy in 1971 to the Science and Astronautics Committee of the House of Representatives:

'The magnitude of the problem is such that we cannot rely upon normal forces to maintain our advantage in technology. We are at the forefront in many technological areas. The costs of breaking new ground in some of these areas are high—higher than private companies or perhaps even private consortia are able to justify because the risks are so great.

'We have recognized this fact in space, defense, and atomic energy areas. Other trading nations have recognized it in the area of civilian R&D and have taken steps to assist technological development. If we are to maintain our advantages in this area we must first of all accept the idea that it has become a proper sphere of government action.'"

And again from Brooks:

"The technical challenges presented by space and defense programs were often much more interesting than those of civilian industry and attracted more than their share of the best talent and the best-trained people, quite apart from salary. The result was to overprice the innovation process in these programs, which caused the lag in civilian technology and the gradual deterioration in our advantage over competitors. It is not surprising that the lag particularly affected the low-technology or mature industries, whose innovative investments tend to be most sensitive to economics."

And further:

"Full utilization of the current R&D volume, redeployed for civil purposes, would imply an enormous expansion in growth or transition to a much more research-intensive style of doing things in both the private and the public sectors. But this transition may require a long learning period before research can be really productive. Just such a long transition period was necessary in the military field, where in the pre-war period the military mind was synonymous with technical backwardness.

"The Federal Government's civilian R&D activity is expanding at a high rate, but it starts from such a small base that it can compensate for only a small percentage decrease in the space-defense areas. Growth is slowed by the different mix of skills needed. The effective utilization of research in a new area of application requires the rather slow and painful creation of new institutional mechanisms and linkages between technical people and ultimate users, linkages that are not assured by the mere generation of the appropriate science" (but require more emphasis on engineering).

And referring to students:

"As a group the potential scientists are apparently highly inner-directed and respond only marginally (for example, by shifting from biology, or from physics to mathematics) to external influences."

Brooks concludes:

"I believe that the United States is experiencing only a few years earlier some of the forces and trends that will become worldwide among industrialized countries: saturation of the population able to undertake science and technology, competition of social welfare and other public expenditures for the government budget, increased public preoccupation with the side effects of technology, disenchantment with science on both the right and the left of the political spectrum, and increased preoccupation of society with equality rather than excellence.

"Furthermore, the scientific system is increasingly international, so that the very concept of national superiority in science or technology is obsolescent. It will be harder and harder to tell who is 'ahead' or 'behind' as frontier science is conducted in multinational institutions like C.E.R.N. and as technology is introduced and diffused by international corporations that will become truly multinational and identify less with particular home countries.

"The United States will never again enjoy its enormous superiority of the first half of the 1960's, but neither is it about to be overtaken dramatically by Europe or Japan. Rather, we are all approaching a common asymptote, which will probably represent a condition of slower growth, both in science and in the economy at large, than we have been accustomed to in the recent years."