Organization of Scientific Activities in Norway

Government, industry, and research have joined forces to develop the country's research capacity.

Robert Major

Norway, which has only 1/25 the area and 1/50 the population of the United States, is by far the smallest of the four countries to be reviewed in this series of articles. I do not know why my country has had the honor of being selected as one of the four, but sometimes it is easier to study principles on a small scale, and this fact may perhaps justify the inclusion of Norway. The population of Norway is about 3.5 million. Almost three-fourths of the country consists of mountains, glaciers, and so on; approximately one-fourth is covered by forests; and only 4 percent is tilled soil. Thanks to the Gulf Stream, coming over from the Gulf of Mexico up along the coast line, the climate is much warmer than you would expect.

Norway does not have the same old well-established scientific traditions that are found in many other European countries. This is probably partly due to the size of the country, but also to the fact that Norway, when it became an independent country in 1905, had not had complete independence for several centuries.

Our first university was established only some 150 years ago; our Agricultural College, some 60 years ago; the Institute of Technology, some 50 years ago; and our second university only 10 years ago. The period prior to World War I can be characterized by the outstanding work of some few individuals within certain fields of the humanities, medicine, and science. The environment for research was, however, too narrow, and our economic resources were too limited for lasting, learned schools to grow up, except in a few fields such as, for instance, geophysics. Research in the industrial field showed the same tendency. Comparatively few companies carried out their own research. Nevertheless, some examples of outstanding work were produced, and some of our leading firms of today were built up at that time entirely from the results of research work.

Between the two world wars scientific life in Norway had a constant but not rapid growth, both in the fundamental and in the applied fields.

During World War II, however, when the scientific resources of the three other countries considered in these articles were mobilized to the utmost and when their institutions for applied research had a time of fantastic expansion, Norway had a very different experience. Our universities were partly closed and our scientific activities came nearly to a standstill. The only bright spot was a small group of Norwegian refugee scientists who took part in military research in Great Britain and later became the nucleus of the Norwegian Defense Research Establishment which was built after the war.

When the war was over, however, it was clear to our Government, to industry, and to all within the research field that very high priority had to be given to the expansion of research. Thanks to excellent cooperation among these parties, this expansion has taken place.

Trades and Industries

As the development since the war has been strongest in applied research, I shall first, for background purposes, say a few words about the trades and industries of the country.

From Fig. 1 you will see that by far our biggest economic factor is industry, and that industrialization proceeds at a good rate of progress. One of our greatest assets here is the abundance of cheap water power. Norway produces today per capita more energy in the form of electricity than any other country, and we can still triple or quadruple this production at a very low cost. This is a great advantage from the standpoint of further development, especially within the electrometallurgical and electrochemical industries.

Shipping constitutes a major and growing factor in our national economy. Norway currently provides 8 percent of the world's tonnage. This has also stimulated growth of the Norwegian shipbuilding industry, which has more than tripled since the war.

Investment in the building of houses, factories, and power plants is at a high level.

Organization for Research

Let us now look at the pattern of research institutions as they have developed thus far. Figure 2 gives, in a simplified form, a survey of the various types of research organizations and institutes. To the left we have the universities, which come under the Ministry of Education. Next we have the various governmental research institutes, coming administratively directly under their respective ministries and working in such special fields as mineral resources, agriculture, fishery, health, communication, and defense. To the right we have the institutes which belong to industry. They comprise both the individual companies' own laboratories and the institutes of research associations formed by special branches of industry. In the middle you will see the research councils. There are three of them. All three have been established since the war, and they represent an entirely new feature in our scientific life. There are also other institutions which have been omitted here in order not to make the picture too complex.

As you can see, this general pattern is not so very different from that found in most other modern countries. There are, however, certain distinctive characteristics which I will try to point out.

Mr. Major is director of the Royal Norwegian Council for Scientific and Industrial Research. This article is adapted from an address delivered 26 Dec. 1958 at a symposium, "Moving Frontiers of Science: Comparative Patterns of Scientific Organization," held during the Washington meeting of the AAAS. This article and the preceding one, by E. S. Hiscocks, were presented during part 1 of the symposium. The articles presented during part 2 will appear in next week's issue.

Universities

The universities in Norway are all governmental universities. This means that they get practically all their money from the national budget, the number of positions and the salaries are established by the Parliament, and all the professors are appointed by the Government on the advice of the universities. By *universities* I mean here the two universities proper, in Oslo and Bergen, and also such institutes of higher learning as the Norwegian Institute of Technology in Trondheim, the Agricultural College at Aas, just south of Oslo, and the School of Business Administration in Bergen, which all give degrees that are at the university level.

As in most countries, in addition to their educational activities the universities carry the main burden of fundamental research work. The national appropriations alone have always been too small to maintain a vigorous scientific life, but research work has also been partly financed by private endowments and through contracts with industry and trades. Since the war a great proportion of the basic and other research at the universities has been financed through grants from the research councils.

The universities have also attracted other institutes as neighbors, thus making four major centers of research in the country. There is a center of technology around the Institute of Technology in Trondheim, a center of fishery research (among others) in Bergen, a center of agricultural research at Aas, and a center covering other fields, such as humanistic, economic, social, medical, and industrial research, in Oslo.

A special feature in Trondheim deserves to be mentioned; there an Engineering Research Foundation has been established at the Institute of Technology, doing sponsored research for industry in cooperation with the institute. This foundation has a much more flexible organization than the Institute of Technology and has therefore also been able to support the institute in many administrative matters.

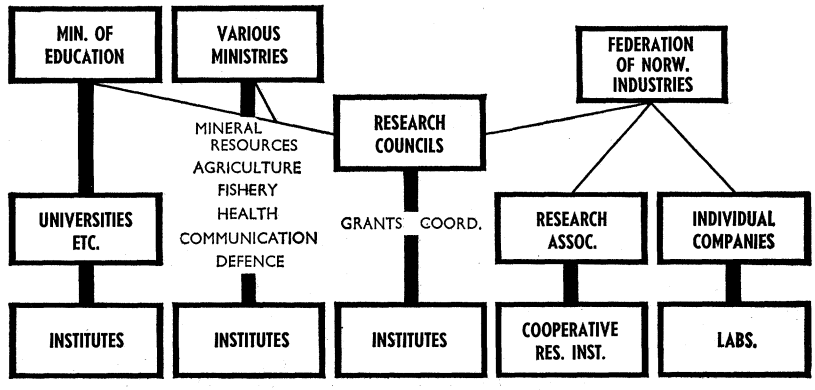
As in so many other countries, there was a great increase in the number of students entering our universities just after the war. By 1954, however, the number had fallen to the prewar level, and it only started to rise again substantially last fall. To get the complete picture, however, we must take into consideration the fact that since the war some 25 percent of our students have taken their degrees abroad because of our own limited study facilities in such fields as engineering, medicine, and dentistry.

	1938 %	1948 %	1957 ESTIMATE %
Industry and mining	24.6	25.7	29.2
Agriculture and forestry	11.1	8.0	6.8
Shipping	9.8	7.8	9.9
Building and construction	5.5	6.7	7.0
Others	49.0	51.8	47.1
	100.0	100.0	100.0

Fig. 1. Gross national product by sector (fixed prices).

As the demand and supply of scientists and engineers have been so much discussed lately, I will say a few words about our experience in these fields. It has, I think, some unique features.

Our only institution for the education of engineers is the Institute of Technology in Trondheim. Because it was in bad shape after the war, we sent a lot of engineering students abroad for their training. This stream of students going to other countries has continued, because of limited capacity at home. In fact, during the last few years nearly 50 percent of our engineers have been educated abroad. We have thus arrived at a total figure per million inhabitants of 130 new engineers per year, with a degree corresponding to an average American master's degree. This is, I think, the highest figure in Europe. In viewing this, however, our present low production of pure scientists and technicians should be noted. The engineers have all been absorbed in industry and research, and a study of the supply and demand made by the Research Council has concluded that our demand will continue at this level in the coming years. Accordingly, the Institute of Technology in Trondheim is being nearly doubled in size, and by 1963 we expect to turn out some 80 percent of our engineers at home, relying on institutions abroad only for the education of engineers in a few specialties. However, much work still remains



1946:	1100	340	0	58	?
1958:	1800	1180	1089	250	?

Fig. 2. Over-all research organization. Figures give total number of personnel.

to be done to build up the graduate school in Trondheim.

For scientists the picture has been very different. Pure science is an unrestricted study, and the universities accept all the qualified students who want to study science. Since the war the number of candidates has been fairly constant but comprises only some 65 percent of the number required, on the basis of a conservative estimate, to meet Norway's needs. Among other problems this created a serious, increasing shortage of science teachers in the secondary schools. The situation thus became rather gloomy.

Last summer, however, the curriculum of the science department of the university was modernized. An attempt was made to make the study more effective and thereby shorten the time of study from an average of 7 or 8 to 5½ years. This change was made known to all potential science students, and at the same time they were informed of the career possibilities for a student of science. Although a modest increase in the number of science students was expected, we were surprised to find that the number of science freshmen last fall rose by more than 100 percent; this means a tripling over the last two years. This very encouraging development has, however, its darker aspect. Now the great difficulty is for a somewhat unprepared university to find ways to educate so many students in rather crowded and inadequately equipped departments.

On the whole, I think we must admit that although it now looks as if we shall get out of our scientific and technical manpower problems reasonably well, this will perhaps be due more to the initiative of our youth and to help from universities abroad than to our own ability to build up our higher education in time. Recent developments, however, seem to indicate that planning and development of our institutions will be more efficient in the future.

The facts which I have given seem to show that most of our universities have not been farsighted enough to adapt their activities to the needs of the future. There may be many reasons for this. I think our system is somewhat too rigid; there is lack of flexibility and too great a distribution of responsibilities. Much good work is being done, but it is my personal view that the building up of a stronger administration in the universities—an administration capable of taking and willing to take responsibility—is a necessary step to insure that the universities will be able to play their vital role in the future life of the nation.

A thorough study of the demand for and supply of university-trained personnel of all categories has lately been made by our research councils. The aim of this has been to establish a factual basis for the development of our academic institutions to fill the future needs of the country.

Before leaving the field of training I will mention one noteworthy organization, the Government Loan Fund for Students. Because most families now find it difficult to finance the studies of their children, a national loan fund for students has been organized, with considerable capital and a further government guarantee. At present more than half of all Norwegian university students at home and abroad have loans averaging 3000 kroner a year. They pay no interest during the time of their study and later can deduct from their taxable income the money they pay back. Through growing fellowship programs gifted students without financial resources are also stimulated to take up a study.

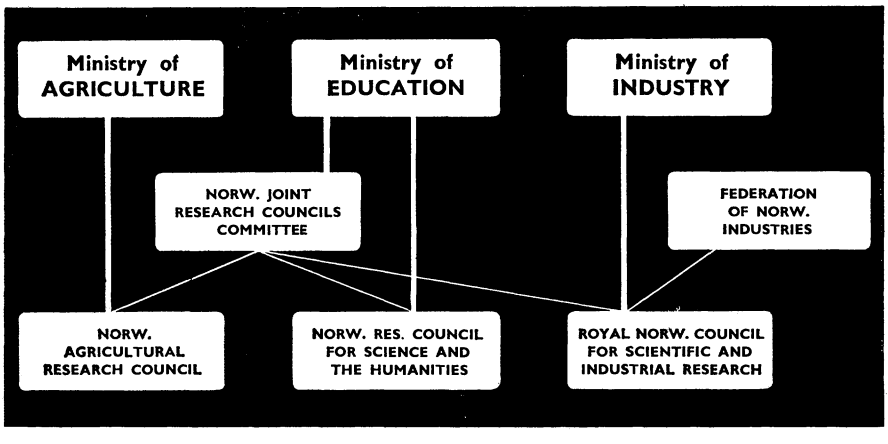


Fig. 3. Research councils in Norway.

Government Research Institutes

The government research institutes under the different ministries do not differ in principle from those in other countries. Therefore, although they play an important role, I shall be very brief in discussing them. The advantage of these institutes is, of course, that they have a resonably secure source of income. On the other hand, they have a very rigid salary system, so it is difficult to maintain a sufficient degree of incentive throughout the system. These are all difficulties which you seem to be well aware of in the United States, where, to a great extent, you get around them by doing a great deal of this sort of work through government contracts to universities, to sponsored research institutes, and to industry.

I have already mentioned the fields in which these institutes work. They have all expanded considerably since the war: this is particularly true of the Defense Research Establishment, which was established at the end of the war and which has since grown to become our biggest research institute. It has more flexibility than is usual for government institutes.

Research in Industry

In industry the interest in research activities has developed at quite a good rate since the war. Research departments and laboratories have grown up in many of the bigger companies and are now being introduced in new factories, but we still have a long way to go to reach an activity comparable to industrial research in the United States. One reason is that we have relatively few companies which are big enough to finance research on a really grand scale.

A statistical study of research personnel and research expenditure in industrial companies is now in preparation, but figures will not be available until the spring of 1959.

Some branches of industry have formed research associations for cooperative research studies. There are now ten of them, the biggest being in the fields of paper and pulp, wood technology, canning, herring oil and meal, and textiles. In many branches of the size of the companies varies so much, and the technical interests are so heterogeneous, that research associations are not the right answer. These factories rely on sponsored research institutes for work which they

cannot undertake themselves (I refer to this below). One characteristic feature is that a very good contact has been established between industry and the various research institutes, and industry is using their services more and more.

It is the general rule in our country that results of industrial research are exploited in already existing companies. Lately, however, a few development companies have been established which specialize in the exploitation of research results. This work looks quite promising so far.

Quite recently industry has formed a new organization called the Norwegian Industries Research Association. This is an organization with the single aim of supporting financially research work of common interest to the member firms. It is an organization set up on a voluntary basis, and all the firms joining it give 0.3 percent of their gross sales receipts to the association every year. All the money of the organization is being used for projects suggested by the Research Council for Scientific and Industrial Research, mentioned below. The association started to operate last fall; most of the bigger companies have joined it, but to get the great bulk of the smaller companies as members remains to be accomplished.

In this connection, I should mention that we have in Norway a law allowing firms to deduct from their taxable income gifts to research institutions. This, however, applies only for gifts not exceeding 10 percent of their income. The research must also have some bearing on the activities of the firm and must be carried out by an institution having some connection with the Government.

Research Councils

A new feature in Norwegian research organization since the war is the establishment of research councils. As you will see from Fig. 3, there are three of them: the Royal Norwegian Council for Scientific and Industrial Research; the Norwegian Research Council for Science and the Humanities; and the Agricultural Research Council of Norway. They all have the task of promoting research within their respective fields. They have come to play a very active part in the scientific life of Norway since the war, and they are also known for the rather extraordinary way in which they get a good deal of their money—from the profits of football pools.

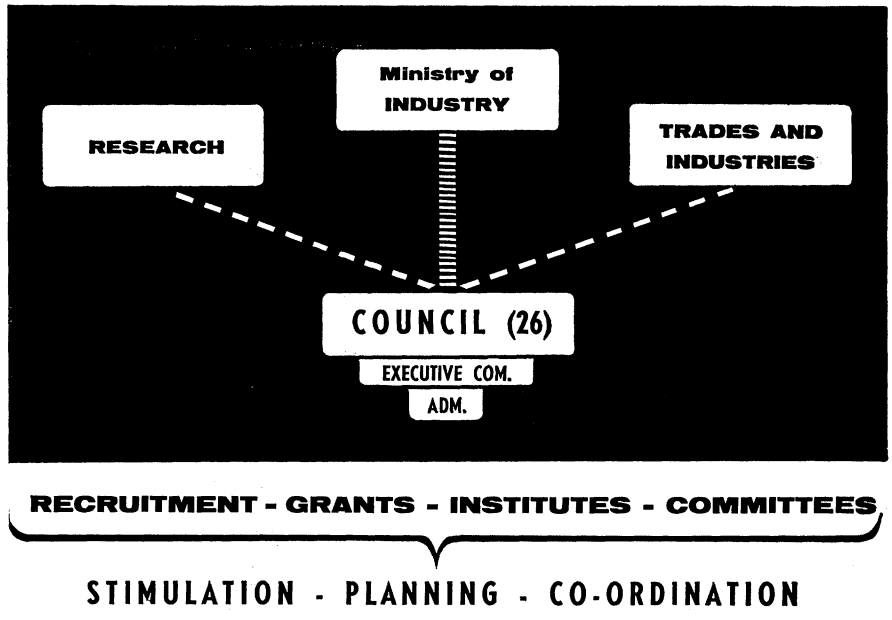


Fig. 4. Organization of the Royal Norwegian Council for Scientific and Industrial Research.

Just after the war the football pools were organized as a semigovernmental company with the aim of supporting sports and research. Of the profits, the first million kroner go to sports. Of the second million, research gets 200,000 kroner; of the third, 400,000 kroner; of the next, 600,000 kroner; and of each additional million, 800,000 kroner. Last year the amount for research had thus increased to some 25 million kroner. The amount is distributed among the three councils through the Joint Committee of the Norwegian Research Councils. The amount is quite appreciable for a small country, but the really important factor is that the money can be used at the discretion of the research councils.

I cannot here go into details about all the councils. I will say only that the Research Council for Science and the Humanities, through grants in all fields of the humanities, medicine, social research, and fundamental science, has contributed greatly to research activities in these fields, while the Agricultural Research Council has, through its activities, stepped up research work in the whole agricultural field.

As an example of the three I shall give a few more details about the Royal Norwegian Council for Scientific and Industrial Research. I choose this because it was the first and is the most comprehensive of the research councils and also because it is with this council that I have had my own experiences.

From Fig. 4 you will see the main characteristics of its organization. It is a semigovernmental institution representing cooperation of government, industry, and research, with the aim of promoting scientific and industrial research and making sure that the research results are made use of in Norwegian trades and industries. The council has 26 members, with approximately equal representation from the three parties mentioned.

In summarizing the work of the Research Council, one should first mention the work done in the recruitment of scientific personnel. Surveys of the supply and estimates of the demand for scientists and engineers have been made, and recommendations for the expansion of our capacity for education have been made to the Government. To support the flow of promising candidates into science, approximately 250 fellowships have been given for postgraduate studies in foreign countries. Fellowships have also been given for postgraduate work in our own country, both for Norwegian citizens and for foreigners wanting to take part in our activities.

Secondly, carefully selected research projects, mostly at the universities, are being supported through grants. The major part of these grants has been given in new fields such as nuclear physics, radiochemistry, industrial microbiology, and automation. They may be small grants for a personal assistant, for instance, or large ones for bigger, long-term projects, new buildings, and so on.

The council has, further, had a series

of committees fostering research in new fields where there was a need for organized long-term research. New institutes have been planned and established, 11 of them so far. Among them I can mention the Institute of Atomic Energy, which, in cooperation with the Netherlands, built the first nuclear reactor to be in operation outside the borders of the five big atomic powers. Very shortly the institute will put into operation the new heavy-water boiling reactor at Halden, which is the first nuclear reactor system to be developed outside the borders of the great atomic powers. Through cooperation with 12 other OEEC countries, the experiences achieved with this reactor system will be available to them all.

The council has also established institutes for building research, for geotechnical research, for ship and shipbuilding research, for electrotechnical research, and so on. They are all institutes of particular interest to important branches of our industries. I might further specifically mention the Central Institute for Industrial Research, which is a sponsored research institute, built on the same principles as the Battelle Memorial Institute in Columbus, Ohio. The Central Institute is now one of our largest, and the number of contracts grows from year to year and also includes contracts from the United States.

As you know, you have in this country a great number of sponsored research institutes, such as the Battelle Memorial Institute, and the Armour Research Institute, but relatively few research associations for cooperative research. In most European countries—for instance, in Great Britain—there are a great number of cooperative research institutes but practically no sponsored research institutes. In Norway we now have three sponsored research institutes; the volume of research in these institutes is about the same as the volume in our cooperative research institutes, and it tends to grow faster.

In this respect we are thus somewhere between the United States and most European countries. We believe that in our country cooperative research is the effective solution for some activities, but we also feel that in other cases sponsored research is the best solution. To the cooperative research institute one sends bigger, open research projects of mutual interest; to the sponsored research institute a company sends research projects that it wants to develop for its own use in competition with others. The sponsored research institute functions, therefore, as an extension of the individual company's own research laboratories.

Through all its activities the Research Council endeavors to achieve a sound coordination of the over-all research activities of the country. As a concrete example of this I might mention the establishment of the Industrial Research Center at Blindern, near Oslo.

Just after the war, when the Research Council was planning some of its institutes, some other industrial research institutes were also being established. Since we are a small country, the Research Council felt that if these institutes were spread around at different places, none of them would be big enough to create a sufficiently creative scientific environment. Therefore, the council secured an area close to the science department of the University of Oslo, built a central building for the sponsored research institute mentioned above, where also smaller institutes could hire premises, and offered ground around the building to other institutes wanting to participate in the center. In doing this the council in no way tried to direct the work of the institutes but simply offered its services to bring them together and thereby facilitate collaboration.

The offer was so very favorably received that the Industrial Research Center is constantly growing and has at present 15 institutes. They are centered around the Central Institute for Industrial Research, which has been equipped with many sorts of expensive equipment, such as an electron microscope and spectrographs, which are used by all the institutes in the center. In this way excellent voluntary coordination both among the institutes and between the institutes and the science department has been achieved. At present about 40 million kroner have been invested in the center, and approximately 500 people work there.

The work of the council is financed through the national budget, the football pools, and industry. The council is a free institution with its own salary system, serving both government and industry. We have come to know the importance in all research work of choosing the right man for the job and of giving him a reasonably free hand. We emphasize strongly the importance of maintaining incentive for all personnel throughout the activities. The freedom we have been given, the flexibility of the system, and the great and united support from government, industry, and research have made it possible to build up a system which seems so far to have functioned reasonably well.

Government Research Contracts

But to come back to the over-all picture, there is one feature which you may miss in Norway—the government research contracts which play such an important role in the United States. In our country they are not used to any great extent. One reason is that problems of direct concern to government are solved in our governmental research institutes —such as, for instance, the Defense Research Establishment. Another reason may be that although it is difficult to carry out research, it is perhaps even more difficult to formulate research projects and evaluate research progress —and I think we have not yet a sufficient number of people capable of administrating research contracts.

There are, however, signs that this is changing, and with our growth in number of sponsored research institutes and in research facilities in industry I think it would be of advantage in the future to solve more national problems through research contracts with appropriate research institutions. It is not unlikely that the research councils may have a growing responsibility in this respect.

Problem of Size

We have also in our national research policy one problem which, I think, you are not very familiar with. That is what I may call the problem of being small. In these times, when each administrative unit, like each country, has so many research problems to tackle and when more and more of them are problems needing the concentrated attack of big scientific staffs, involving high expenditure, a small country meets with certain difficulties.

There are two ways of solving this problem. The one is to make use of the results from other countries when they are available and to concentrate our own efforts in areas where we have special qualifications or special needs. The other is to take up bigger projects in cooperation with one or more other countries, as we have done in atomic energy

with the Netherlands, Sweden, and other OEEC countries, in defense research and in fundamental nuclear physics through our participation in the CERN organization in Geneva. A closer cooperation between the Scandinavian countries in higher education and in many fields of research is also being developed.

What for you in the United States would usually be just routine cooperation will often for us be international cooperation, involving to some extent language and other difficulties. I do believe, however, that through concentration at home on the one hand and a realistic cooperation with foreign countries on the other, many of the difficulties of being small can be overcome.

From what I have said it will be evident that research activities have grown considerably in Norway since the war. Figure 5 shows the increase in the total number of individuals in university and other research work. The solid line indicates personnel in all kinds of research; the broken line shows personnel in scientific and industrial research only. Since we do not yet have exact figures for the individual companies' own research personnel, those figures are not included. You will see that from 1946 to 1958 the number of individuals in all kinds of research has grown by a factor of slightly less than 3. The biggest growth, however, has been in scientific and industrial research, where the number has grown by a factor of 4.

Figure 6 shows the expenditure in universities and research institutions, again with figures for the industrial companies' own research personnel excluded. You will see that in kroner the expenditure has grown by a factor of more than 6, but with fixed prices this factor is only approximately 4. For scientific and industrial research only, the rate of growth is somewhat larger.

You may now have got the impression that research is at a very high level in Norway. What the figures show is, however, more the rate of growth than the actual level. If we estimate the research expenditure of industrial companies and add this figure, we will find that what Norway spent in research and development in 1957 is not more than some 0.6 percent of its gross national product. This is less than half the corresponding figure for the United States and probably only one-third the corresponding figures for Great Britain and Canada. We may of course say that Norway is a small country and has not such great defense and other responsibilities and can therefore have a lower figure. Other factors, however, point in the opposite direction, so I believe that if we are to maintain our culture, our social standard, and our security, and have trades and industries which cannot only compete with those of Western countries but also withstand the growing commercial competition we have begun to experience from the Soviet

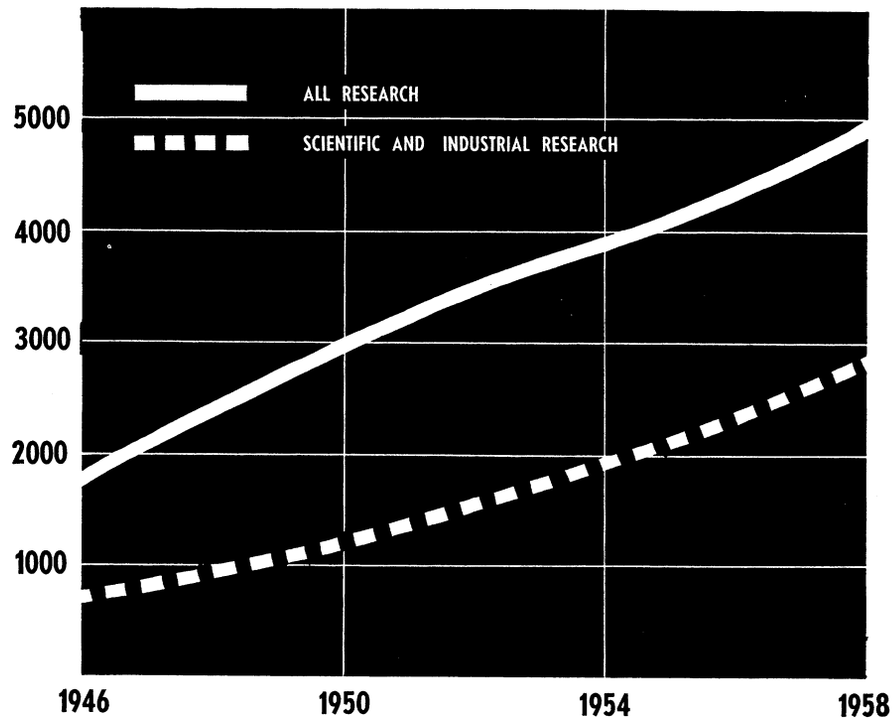


Fig. 5. Total number of personnel in research work, 1946–58. Universities, but not industrial laboratories, are included.

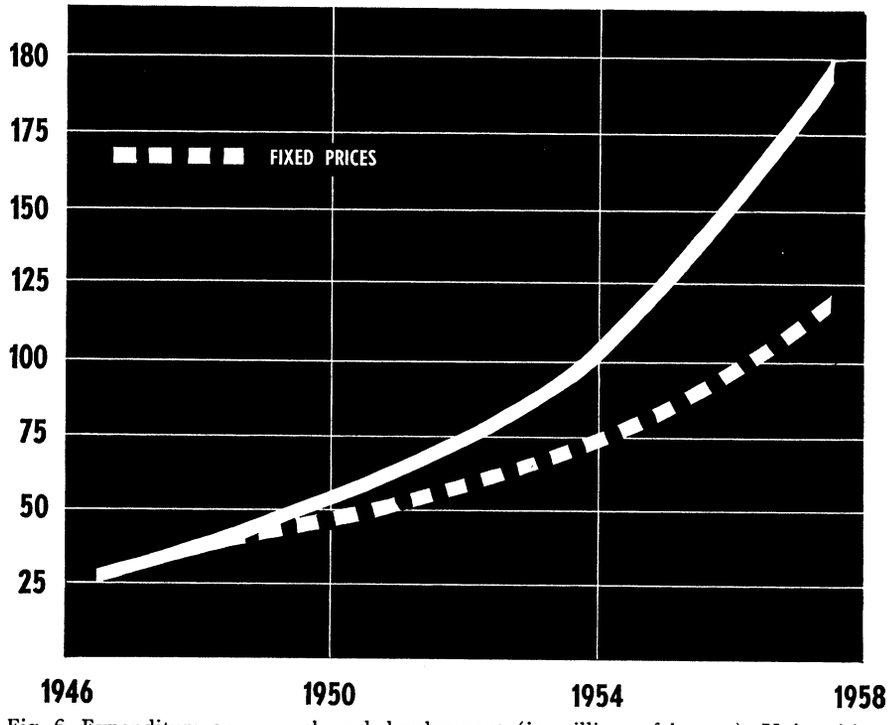


Fig. 6. Expenditure on research and development (in millions of kroner). Universities, but not industrial laboratories, are included.

Union, we must continue to expand our research.

There is also one new problem we have to face. It is probably right to assume that the attempt to create a free trade system in Europe, in spite of the present difficulties, will ultimately lead to a positive result. Although this as a whole must be favorably received, it will nevertheless create problems for certain branches of our industry. We must expect that some of these industries, now protected by customs duties, will be unable to compete in a free market. They will thus have to be replaced by industries in fields where we have special natural conditions—such as, for instance, the electrometallurgical and electrochemical fields. Since these particular industries, however, require heavy capital investments, we must also look for other possibilities. Here I think "brain" industries would be a good answer. To make such changes in our industries successfully, and in time, will require, to my way of thinking, some early and wise decisions in the fields of education and research.

Summary

By way of a summary, may I say that I believe we now have in Norway an over-all pattern for the administration of research which fits our present situation reasonably well. There are weaknesses, as I have pointed out, but there are also signs that we have a fair chance of putting them right. The system is sufficiently flexible to allow for initiative, and we know we shall have to make changes to fit our future needs. We are in the happy situation of having our youth show an increasing interest in research work, so if we can sucessfully master our training problems we should have the good recruitment we consider essential for progress in research. The problem of "being small" can probably be solved, or at least remedied, through a combination of concentration and international collaboration.

In think it has now become clear to the greater part of our population, and specifically to a great number of influential persons, that if we in Norway are to maintain and develop our spiritual and material culture, we shall have to continue the progress in research. We thus hope that in the future, through a united effort of our Government, our trades and industries, and our research, we shall be able to contribute our share to the common fund of knowledge and shall be able also to use this knowledge to expand the social and economic life of our nation and contribute to the security of all free nations.

Spectroscopic Evidence of Metabolic Control

Rapid measurements of intracellular events afford new evidence on mechanisms for metabolic control.

Britton Chance and Benno Hess

The interaction of glucose and oxygen metabolism has been the subject of study ever since Pasteur's discovery 100 years ago of the metabolic response of glucose utilization which now bears his name (see *1, 2*). Recent interest has been stimulated by Warburg's hypothesis that irreversible damage to the respiratory mechanism and a consequent increase of glycolysis are associated with cancerous growth (*3*). With greater knowledge of the enzymatic pathways for glucose and oxygen metabolism and of the significance of intracellular levels of substrates, coenzymes, phosphate, and adenosine phosphates, general principles and specific mechanisms for the Pasteur reaction (*4–11*) have been proposed. Increasing awareness of the structural relationships of enzyme systems within the cell (*11, 12*) adds, however, to the problem of ordinary chemical analysis a dimension with which it is not currently able to cope, namely, the control of metabolism by redistribution of rate-limiting substances among the intracellular structures. Such changes in concentration might well remain undetected in chemical analyses of the average concentration of such components (*2, 11*). It is an appropriate time, therefore, to describe results of the measurements of changes of concentrations of possible control substances at the site of their action within the cell.

The development of methods for the direct spectrophotometry of intracellular respiratory pigments and their applications to the measurements of the kinetics of oxidation of cytochromes, flavoprotein, and pyridine nucleotide, together with the adaptation of rapid flow techniques to rapid reaction kinetics of intact cells, were described several years ago (*13*). The advantages of ascites tumor cell suspensions for experimental study with these new methods have been pointed out from the standpoint of physiology and biochemistry (*3, 14*) and also from the standpoint of the requirements of the spectrophotometric technique (*13*). It has further been found that ascites tumor cells are remarkable material for the study of interactions between glucose and oxygen utilization, overbalanced in favor of glycolysis. The cells furthermore show not only a Pasteur and a Crabtree effect (*15*), but also a short-lived and intense metabolic response to glucose addition which sheds considerable light on possible mechanisms of metabolic regulation (*16*).

Even though it was suggested some time ago (*17*) that it is not the enzymes but their interactions that are responsible for tumor cell metabolism, explanations for the relatively low respiratory activity of some types of tumor cells have been advanced on the basis of low cytochrome *c* and low cytochrome oxidase activities (for a summary, see *18*).

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