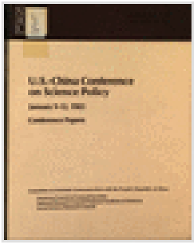

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U.S.-China Conference on Science Policy

January 9-12, 1983

Conference Papers

Committee on Scholarly Communication with the People's Republic of China

American Council of Learned Societies
National Research Council/National Academy of Sciences
Social Science Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and Institute of Medicine.

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The views expressed in this report are those of the American and Chinese participants in the U.S.-China Conference on Science Policy. They are in no way the official views of the Committee on Scholarly Communication with the People's Republic of China or its sponsoring organizations -- the American Council of Learned Societies, the National Research Council/National Academy of Sciences, and the Social Science Research Council.

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PREFACE

The U.S.-China Conference on Science Policy was held at the National Academy of Sciences in Washington, D.C., January 9-12, 1983. It was the first bilateral meeting between the National Academy of Sciences and the Chinese Academy Sciences to focus specifically on science policy. It was part of the exchange program conducted by the Committee on Scholarly Communication with the People's Republic of China (CSCPRC). Funds for the conference were provided by the National Science Foundation.

The Committee on Scholarly Communication with the People's Republic of China was founded in 1966 by the American Council of Learned Societies, the National Academy of Sciences, and the Social Science Research Council. Since 1972 the Committee has conducted an exchange program with China including symposia, delegation visits, exchange of individual scholars, and a program of advanced study and research in China for American graduate students and scholars. Fields covered in the exchange program range widely across the natural sciences, engineering, medicine, social sciences, and the humanities. Chinese counterpart organizations include the Chinese Academy of Sciences, the China Association of Science and Technology, the State Scientific and Technological Commission, the Chinese Academy of Social Sciences, and the Ministry of Education. Present sources of funding for the CSCPRC include the U.S. Information Agency, the National Science Foundation, the National Endowment for the Humanities, the Department of Education, the Department of Agriculture, the Ford Foundation, the Starr Foundation, and the MacArthur Foundation. Administrative offices of the Committee are located in the Office of International Affairs, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418.

The U.S.-China Conference on Science Policy in January 1983 is an important component of the Committee's exchange program with the Chinese Academy of Sciences. Papers prepared for the conference covered such topics as industrial innovation, research and development, technology transfer, technology assessment, scientific education and professional training, and specific case studies in environment, rural energy, biotechnology, the synthesis of insulin, the development of antibiotics, and agricultural development strategy. In addition, there was a Chinese paper describing the utilization and transformation of the North China Plain. This conference formed the basis for development of a second meeting, to be held in China in 1985, focusing on analysis and formulation of S&T policy, structural reform in scientific research management, the relationship between the development of S&T and productivity, and the promotion of new technology industry.

Heading the Chinese delegation to the conference was Hu Yongchang, Deputy Secretary General of the Chinese Academy of Sciences. Eugene B. Skolnikoff, Director of the Center for International Studies at the Massachusetts Institute of Technology, served as American co-chairman. Represented at the meeting were individuals from American and Chinese universities, industrial enterprises, and government agencies. Following the conference the Chinese delegation visited several cities in the United States at the invitation of the CSCPRC.

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TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH

Edwin Mansfield

My task is to summarize the present state of research on the relationship between technological change and economic growth, including the role of organized industrial research and development (R&D), concepts of social and private rates of return from investments in industrial innovation, and changes in the composition and returns from innovative activities in recent years. Also, I will try to describe the nature of the evidence used by American economists to assess these matters, as well as the limitations of this evidence.

Because a great deal has been written on these topics, this paper must be both sketchy and selective. The books and articles cited in the footnotes provide a much more complete account of the work that has been carried out in this area in the United States.

Economic Effects of a Specific Technological Innovation

First, let's consider the available techniques for estimating the effects on the economy as a whole of a specific technological innovation. Economists have tended to concentrate their attention on the estimation of the social rates of return from technological innovations, the social rate of return being analogous to the rate of return earned on a private investment. Specifically, the social rate of return is the interest rate received by society as a whole from the investment in a new technology. Of course, there are a variety of problems in measuring the social rate of return from an investment in new technology. Any innovation, particularly a major one, has effects on many sectors of the economy, and it obviously is very hard to evaluate and summarize these effects. Nonetheless, assuming that the innovation is basically resource-saving in nature, a technique has been devised to provide at least rough estimates of an innovation's social rate of return.

To illustrate this technique, suppose that the innovation is a new product that results in a saving to users (for example, a new type of metal that results in a potential saving to makers of household appliances). If the innovation results in a cost reduction in the industry using the innovation, one can estimate the annual saving in this industry and relate the stream of R&D (and other) inputs reponsible for the innovation to this stream of resource savings. In the simplest possible case, one could estimate in this way the social rate of return from the investment in the innovation. But things are generally not this simple, the result being that a variety of additional computations must be made. To begin with, the extent of the cost reduction in the industry using the innovation depends on the pricing policies of the innovator, which may, of course, set a price so as to reduce this saving and increase its own profits. If the innovator earns economic profits from its innovation, these profits must be added to the resource saving of the industry using the innovation to get the total value of resources saved by the innovation.

Further, note that these profits must often be adjusted. If the innovation replaces another product, and if profits were being earned on the product that is replaced, this additional resource saving is not the profits of the innovator (from the innovation), but these profits less those that would have been made (by the innovator and/or other firms) if the innovation had not occurred and the replaced product had been used instead. Also, if other firms imitate the innovator and begin producing the innovation and sell it to the industry using the innovation, their profits from the sale of the innovation (as well as those of the innovator) must be included in the estimate of social benefit.

Turning to the R&D (and other) inputs responsible for the innovation, the R&D costs must be adjusted to allow for the fact that the innovator invested R&D resources in uncommercialized R&D projects. One way to make this adjustment is to multiply the R&D costs by the average number of dollars spent on uncommercialized R&D projects per dollar spent on a commercialized R&D project in the innovating firm during the relevant period. Also, it is important to recognize that other firms or research organizations may have invested resources (prior to the introduction of the innovation in question) in R&D and related innovative activities aimed at innovations of essentially the same kind as this one. One must try to estimate the amount of such expenditures as best one can. Sometimes, of course, this can be a very difficult step, although, in most cases studied, the results seem quite insensitive to these estimates. In addition, environmental costs must sometimes be taken into account, and adjustments must be made if some of the resources saved are not fully employed.

Based on the discussion thus far, it should be clear that the estimation of the social rate of return from investments in innovative activity is by no means a simple or straightforward task, even for those innovations where the model described above is reasonably applicable. (More will be said below concerning the applicability of the model.) Indeed, the the truth is that it requires a considerable amount of judgement, the willingness to become immersed in an enormous amount of detail, and the cooperation of firms, agencies, and research organizations. Nonetheless, economists have shown that it is not impossible to obtain the required data and to carry out the necessary computations. At this point, published estimates of the social rate of return have been made for perhaps 100 technological innovations. Of course, this still is only a relatively small number, but it must be recognized that this technique is still in its infancy.[1]

Empirical Results

Table 1 illustrates the kinds of results that have been obtained. It shows estimated social rates of return for 17 innovations. The results seem to have at least three implications. First, they indicate that the social rate of return from the investments in these seventeen innovations has been very high. The median estimated social rate of return is about 56 percent. Moreover, for a variety of reasons, these estimates are likely to be conservative lower bounds. Clearly, the investments that have been made in industrial innovations have, on the average, yielded handsome social returns, if these innovations are at all typical.

Second, the results indicate that the private rates of return from the investments in these innovations have been much lower than the social rates of return. The median private rate of return was about 25 percent. In interpreting this number, it is important to recognize the riskiness of this kind of investment. This riskiness is evidenced by the enormous variation in the private rates of return in Table 1. In the case of six innovations the private rate of return was less than 10 percent, while for five innovations, it was more than 40 percent.

Third, the results indicate that, in about 30 percent of the cases, the private rate of return was so low that no firm, with the advantage of hindsight, would have invested in the innovation, but the social rate of return from the innovation was so high that, from society's point of view, the investment was well worthwhile.[2]

Table 1 Social and Private Rates of Return from Investment in Seventeen Innovations

	Rate of Return (percent)	
Innovation	Social	Private
Primary metals innovation	17	18
Machine tool innovation	83	35
Component for control system	29	7
Construction material	96	9
Drilling material	54	16
Drafting innovation	92	47
Paper innovation	82	42
Thread innovation	307	27

Innovation	Rate of Return (percent) Social	Private
Door control innovation	27	37
New electronic device	Negative	Negative
Chemical product innovation	71	9
Chemical process innovation	32	25
Major chemical process	56	31
Chemical process innovation	13	4
Household cleaning device	209	214
Stain remover	116	4
Dishwashing liquid	45	46
Median	56	25

E. Mansfield et al., "Social and Private Rates of Return from Industrial Innovations," Quarterly Journal of Economics, May 1977.

Recent Applications of This Model

The model and substantive results described very briefly in Sections 2-3 were first published in 1977. In the past several years, this model has been utilized repeatedly in policy-oriented studies in the United States, and the results obtained in these follow-on studies have been very similar to those obtained in our original study. To extend our sample and to replicate our analysis, the National Science Foundation commissioned two follow-on studies, one by Robert R. Nathan Associates and one by Foster Associates. Nathan, based on its sample of 20 innovations, found the median social rate of return to be 70 percent and the median private rate of return to be 36 percent. Foster, based on its sample of 20 innovations, found the median social rate of return to be 99 percent and the private rate of return to be 24 percent. Thus, their results, like ours, indicate that the median social rate of return tends to be very high, and much higher than the private rate of return.

This model has also been used to try to quantify the economic benefits to the American economy from secondary applications of NASA technology. In particular, Mathematica has carried out a study to estimate the benefits from cryogenic multilayer insulation, gas turbines (in the production of electric power), integrated circuits, and computer-assisted structural analysis. There are a number of problems in adapting our model for these purposes, as Mathematica is well aware. Nonetheless, the results of the study seem to have been of interest and use to the relevant policymakers in the United States.

Finally, proper caution should be exercised in interpreting our results. Our sample of innovations is not a random sample, the data sometimes are rough, and for a few of the innovations they are based partly on forecasts. Further, the models that we use are simplified in many respects. For these and other reasons, our results should be treated with considerable caution. The measurement of social and private rates of return from investments in new technology is an extremely difficult business, which is one good reason why so few such measurements have been attempted until recently. Nonetheless, we must make the best estimates we can.

Results for Agriculture

In previous sections, we have confined our attention to manufacturing. It is important to note that a number of studies of this sort have also been carried out for agriculture. One of the first such studies was Griliches's study of hybrid corn.[3] Based on data concerning the increase in yields resulting from hybrid corn, the value of corn output each year, the price elasticity of demand for corn, and the amount spent each year on hybrid-corn research, he could estimate the rate of return from the investment in hybrid-corn research, which turned out to be 37 percent. Clearly, a 37-percent rate of return is high. However, in evaluating this result, it is important to bear in mind that this is the rate of return from an investment which was known in advance to have been very successful. Thus, it is not surprising that it is high.

Another study, based on many of the same principles, was carried out by Peterson[4] to estimate the rate of return from poultry research. This study, unlike the previous one, looked at the rate of return from all research in this particular area, successful or not. In other words, it included the failures with the successes. The resulting rate of return was 18 percent, which again is a rather high figure. However, as would be expected, this figure is lower than that for hybrid corn. A further study, by Schmitz and Seckler, used basically the same kind of techniques to estimate the social rate of return from the investment in R&D pertaining to the tomato harvester. The result depends on how long workers displaced by the tomato harvester remained unemployed, but the authors report that, even if the tomato workers received compensation of $2 to $4 million per year for lost jobs, the net social rate of return from the harvester would still have far exceeded 100 percent.[5]

It is important to recognize that all of the rates of return cited so far are average rates of return. That is, they are the average rate of return from all of the amounts spent on the relevant R&D. For many purposes, a more interesting measure is the marginal rate of return, which is the rate of return from an additional dollar spent. This is the measure that is most relevant in determining whether there is an underinvestment in civilian technology. If the marginal rate of return from investment in civilian technology is higher than the marginal rate of return from using the extra resources in other ways, more resources should be devoted to civilian technology. Thus, a very high marginal rate of return from investments in civilian technology is a signal of an underinvestment in civilian technology.

Using econometric techniques, a number of studies have estimated the marginal rate of return from both agricultural and manufacturing R&D. These studies have been carried out by Evenson, Griliches, Mansfield, Minasian, Schultz, Terleckyj, and others. Practically every study seems to indicate that the marginal rate of return is high, generally in the neighborhood of 40 to 50 percent. Of course, as stressed above, these studies are based on a number of simplifications, and it would be very risky to attach too much significance to them, since they are rough at best. All that can be said is that the available evidence, for what it may be worth, suggests that the rate of return has been high.[6]

Research and Development and Economic Growth: Early Studies

It is generally accepted that economic growth is an important goal of our society. Of course, this does not imply that economic growth is, in some simple sense, what public policy should attempt to maximize. Clearly, the desirability of a particular growth rate depends on the way it is achieved, how the extra output is distributed, how growth is measured, and many other things. There is, of course, a large literature on the benefits and costs of economic growth. Also, it should be emphasized at the outset that, by focusing attention on the economic effects of R&D, I am not implying that only these effects of R&D are important or relevant. On the contrary, increased knowledge is clearly of great importance above and beyond its strictly economic benefits.

What is the relationship between R&D and economic growth? The pioneering studies in this area--by Robert Solow, Moses Abramowitz, and Solomon Fabricant--occurred in the mid-fifties. In many respects, Solow's paper was most influential. Assuming that there were constant returns to scale, that capital and labor were paid their marginal products, and that technological change was neutral, Solow attempted to estimate the rate of technological change for the American non-farm economy during 1909-49. His findings suggested that, for the period as a whole, the average rate of technological change was about 1.5 percent per year. In other words, the amount of output that could be derived from a fixed amount of inputs increased at about 1.5 percent per year. Based on these findings, he concluded that about 90 percent of the increase during this period in output per capita was attributable to technological change, whereas only a minor proportion of the increase was due to increases in the amount of capital employed per worker. This conclusion received a great deal of attention--and caused consternation among economists who had focused much more attention on the factors underlying the amount of capital employed per worker than on those underlying the rate of technological change.[7]

Economists soon began to feel somewhat uneasy about the basic methodology used in these studies. In essence, this methodology was the following: Economists, who view the total output of the economy as being due to various inputs of productive services into the productive process, began by specifying these inputs as labor and capital and by attempting to estimate the contribution of these inputs to the measured growth of output. Then, whatever portion of the measured growth of output that could not be explained by these inputs was attributed to technological change. The crudeness of this procedure is obvious.

Since the effect of technological change is equated with whatever increase in output is unexplained by other inputs, the resulting measure of the effect of technological change does not isolate the effects of technological change alone. In addition, it contains the effects of whatever inputs are excluded--which, depending on the study, may be economies of scale, improved allocation of resources, changes in product mix, increases in education, or improved health and nutrition of workers.

To eliminate some of these deficiencies, a number of additional studies were carried out in the early sixties, the most comprehensive and influential being by Edward Denison. Denison attempted to include many inputs--particularly changes in labor quality associated with increases in schooling--that were omitted, largely or completely, in earlier studies. Since it was relatively comprehensive, his study resulted in a relatively low residual increase in output unexplained by inputs included in his study. Specifically, Denison concluded that the "advance of knowledge"--his term for the residual--was responsible for about 40 percent of the total increase in national income per person employed during 1929-57. Technological change can stem from sources other than organized research and development, as evidenced by John Jewkes' findings concerning the importance of independent inventors as a source of major inventions, and the findings by Hollander, and others, concerning the importance of technological changes that depend in no significant way on formal research and development. Denison estimates that about one-fifth of the contribution to economic growth of "advance of knowledge" in 1929-57 can be attributed to organized research and development. But this was the roughtest kind of guess. Denison would be the first to admit that this estimate was largely a guess.

Denison's More Recent Results

Since the early studies described in the previous section, there have been a number of economic studies of the contribution of technological change and R&D to economic growth, including that of Griliches.[8] Perhaps the most recent major study was carried out by Edward Denison.[9] In Table 2, we show his estimates of the sources of the growth of national income per person employed (NIPPE) during 1948-76. According to these estimates, the advance of knowledge was responsible for 1.4 percentage points of the annual growth rate of NIPPE during 1948-69, and 1.6 percentage points of the annual growth rate of NIPPE during 1969-73. The effects of other factors, such as changes in the characteristics of the labor force, changes in capital and land per person employed, and economies of scale, are also estimated in Table 2.

According to Denison, there was a sharp decline in NIPPE during

1974 and 1975. Such declines were without precedent in the period since World War II. Because of them, the 1973-76 rate of growth of NIPPE was negative (-0.5 percent). When the 1948-69 period is compared with the 1973-76 period, the adjusted rate of growth of NIPPE fell by 3.3 percentage points (from 2.7 percent to -0.6 percent). Denison's findings indicate that 0.4 percentage points of this decline were due to the use of more resources to meet pollution, safety, and health regulations (and to prevent crime). Another 1.2 percentage points of this decline were attributable to six factors: (1) a steeper drop in working hours; (2) an accelerated shift in the age-sex composition of employed labor; (3) a slower growth of fixed capital per worker; (4) a slower growth of inventories per worker; (5) reduced gain from resource reallocation (such as the movement to industry of labor overallocated to farming); and (6) reduced gain from economies of scale.

Denison concludes that 2.1 percentage points of the 3.3 point drop in the growth rate of NIPPE remain in the residual called "advances in knowledge and not elsewhere classified." To some extent, this may be due to a slowdown in the rate of technological change and in the rate of innovation. As is well known, many experts in the United States believe that there has been a reduction in the rate of innovation, particularly in areas like pharmaceuticals and agricultural chemicals. Although the evidence is far from adequate, this may be the case, at least in some sectors of the economy.

Table 2 Sources of Growth of National Income per Person Employed, Nonresidential Business Sector[a]

Item	1948-69	1969-73	1973-76	Change from 1948-69 to 1973-76
Growth rate of NIPPE	2.6	1.6	-0.5	-3.1
Effect of irregular factors	-0.1	-0.5	0.1	0.2
Adjusted growth rate	2.7	2.1	-0.6	-3.3
Changes in labor characteristics				
Hours of work	-0.2	-0.3	-0.5	-0.3
Age-sex composition	-0.1	-0.4	-0.3	-0.1
Education	0.5	0.7	0.9	0.4
Changes in capital and land per person employed				
Structures and equipment	0.3	0.2	0.2	-0.1
Inventories	0.1	0.1	0.0	-0.1
Land	0.0	-0.1	0.0	0.0
Improved allocation of resources[b]	0.4	0.1	0.0	-0.4
Changes in legal and human environment [c]	0.0	-0.2	-0.4	-0.4
Economies of scale	0.4	0.4	0.2	-0.2
Advances of knowledge (and not elsewhere classified)	1.4	1.6	-0.7	-2.1

a) Detail may not add to totals due to rounding.

b) Includes only gains due to the reallocation of labor out of farming and out of self-employment in small nonfarm enterprises.

c) Includes only effects on output per unit of input of costs incurred to protect the physical environment and the safety and health of workers, and of costs of crime and dishonesty.

Source: E. Denison, Accounting for Slower Economic Growth (Washington, D.C.: Brookings, 1979).

Difficulties in Estimating R&D's Contribution to Economic Growth

How reliable are these estimates of the contribution of R&D to economic growth in the United States? To appreciate their limitations, a number of problems of a fundamental nature must be understood. First, the measured rates of growth of output on which these estimates are based suffer from a very important defect, particularly for present purposes, because, to a large extent, they fail to give proper credit and weight to improvements in the quality of goods and services produced, and these improvements are an important result of research and development. For example, the growth rate would have been the same whether antibiotics were developed or not, or whether we devoted the resources used to research the moon to public works. In general, only those changes in technology that reduce the costs of end products already in existence have an effect on measured economic growth. Unfortunately, the measured growth of national income fails to register or indicate the effects on consumer welfare of the increased spectrum of choice arising from the introduction of new products.

Second, the models on which these estimates are based may not recognize the full complexity of the relationships among the various inputs. In particular, if the returns to some input are dependent on the rate of technological change and this is not recognized explicity, some of technology's contribution to economic growth will be attributed incorrectly to other inputs. This may be the case with education, since the returns to education would probably have been less if technological change had occurred at a slower pace. It may also be the case with "the reallocation of resources," a factor sometimes used to explain part of the residual increase in output.

Third, it is not clear how one can get from an estimate of the contribution to economic growth of technological change (or advance of knowledge, in Denison's terms) to an estimate of the contribution to economic growth of research and development. Clearly, there is no reason why these two estimates should be the same; on the contrary, one would expect the latter estimate to be smaller than the former. But the estimate that results from the models discussed above is the former estimate, not the latter--which is the one we often want. As pointed out above, Denison does make an attempt to derive the latter estimate from the former, and to do so, he is forced to make extremely rough assumptions. To a certain extent, numbers must simply be pulled out of the air.

Fourth, there are difficulties in measuring inputs, the measurements of aggregate capital being a particularly nettlesome problem. Since errors in the measurement of inputs will result in errors in the estimated contribution of these inputs to economic growth, these errors will also be transmitted to, and will affect, the residual unexplained increase in output, which is used to measure the contribution of technological change to economic growth. Also, it is difficult to adjust for quality changes in inputs, and there are problems in constructing proper price deflators. According to work by Jorgensen and Griliches, there are important measurement errors and errors of aggregation in the measures that are ordinarily used, and these errors inflate the residual.

Fifth, there are difficulties caused by the fact that much of the nation's R&D is devoted to defense and space purposes. For example, some observers note the tremendous increase in R&D expenditures in the postwar period and conclude that, because productivity has not risen much faster in the United States than before the war, the effect of R&D on economic growth must be very small. What these observers forget is that the bulk of the nation's R&D expenditures has been devoted to defense and space objectives and that the contribution of such expenditures to economic growth may have been limited. Moreover, they fail to realize that improvements in defense and space capability per dollar spent caused by military and space R&D will not show up in our measures because government output is valued at cost. (Also, they fail to recognize the fact that product improvements and new products often fail to register in our output measures and that the effects of R&D often occur with a considerable lag.)

Based on the available evidence, technological change seems to have been a very important factor, perhaps the most important factor, responsible for our economic growth. But because of the problems and limitations described above, it is clear that the current state-of-the-art in this area is not strong enough to permit us to make very accurate estimates of the contribution of R&D to the economic growth of the United States. At best, the available estimates are rough guidelines. In no sense is this a criticism of the economics profession or of the people working in this area. On the contrary, a great deal of progress has been made since the pioneering ventures into this area about 25 years ago.

Research and Development and Productivity Increase in Individual Industries

Next, let's turn to the relationship between R&D and the rate of productivity increase in individual industries. During the late fifties, important work was going on at the National Bureau of Economic Research concerning the rate of productivity increase in various industries, this project culminating in John Kendrick's book. As part of this work, N. Terleckyj carried out a study of the relationship between an industry's rate of increase of total factor productivity during 1919-53 and various industry characteristics. According to his results, an industry's rate of growth of total factor productivity was related in a statistically significant way to its ratio of R&D expenditures to sales, its rate of change of output level, and the amplitude of its cyclical fluctuations. Specifically, the rate of growth of total factor productivity increased by about 0.5 percent for each tenfold increase in the ratio of R&D expenditures to sales and by about 1 percent for every 3 percent increase in the industry's growth rate.[10]

Subsequently, two other papers appeared on this topic, one pertaining to agriculture, one pertaining to manufacturing. The agricultural study, by Zvi Griliches, investigated the relationship in various years between output per farm in a state and the amounts of land, labor, fertilizer, and machinery per farm, as well as average education and expenditures on research and extension in a state. The results indicate that, holding other inputs constant, output was related in a statistically significant way to the amount spent on research and extension. Moreover, the regression coefficient of this variable remains remarkably stable when cross sections are deleted or added, and when the specification of the model is changed somewhat.[11]

The manufacturing study I did was based on data regarding ten large chemical and petroleum firms and ten manufacturing industries in the postwar period. Both for firms and for industries, the measured rate of productivity change was related in a statistically significant way to the rate of growth of cumulated R&D expenditures made by the firm or industry. The specific form of the relationship depends somewhat on whether technological change is assumed to be disembodied (better methods and organization that improve the efficiency of both old capital and new) or capital embodied (innovations that must be embodied in new equipment if they are to be utilized). If technological change was disembodied, the average effect of a 1-percent increase in the rate of growth of cumulated R and D expenditures was a .1 percent increase in the rate of productivity increase. If technological change was capital embodied, it was a .7-percent increase in the rate of productivity increase.[12]

In addition, Jora Minasian studied the relationship between value added, on the one hand, and labor, capital, and cumulated R&D expenditures, on the other, in 17 firms in the chemical industry during 1948-57. (His paper was a continuation of work started in his doctoral dissertation.) In all but one of the specifications of the model tried by Minasian, a firm's cumulated R&D expenditures were related in a statistically significant way to the firm's value added, holding its labor and capital inputs constant. Moreover, his estimate of the regression coefficient for cumulated R&D expenditures was strikingly close to the result I obtained. Thus, the findings of the two studies tended to reinforce one another.[13]

Murray Brown and Alfred Conrad carried out a study of the relationship between R&D expenditures (as well as education and other variables) and productivity increase in a number of U.S. manufacturing industries in the postwar period. Their results indicated that R&D expenditures had a statistically significant effect on the rate of productivity increase. Also, in their judgement, their findings indicate that a given percentage increase in R&D expenditures in durable goods industries produces a substantially larger percentage increase in productivity than does the same percentage increase in R&D expenditures in nondurable goods industries.[14]

How reliable were these estimates of the relationship between R&D and productivity increase in individual industries? Clearly, one advantage of these studies over those described in the previous section is that the effect of R&D is not derived indirectly as a residual. Instead, an industry's--or a firm's or area's--R&D expenditures are introduced as an explicit input in the productive process. Thus, it is possible to obtain explicit relationships between R&D and productivity increase: We no longer have to attribute to technology or R&D and whatever we cannot explain by other factors. This is a real advantage.

But a number of important problems remain. First, too little is known about the characteristics of the activities that firms call "research and development." This lack of information has been a hindrance to progress in this area, since, without a reasonable amount of information on this score, it is difficult to interpret or evaluate models relating R&D expenditures to other economic variables. Clearly, if the figures on "research and development" contain routine technical services and other such activities, the estimates based on these figures will be affected. It is difficult to tell how important this problem is, but for some purposes, I would guess it to be a serious problem. As we shall see in subsequent sections, economists are beginning to disaggregate R&D, which for many purposes is a good thing.

Second, even if one were sure that the R&D figures were reliable, there would still be the possiblity of spurious correlation. Firms and industries that spend relatively large amounts on research and development may tend to have managements that are relatively progressive and forward looking. To what extent is the observed relationship between R&D and productivity increase due to this factor rather than to R&D? Obviously, this is difficult to answer since the quality of management is very difficult to measure. Nonetheless, most investigators seem to feel that only a small part of the observed relationship is due to spurious correlation of this sort.

Third, a large percentage of the R&D carried out by many industries is directed at productivity increase in <u>other</u> industries. Consequently, relationships between R&D in an industry or firm and productivity increase in the <u>same</u> industry or firm catch only part of the effect of R&D. Also, the estimates that are obtained depend on the extent of the lag between the time when R&D is carried out and the time when the effects of R&D show up in productivity indexes. Clearly, this lag is often substantial. As we shall see in the next section, progress has been made on both these scores.

More Recent Results

During the 1970s and early 1980s, studies of the relationship between R&D and productivity increase were carried out by Griliches, Nadiri, Scherer, Terleckyj, myself, and others. Terleckyj used econometric techniques to analyze the effects of R&D expenditures on productivity change in 33 manufacturing and nonmanufacturing industries during 1948-66. In manufacturing the results seem to indicate about a 30 percent rate of return from an industry's R&D based on the effects of an industry's R&D on its own productivity. In addition, his findings show a very substantial effect of an industry's R&D on productivity growth in other industries, resulting in a social rate of return greatly exceeding 30 percent.[15]

Griliches carried out an econometric study, based on data from almost 900 firms, to estimate the rate of return from R&D in manufacturing. His results pertained only to the private, not the social, rate of return. He found that the private rate of return was about 17 percent. It was much higher than this in chemicals and petroleum and much lower than this in aircraft and electrical equipment. He found that the returns from R&D seemed to be lower in industries where much R&D is federally financed.[16]

In October 1981 the National Bureau of Economic Research held a conference in Lenox, Massachusetts, which was concerned in part with this topic. A number of papers were of relevance, but I will focus here only on F.M. Scherer's. He reported the results of a large data collection project about the industrial "destination" (locus of ultimate use) of a sample of patents. Using this information, he reclassified R&D expenditures by industry use, rather than by industry where the R&D activity took place. Based on the results, he concludes that R&D is significantly related to productivity growth. Other papers at the conference, such as that by Griliches and Lichtenberg, seem to come to similar results.[17]

Basic Research and Productivity Growth

The foregoing studies look at the relationship between total R&D input and productivity change, but they tell us nothing about the effect of the composition of an industry's or firm's R&D on its rate or productivity change. In particular, they tell us nothing about the role of basic research in promoting productivity increase. Basic research is defined by the National Science Foundation as "original investigation for the advancement of scientific knowledge...which (does) not have immediate commercial objectives." Does basic research, as contrasted with applied research and development, make a significant contribution to an industry's or firm's rate of technological innovation and productivity change? Although the studies cited above indicate that an industry's or firm's R&D expenditures have been directly related to its rate of productivity change, they have been unable to shed light on this question because no attempt has been made to separate basic research from applied research and development. In 1980, I published an econometric study to determine whether an industry's or firm's rate of productivity change in recent years was related to the amount of basic research it performed, when other relevant variables (such as its rate of expenditure on applied R&D) are held constant. This study has various limitations, but its findings seem of interest, particularly since so little research has been done on this score.

The results indicate that there is a statistically signficant and direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity when its expenditures on applied R&D are held constant. To some extent, this may reflect a tendency for basic research findings to be exploited more fully by the industries and firms that were responsible for them. Or it may reflect a tendency for applied R&D to be more effective when carried out in conjunction with some basic research. Whether the relevant distinction is between basic and applied research is by no means clear: there is some evidence that basic research may be acting to some extent as a proxy for long-term R&D. Holding constant the amount spent on both applied R&D and basic research, an industry's rate of productivity increase seems to be directly and significantly related to the extent to which its R&D is long-term. This seems to be the first systematic evidence that the composition, as well as the size, of an industry's or firm's R&D expenditures affect its rate of productivity increase.[18]

Changes in the Composition of Industrial R&D Expenditure

If it is true that an industry's rate of productivity increase is affected by the extent to which its R&D is long-term, one is led to investigate the extent to which changes have occurred in recent years in the composition of various industries' R&D expenditures. There is a widespread feeling that industry has been devoting a smaller share of its R&D expenditures to basic research, long-term projects, and risky and ambitious projects. Unfortunately, however, little data have been available on this score. To help fill this gap, I obtained information from 119 firms concerning the changes that occurred in this regard between 1967 and 1977, and the changes they expected between 1977 and 1980. The firms, all of which spent over $10 million on R&D in 1976, included in the sample accounted for about one-half of all industrial R&D expenditures in the United States in 1976.

The results of this survey indicated that the proportion of R&D expenditures devoted to basic research declined between 1967 and 1977 in practically every industry. In the aerospace, metals, electrical equipment, office equipment and computer, chemical, drug, and rubber industries, the proportion devoted to basic research dropped substantially. In the sample as a whole, the proportion fell about one-fourth, from 5.6 percent in 1967 to 4.1 percent in 1977.

In four-fifths of the industries, based on a rough measure of the perceived riskiness of projects, there was also a decline between 1967 and 1977 in the proportion of R&D expenditures devoted to relatively risky projects. In some industries, like metals, chemicals, aircraft, drugs, and rubber, this reduction was rather large.

Why did so many firms cut back on the proportion of their R&D expenditures going for basic research and relatively risky projects? The reason most frequently given by the firms was the increase in government regulations, which reduced the profitability of such projects. This reason was advanced particularly by the chemical and drug firms. Another reason advanced by some of the respondents was that breakthroughs are more difficult to achieve than in the past, because their fields have been more thoroughly worked over. Still another reason was the relatively high rate of inflation.[19]

Private Returns from a Major Firm's Aggregate Investment in Innovative Activities

Finally, it should be noted that firms are becoming increasingly active in estimating the returns from their innovative activities. For example, one of the nation's biggest firms has made estimates since 1960 of the benefits obtained from its R&D efforts, these estimates being used for internal planning purposes. This firm is among the largest members of an industry that is neither among the most research-intensive nor among the least research-intensive. In terms of the percent of sales devoted to R&D, this firm is reasonably representative of our nation's largest firms.

For each year since 1960 this firm has put together a careful inventory of the technological innovations arising from its R&D and related activities. Then it has made detailed estimates of the effect of each of these innovations on its profit stream. Specifically, in the case of product innovations, the firm computed for each new product the expected difference in cash flows over time between the situation with the new product and without it, including the effect of the new product on its profits from displaced products. In the case of process innovations, it computed the expected difference in cash flow between the situation with the new process and the situation without it, this difference reflecting, of course, the savings associated with the new process. In addition, the firm has updated these estimates each year. In other words, as time has gone on, the firm has revised its estimates of the returns from past innovations. This, of course, is of crucial importance, since it means that the firm's estimates for innovations occurring ten years or more ago are based on a decade or more of actual experience, not just forecasts.

Besides these data on the private benefits from the firm's technological innovations, figures are also available concerning the firm's expenditures on R&D and related innovative activities each year. Using these cost figures, as well as the figures concerning the total cash flow of benefits stemming from the new products or new processes that came to fruition each year, we can compute the rate of return from the investment that resulted in each year's crop of innovations.

Table 3 shows the results for 1960-72. Although these figures are interesting, their limitations should be stressed. For one thing, the firm does not attempt to include in its calculations any innovation where the discounted value of its benefits (the discount rate being 15 percent) is less than $200,000. Since the firm's benefit figures omit the benefits from such minor innovations, the rates of return are almost surely underestimates. Nonetheless, despite these and other defects in the data, the results illustrate the sorts of analyses carried out in this area by some leading U.S. firms.[20]

Table 3 Private Rates of Return from Total Investment in Research and Development and Related Innovative Activities, Major Industrial Firm, Process and Product Innovations, 1960-1972

Year	Both Products and Processes	Products (percentages)	Processes
1960	31	21	34
1961	9	0	15
1962	7	17	negative*
1963	26	13	30
1964	15	9	18
1965	16	27	-1
1966	25	22	27
1967	11	11	12
1968	2	-1	5
1969	3	13	-15
1970	6	9	3
1971	12	16	10
1972	14	14	14
1960-1972	19	14	22

*No major process innovations occurred in 1962.

Conclusions

A considerable amount of research has been carried out by U.S. economists to understand better the relationship between technological change and economic growth. The findings of this research seem to have been of use to policymakers in both the public and private sectors. It is difficult to predict the extent to which these findings and tools may be of use in the People's Republic of China, where the economic system is so different from that in the United States. (In particular, prices play a somewhat different role and are determined differently in the two countries.) But it seems likely that they should be of some value.

FOOTNOTES

1. E. Mansfield et al., "Social and Private Rates of Return from Industrial Innovations," Quarterly Journal of Economics, May 1977.

2. E. Mansfield et al., The Production and Application of New Industrial Technology (New York: W.W. Norton, 1977).

3. Zvi Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy 66 (1958): 419.

4. Willis Peterson, "Returns to Poultry Research in the United States," Journal of Farm Economics 49 (1967): 656.

5. A. Schmitz and D. Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics 52 (1970): 569-77. Since the concept of rate of return varies somewhat from study to study, the results are not always entirely comparable.

6. For a description and evaluation of these studies, see E. Mansfield et al., Technology Transfer, Productivity, and Economic Policy (New York: W.W. Norton, 1982).

7. R. Solow, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, 1957. Also, see E. Mansfield, "Contribution of R and D to Economic Growth in the United States," Science, February 4, 1972

8. Z. Griliches, "Research Expenditures and Growth Accounting," in B. Williams (ed.), Science and Technology in Economic Growth (London: Macmillan, 1973).

9. E. Denison, Accounting for Slower Economic Growth (Washington, D.C.: Brookings, 1979).

10. J. Kendrick, Productivity Trends in the United States (Princeton: Princeton University, 1961).

11. Z. Griliches, "Research Expenditures, Education, and the Aggregate Production Function," American Economic Review, 1964.

12. E. Mansfield, "Rates of Return from Industrial Research and Development," American Economic Review, 1965.

13. J. Minasian, "Research and Development, Production Functions, and Rates of Return," American Economic Review, 1969.

14. M. Brown and A. Conrad, in The Theory and Empirical Analysis of Production, M. Brown, ed. (New York: Columbia, 1967).

15. N. Terleckyj, Effects of R and D on the Productivity Growth of Industries (Washington, D.C.: National Planning Association, 1974).

16. Z. Griliches, "Returns to Research and Development Expenditures in the Private Sector," in J. Kendrick and B. Vaccara, New Developments in Productivity Measurement and Analysis (Chicago: National Bureau of Economic Research, 1980).

17. F. M. Scherer, "Using Linked Patent and R and D Data to Measure Interindustry Technology Flows," to appear in Z. Griliches (ed.), R and D, Patents, and Productivity (forthcoming).

18. E. Mansfield, "Basic Research and Productivity Increase in Manufacturing," American Economic Review, December 1980. Of course, it should be recognized that the distinction between basic research and applied R and D can be very difficult to make, and that the data are rough.

19. E. Mansfield, "Research and Development, Productivity and Inflation," Science, September 5, 1980; and E. Mansfield et al., Technology Transfer, Productivity, and Economic Policy, op. cit.

20. See E. Mansfield, "How Economists See R and D," Harvard Business Review, January 1982.

ON SOME POLICIES OF INDUSTRIAL RESEARCH AND DEVELOPMENT OF OUR COUNTRY IN THE PERIOD OF ADJUSTMENT

Yu Desheng, Cao Tingsheng, Xu Shoubo

In 1979 the government of our country adopted a policy of adjusting, reforming, rectifying, and improving the whole national economy. Following this policy, a number of new things have taken place in recent years in the industrial field with regard to research and development.

In the more than 30 years since the founding of the People's Republic of China, we have relied on our own efforts, an independent and pretty complete system of socialist industries and national economy, which has grown out of nothing and developed, on an independent basis, highly technology-demanding electronics, computer, pharmaceutical, precise and heavy machine-building, chemical and nuclear industries, etc., thus making our country's industry as a whole a sector of our national economy, which is relatively complete in its kind and system and can meet in general the needs of the people's life and for further development. By 1981, the total industrial output value reached 78 million yuan RMB and the scientific research in our country had also greatly developed. Science and technology had played an important role in the development of our national economy, particularly in industry. However, we had also noticed that it was still necessary to give better play to science and technology. In the various departments of the national economy, there were quite a lot of production and technical problems that had not been taken seriously and solved for a long time and some rather sophisticated scientific and technological achievements had not been put to use and spread in production and construction. For instance, based on research and experiment, we had succeeded in developing certain precision equipment, but their production was hampered by the inability to provide basic components by the engineering industry and the lack of competency in some basic technology; while several hundred new and sophisticated materials had been developed, some ordinary materials were still quite poor in quality. Furthermore, many industrial enterprises were high in consumption and cost but low in labour productivity and quality, making them non-competitive in the international market.

Two reasons may be given for these phenomena. First and foremost was the failure to give proper emphasis to science and technology, resulting in inadequate attention to and absorption of new scientific and technological achievements, which in turn made the development of science and technology short of proper incentive. Another reason was that after the ten years of turmoil and disorder, there had not been appropriate guiding policies for the different types of scientific research in different fields, and therefore many research departments did not pay sufficient attention to their own particular features and functions so that the research results could not be smoothly communicated to production departments, which made science and technology unable to serve the national economy satisfactorily and play the role of a strong lever for promoting its development. Facing these problems in research and development, in 1981 the State Council instructed the State Scientific and Technological Commission to hold a special meeting to sum up the past experiences, and based on a better understanding of the role of science and technology, a fundamental policy of developing science and technology for promoting the development of the national economy was formulated. Its main conditions were:

1. To coordinate the development of science and technology with social development and take the promotion of economic development as its principal task.
2. To emphasize the research of production processes and proper selection of technologies so as to form a rational technical structure.
3. To strengthen the technical development in factories, mines, or other enterprises and make greater effort for spreading.
4. To ensure a step by step development of basic research on a steady basis.
5. To take learning, digesting, and absorbing foreign technologies as an important approach to develop science and technology in our country. It is exactly under the direction of the principle of adjusting our national economy and through practising a series of specific policies, new things and new problems have taken place in the scientific and technological work of the industrial field of our country.

A. Bringing the Intitiative of the Basic Level into Play and Giving More Right for Research Institutes to Their Own

During recent years, the Central Party Committee and the State Council have been emphasizing giving full play to the initiative of the local governments and various departments. All provinces, municipalities, and industrial departments have accordingly intensified their research work on scientific and technological policies. Apart from the country-wide basic policies set forth by the Central Government and specific policies based on their characteristics in resources, geography, history, etc. Following the Central Party Committee's instructions for the construction of the Capital, the Beijing municipal government, for instance, has decided that the main direction for the industrial development in Beijing is to vigorously develop the food-processing industry, light and textile industries, electronic industry, household electrical appliance industry, building material industry and other industrial productions necessary for the people's life so as to serve the people in the Capital in their political, cultural, and economic life. At the same time it has also specified the direction of investment for research and development and a series of policies of priority concerned. Therefore, a system of development strategies and scientific and technological policies covering the central and local authorities as well as the various forces of research and development are gradually taking shape. This is a multi-level administration and multi-section conception of scientific and technological policies. At present, besides carrying out the central authority's policy of overall importance, the leading organization of science and technology at various levels should also pay attention to the market and production information that reflects the people's needs and work out their own policies so as to react in time to the continuously arising and ever-changing needs.

This diversification of policies has made the policies more efficient. The policies worked out by the departments and regions are in many cases more suitable to the conditions in those departments and regions and therefore more useful to accomplish the aim set up for economic and social development.

For instance, in order to make use of advantages and avoid disadvantages, some coastal cities have moved the production of some high energy-consuming and raw material deficient products to suitable inland places and switched to technology-concentrated industries and products themselves and made their own plan for research and development on this basis, thus obtaining higher economic benefits for their areas and even the whole country.

Due to this change in policy structure and the formulating mechanism, a relationship is established between the policy formulation to suit the specific conditions of an organization and the interest and benefit of the organization concerned. This reduces the intermediate links and the process from the arising of problems to the working out of a policy to deal with them, resulting in significantly increased sensibility to respond to the changed objective needs and the market as well as production conditions. One of the concrete advantages of doing so is the possibility of adjusting the direction of research and development and to concentrate the efforts in time so that the process of development can be accelerated and the time from research to production of products can be shortened.

Along with more right given to the enterprises to decide for themselves, many experiments have been done to extend the right for research institutes to act on their own in the different areas and by different departments. However, since the reform of the whole administrative system in our country is still at the experimental stage, it is neither in every research institute nor in every field of administration, that the right has been extended. At present, the extension mainly concerns such respects as planning, income allocation and awards and bonus to the staff, etc. This mainly means that on the prerequisite of fulfilling the task assigned from higher levels, research institutes can undertake on their initiative contractual projects beyond their plans according to their capabilities; financially they are allowed to take part of their contractual income from the projects or excess income after fulfilling their planned financial quota as fund for research and development on their own initiative as well as for collective welfare and bonus to individuals.

Experiences have so far told us that the results of these practices are positive. Firstly, it enhances the enthusiasm of all research institutes and the research personnel, so that the efficiency of research and development work is greatly increased. For instance, according to the investigation made in the research institutes in five places within Shanghai area, the research program is carried out much better than a year ago since the extension of their right to act on their own, and the rate of application of research results are much higher than before.

Secondly, it makes research institutes now have their own independent income, which provides more possibility for developing their research programs, thus greatly improving the benefits from the national funds for research and development. A few research institutes can do with their own income and no longer need financial support.

Thirdly, it improves the welfare for staff and workers of research institutes. A part of their income is used for building new apartments, running nurseries and other welfare facilities, further bringing into play their initiative.

Fourthly, it raises the level of administration for research and development, particularly in the cost accounting for research projects and paying attention to economic research and development.

All these are reflected in a concentrated way in the increase of efficiency of research institutes. Of course, the present extension is still at the experimental stage, far from solving all the problems. But this is a good beginning. In fact, it has already gone beyond for a long time the test period at selected points, and the right of all research institutes has been extended to some extent.

B. The Beginning of a Combined Three-in-one Planning System for Scientific and Technological, Economic, and Social Development

The economy of our country is a planned one, and planning is essential to the development of the country. However, for a long period of time, our planning procedure has not been without problems, one disadvantage of which was that the economic planning and the planning for the development of science and technology came apart from one to the other. The planning departments in formulating a plan for the national economy usually ignored the factors of science and technology and stated no definite requirements to the departments of science and technology. On the other hand, the departments of science and technology did not know much about economic construction. But since the State Council stated that scientific and technological, economic and social developments should proceed in a coordinated way, both the central and local governments have all started to work out for the national economy combined three-in-one plans for scientific and technological, economic and social development and achieved certain preliminary results. For example, last year, with the help of the State Scientific and Technological Commission, the State Planning Commission and the State Economic Commission, a test at a selected point was made in Tianjin for the combined three-in-one planning for scientific and technological, economic and social development. They selected the bicycle industry and knitting industry to make the test and formed a planning group of specialists in various trades to carry on extensive investigations on the needs in the foreign and domestic markets, the process and technology for making products of these industries, the scientific and technological achievements that could be applied, the process or technology necessary to import as well as the problems and requirements for energy-saving, pollution abatement, personnel training, welfare of staff and workers, etc. Based on these investigations, the direction for development during the period of the Sixth Five Year Plan (1981-1985) was fixed and a plan for increasing product varieties, improving quality, energy saving, pollution abatement and personnel training was formulated.

This combined three-in-one planning has the following characteristics worth mentioning:

The first is the combination of science and technology with the economy. On working out such a comprehensive plan, the people working in the fields of production, science and technology, marketing, administration resources, environmental protection, foreign trade, etc., were organized together to offer information and opinions, and succeeded in changing the past contradictory and impractical plan in which each went his own way without the slightest mutual cooperation, for the present plan in which all parts are closely related conditionally with one another. This plan clearly defines the direction for science and technology to serve production and provides the development of production with scientific and technological basis. For instance, the plan includes such stipulations as to apply 23 items of existing scientific research results, carry on 18 research projects according to the needs of production and import 4 plants.

The second characteristic is the embodiment of the policy to develop economy with intension as its main content, i.e. to effect a rapid economic development by improving the technologies. During the Sixth Five Year Plan, it is planned that the bicycle industry in Tianjin should increase its production capacity by 3 million bicycles. If this goal were to be achieved by means of extension, then many new factories would have to be built and thirteen existing factories would have to be shifted to bicycle production, too. After an overall planning, it is decided that the capacity should be developed mainly through intension and the total investment within the five years shall be 106 million yuan, of which 35 million is for new construction and for modernization of existing factories, 68 million for introduction of new technology and equipment, and 3 million for research and development. The implementation of this plan will lead to an increase of the total capacity by 3 million bicycles and the output value will increase from 560 million yuan in 1980 to 1170 million yuan in 1985. Labor productivity will also increase from 28,472 yuan per capita to 47,216 yuan per capita. In average, for each new bicycle produced, the investment required is 27.5 yuan instead of 100 yuan in the case of building new factories.

The third characteristic is a more intensive prediction of the market demand so as to produce in accordance with the market demand both at home and abroad. As mentioned earlier, our economy is a planned one. We can not base our production on the market signal alone, particularly if it is only the recent market demand. However, the fundamental objective of production is to satisfy the needs of the consumers, so we cannot but pay sufficient attention to the restriction of production (and indirectly research and development) by market. Looking back, the malpractice of the economic system of our country was conspicuously shown in its neglect of the functions of the market. But a planning like this requires a market basis for production and for science and technology, a production in Tianjin, a prediction of the demand profile for bicycles both at home and abroad until 1985 was made, taking into account such factors as the increase of population, the growth of the people's purchasing power, the average time for renewal of bicycles, etc., so that the target of the production plan could be properly defined and research and development oriented.

This, of course, is just a beginning, and it is quite difficult to work out such a three-in-one plan for one industry alone since a solution to pollution as well as to some social problems such as population, employment, houses, etc., needs more comprehensive planning in a wider scope. Other problems such as coordination, cooperation and technical transfer among regions and the coordination in international trades also depend on the coordination of a high level.

C. The Strengthening of Region-to-Region Economic & Technical Cooperation and Technical Transfer

Technical transfer is not only an effective approach to develop the economy and improve efficiency, but also an effective approach to rapidly raise the scientific and technological level of the cadres in the beneficial areas to prepare them for future research and development. Therefore, the government of our country regards the technical transfer as an important policy. In the Fourth Session of the Fifth People's Congress, Premier Zhao Ziyang said, "We have to properly organize the transfer of science and technology from laboratory to production unit, from exclusive military technology to both military and civilian use, from coast to inland, from foreign countries to our own country."

During the recent years, apart from the projects assigned by the State, the economic relations among the provinces and departments have also greatly strengthened, giving rise to many big projects of cooperation, e.g. the cooperation of forest project between Shanghai and Inner Mongolia Autonomous Region, the cooperation of coal mine project among Shanghai, the Ministry of Coal Industry and Anhui Province, etc. There are all together more than 10 projects of cooperation of different kinds between Shanghai and seven provinces. Tianjin has already signed formal agreements for economic and technical cooperation with nine provinces and has already agreed on 304 cooperative projects. This kind of cooperation, in general, goes together with technical transfer and the developed regions are usually more advanced in technology. These cooperative projects are of mutual benefit, but from a technological point of view, more beneficial to the less developed regions.

Roughly speaking, the following types of cooperation in this connection exist:

1. Overall agreements signed between provinces or between cities and provinces. In this type of cooperation, the economically and technically advanced regions help their partners to build up factories by supplying equipment and technology and get paid with goods they are interested in. For instance, Tianjin assists Yunan Province in building up carpet factories, wool textile mills, leather factories, etc., and Yunan Province provides Tianjin in return with wood it is short of.

2. Supply of equipment and technology by the economically advanced regions to the raw material producing areas in the form of credit for them to establish processing capacity and make semi-finished products for paying back. In this type of cooperation, the raw material producing areas get technologies and develop local industries. For example, Tianjin helps Qinghai Province to build a carpet yarn factory, the product from which is shipped to Tianjin for producing the famous Tianjin carpets. Shanghai helps Sichuan Province to expand its silk yarn processing capacity, and part of the additional products is shipped to Shanghai.

3. Technical service. Some examples of this kind of cooperation are the technical services provided by Shanghai and Tianjin to the inland enterprises for increasing the rate of acceptance of products and solving quality problems of some machine parts.

4. Joint venture. In this type of cooperation, the more advanced regions usually invest with funds, equipment and technology, while their partners provide buildings, labor, raw materials, etc. The examples are the Shanghai-Zibo Ceramic Material Factory, which is a joint venture between Shanghai and Zichuan Radio Factory in Shangdong Province, producing ceramic steel badly needed by the electronics industry in Shanghai; the cold storage run jointly by Tianjin and Shangdong Province, etc.

5. The advanced regions help the backward regions rectify their enterprises, carry on comprehensive treatment, improve their

management and raise their product quality up to the specification of their own famous products to get paid or to allow their partners to use their brand name against payment. This type of cooperation in essence is a transfer of managerial technologies.

There are other types of cooperation. Generally, this kind of overall economic and technical cooperation is usually approved through agreements signed between the departments of administration of various provinces and cities, and then handed over to enterprises, research institutes and/or design units for implementation. But simple projects, especially those mentioned in type 3 and type 5, often resulted from direct agreements between the enterprises concerned.

This kind of cooperation with accompanying technical transfer has tremendous significance to our country's economy and social progress.

In the first place, it can bring about rapid and vigorous economic and social development of the economically backward regions. This is because the technologies involved are rather advanced and very applicable. They grow out of the cultural and social soil of the same nation, use the same language as a means of communication and are therefore easy to learn and quick to yield benefit. On the contrary, the technologies imported from foreign countries are usually more difficult to master and are of higher cost. The technical gap between the advanced regions and the backward regions are often quite large. Taking the example of production costs for a bicycle, it is around 60 yuan each in Shanghai, but more than 100 yuan in quite a number of places. It runs even higher than 200 yuan in some areas because the manufacture of bicycles there has just been developed recently. The main reason for this situation are their poor mastery of technologies and workmanship and the low rate of acceptance of their products. For instance, the rate of qualified welding processes in Shashi, Hubei Province used to be 40% only, but as a result of the technical services given by Shanghai, it has reached 90%. The larger the technical gap, the higher the economic benefit of this kind of technical transfer will be.

The effect of the technical transfer is often shown not in economy only, because along with the solution of their technical problems, the backward regions are in a position to develop many industries that were not possible to develop in the past. Generally, the technical transfer will also help raise the cultural and educational levels of the workers or even of the whole region in question, and create more employment opportunities. This is very important to the modernization of the entire country.

For instance, many high energy-consuming industries are concentrated along the coast that are short of energy supplies, and many raw materials for light industries are produced inland while their processing is usually concentrated in coastal areas, etc. The solution to these problems of course depends mainly on the planning of the State and one of the main approaches is to promote technical and economic cooperation between regions. However, the technical and economic cooperation between regions on their own initiative often have such advantages as lower investment, higher flexibility, filling in of blanks in the state plans, etc., and therefore have irreplaceable functions in improving the distribution of industries.

Thirdly, such technical transfer is also beneficial to the advanced regions themselves.

Since the technical transfer is to be paid, it will inevitably be accompanied by a flow of materials and funds opposite to the direction of technical transfer. For example, Shanghai, Tianjin, Beijing, and Jiangsu Province all depend on other provinces for cotton textile raw materials, energy and so on. Through the export of technology and capital, they can get back the raw materials, primary products, electrical power, fuel, etc. that they are short of. Moreover, competition also promotes industrial progress. For many years, several developed industrial areas along the coast have been holding an absolute position in technology and due to the lack of external competition and the inland's inability to compete, the progress in these areas has been slow and old products have been in domination. However, as a result of technical transfer, the industry and technology in the previous backward regions have rapidly developed and are "threatening" the advanced regions, pushing them to make further progress so as to keep their leading position. This kind of repeated combat and competition serves to raise the technical level of the whole nation.

Fourthly, it helps expand the export of the industrial products of our country. Since the domestic market demand of our country is very high, the coastal cities with export potential are usually left with very limited export capacities after fulfilling the sale quota set by the State. This is actually one of the reasons why in some cases we are not able to satisfy the needs of our foreign customers though we do produce suitable products for export. Now other regions can take over a great part of the task for satisfying the domestic market demand, so the advanced regions are in a position to adjust their product varieties and develop the products suitable to be sold in international markets.

D. The Emergence of the Various Types of Combination of Research and Development with Production

According to the administrative subordination, the scientific research forces in China can be classified into 5 contingents, i.e. the Chinese Academy of Sciences (Academia Sinica), the research institutions affiliated with various ministries under the State Council, the research institutions affiliated with universities and colleges, research institutions in local areas and affiliated with the Defense Department. They all take part in industrial research and development in various degrees. The research institutions for national defense usually did not participate in the industrial research of civilian use in the past, but during the recent years as part of national defense industry has engaged in the production of products for civilian use, part of its scientific research force has also plunged into the work in this respect. However, owing to the fact that the above-mentioned contingents of scientific research have been subordinated to their own administrative systems respectively, and assigned to research tasks and funds by their own authorities, two problems have arisen.

One is lack of cross relationship between these research forces, resulting in an unclear division of labor and duplication of works. The other is lack of a close relationship among research units, institutions of higher learning and industrial enterprises. This means a rather serious disjointing between research, development, and production. These problems have led to a consequence that many achievements in scientific research cannot be applied in time to production and quite a number of key scientific and technological problems in production are not attended to or even there appears problems of insufficient research assigned to research units and institutions of higher learning.

Now what kind of scientific research system should be established so as to create a better combination between research and production seems to us a problem both urgent and difficult to solve. Nevertheless, what is fortunate is that there are already attempts made in this respect. Roughly speaking, there are the following types of combination of research and development with production at present.

1. The research and development forces in enterprises strengthened. China has now nearly 400,000 factories and enterprises in total. Their production and technical conditions are of great importance to the development of the national economy. Judging by the existing conditions, a majority of the enterprises have great potential. In quite a period of time to come, the emphasis for developing our economy will not be laid on building new factories, but on giving play to the potential of existing enterprises, innovation and modernization, which depends on the use of new processes and new technology. However, for a long period of time the technical development in factories and enterprises is a weak link, and they practically do not have their own research capabilities with the exception of a few enterprises. In recent years, as the economic adjustment and the reform of administrative system go deeper and deeper, the market competition grows stronger, making the enterprises more interested in developing new technologies and producing new products. Moreover, along with the enterprises having more right to act on their own, they now have more sources for funds than before. Thus many enterprises and factories have established their own research and development facilities and already made some achievements (of course some of them have not been approved). For example, Shanghai No. 5 Iron and Steel Work set up its own research institute in 1978 on the basis of its central laboratory and there are now more than 200 technical workers on the level of assistant engineer and even higher. In a short period of two years only, the institute organized over 150 research projects, out of which about 100 have already passed appraisal and are playing their roles in production. The institute's investment for the research projects during the two years period was 2 million yuan, but the yearly economic benefits have amounted to 8 million yuan according to preliminary calculations. Many new industrial cities have appeared in recent years in China and their pace in developing their industry is pretty fast, which has a bearing on the establishment of research institutions in the enterprises. For

instance, since 1979 research institutes in the various factories in Siping, Liaoning Province have either been imported from foreign countries or independently developed 324 items of processes and technology, process materials and products, 90% of which are already put into production. In Yantai, Shangdong Province, there are now already 27 research institutes and over 30 research departments or groups attached to the factories there for the last five years and the total achievements in scientific research are more than 2,050 items, of which 1,483 are already being used in production. At present there are about 10,000 new products going into production all over the country each year, mainly through strengthening the research forces in enterprises.

2. Associated entities of scientific research and production. These associated entities are loosely united technical and economic forms between several economic entities, and scientific research units without changing their subordinations, but with a view to promoting the development of production by scientific research to vigorously raise the economic benefits, using mutual benefit and interests as a lever. During recent years, these forms have greatly developed. Examples are the textile dying and printing association, combination lathe association, refrigeratory equipment association, etc., having successfully established in Dalian. These associations have united many research institutions and factories and greatly accelerated the research-production cycle, bringing about tremendous economic benefits. Another example is Gaoqiao Chemical Company in Shanghai formed around the utilization of resources by the Refinery and Chemical Works in Gaoqiao, a suburb of Shanghai, Shanghai Petrochemical Research Institute and other units. In this association, the Petrochemical Research Institute specializing in catalyst research has been playing a very important role.

3. Exhibition (or fair) of achievements in scientific research. Many large cities and some provinces in China have organized such exhibitions in recent years. Local units as well as organizations in other places participate in these exhibitions. In these exhibitions, the production units cannot only take over the achievements in scientific research, but also put forward difficult production problems for the research units to work on. In June 1981, the Municipal Scientific and Technologcial Commission of Shenyang organized more than 60 research units to exhibit their 468 items of research achievements for eight days and there were more than 70 factories and enterprises presenting 130 urgent problems to be solved. Moreover, 443 units established their relations with each other and 40 contracts for technical transfer and technical contracting were signed. Among the problems presented by the production enterprises, 14 have already been accepted by the research units.

4. Remunerative transfer of achievements in scientific research through contracts. This kind of cooperation is usually for one time only. The party which sells its research results undertakes to train the buyer's personnel, teach them techniques and provide them with drawings and documents while the buyer pays the seller according to

the terms of payment, either once for all or in installments in proportion to the profits. There are also cases of payment in yearly installments. Since there are no laws for scientific and technical transfer in China, a majority of such transfers just follow the usual pattern and greatly differ from one place to another.

5. Research projects entrusted through contracts. In this case, it is mainly the factories, mines and enterprises which propose the subjects based on the problems arising from their production and entrust them to suitable scientific research units for solution. There are also some cases in which the local scientific and technological commissions and the departments in charge of scientific and technological affairs in various ministries or state commissions assign research subjects to certain scientific research institutions for them to work on, based on the proposals from below. Generally speaking, the party which entrusts the subjects shall undertake to provide some funds or materials to facilitate the research.

6. Organizing training courses (or seminars) for disseminating the technical achievements that are not very complicated and can be applied in a broad range. One example of this type is the seminar on "Vortex Cutting Nozzle for Melting and Cutting Cement Products," organized by Liaoning Xinguang Machinery Plant. This seminar had more than 100 participants from 19 provinces in China. They made remarkable progress by attending lectures and participating in actual operations.

7. Establishing technical service centers or consulting companies. Technical service centers of consulting companies are organizations formed within an area (e.g. a city or a county) or an industry (e.g. textile industry) by engaging experts from various units (mainly research institutes, universities and production units). Their object is to provide enterprises with necessary technical knowledge and help solve the problems in developing production. Generally, they are organized by and under the leadership of the local scientific and technological commissions or the scientific and technical associations. Their sources of funds are service fees paid by their clients and some subsidies from the local governments. These organizations also give advice to the administrative authorities on various levels.

8. Factories run by the research institutions themselves. During recent years, many research institutions have either built up or expanded their attached factories so as to meet the requirements of pilot plant test.

Besides, there are also other types of factories attached to research institutions.

E. Diversification of Sources of Funds for Scientific Research and Appropriation that Requires a Pay-back

Two main changes have taken place with regard to funds for scientific research during recent years: one is the diversification of sources of funds for scientific research and the other is the practice of a system in which certain research funds have to be partly or completely paid back. Roughly speaking, there were two sources of funds for industrial research in China in the past: the operating expenses of various research institutions, and some subsidies controlled by the State Scientific and Technolgical Commission for trail production of new products, pilot plant tests and important research projects. Both of them came from the state budget. The former was annually appropriated by the various departments responsible for it while the latter was partly controlled directly by the SSTC with the rest allocated to the units responsible for scientific and technical affairs (provincial and municipal scientific and technological commissions and scientific and technical bureaus of various ministries). The appropriations did not have to be returned.

Along with the extended right for enterprises and research institutes to act on their own in recent years, apart from the above-mentioned sources, research institutions have had at least the following additional sources of funds:

1. The remunerations for technical transfer by research organizations to factories and other users. Besides the part handed over to the higher authorities, these remunerations will be partly used for paying tax, partly for welfare (e.g. housing, cultural facilities, etc.) and as bonuses for the staff and workers, leaving a considerable percentage for reinvestment on scientific research.

2. The funds provided by the units that entrust research projects. There were such cases before, but only of a very limited number and most of them were the projects entrusted by the defense department. Along with the current increase in bilateral relations, cases of such relationship have also increased.

3. Possibilities of getting funds through credit for certain research projects that are of high applicability and shorter cycle, especially projects for developing new products. One possibility is credit from the banks and the other is credit from the future users in the form of a down payment for new products, which will be paid back with the new products.

Besides, the research institutions affiliated to enterprises can draw a certain percentage of the projects kept by enterprises as funds for scientific research. A certain percentage of the reserve funds of enterprises for innovation and modernization of the fixed assets can also be drawn as funds for scientific research. In some places (e.g. Jiangxi Province, Shandong Province, Yantai City, etc.) these are stipulated in the local laws or decrees.

Furthermore, there are other minor sources, for instance, the local financial subsidies, appropriation of part of administration expenses of enterprises as funds for scientific research, etc.

Now, the State Council has already decided that the original subsidies for trial production of new products will be replaced by "funds for development of science and technology," which is divided into three parts controlled by the State Scientific and Technological Commission, various ministries under the State Council, and the provincial and municipal governments respectively. When using this fund, contracts should be signed, with stipulations of "not to be returned," "to be partly returned" or "to be completely returned" respectively, according to the nature of the research project concerned and the paying-back capabilities of the users.

The past experiences of giving funds gratis showed some disadvantages. For instance, in order to get funds, some research units submitted research projects for consideration quite blindly without paying sufficient attention to how the future of these projects and their economic results would be, or even went so far as to use the funds for other purposes, making the overall benefit of the funds lower, judging by the results of the experiments at selected areas, this reform had positive results. The use of funds requiring a pay-back has made research units stronger in the sense of responsibility, pay more attention to feasbility and prediction, and improve the management of their research work. This procedure has also promoted the accumulation and increase of the funds for scientific research, making it possible to arrange more and more research projects.

F. Changes in Principles of Choosing Subjects of Research and Development

Generally speaking, the present choice of the subjects for industrial research and development is characterized by the following features:

1. A combination of subjects assigned by higher authorities and optional subjects. If we say the research subjects of various research units were mainly assigned by the higher authorities through instructive plans some years ago, then in recent years while still following these plans for major subjects, the proportion of optional subjects and subjects arising from production practices has increased. Besides giving importance to the subjects assigned to themselves, the administrative organizations for scientific research at different levels try their best to give financial and material support to the subjects or projects coming from production and chosen by research units themselves as long as these subjects are following the right direction. Once achievements are made, they also help spread them in an active way. For example, there were altogether 141 appraised projects in Changzhou, Jiangsu Province between 1979 and 1980. Out of this total, 63 were in the plans and 78 outside, equal to 56% of the realized projects. These projects outside the plans got not only financial supprot, but also such materials as steel, wood, etc. that were supplied only to the projects assigned by the higher authorities before.

2. Strengthened sense of maket. As a result of the reform of economic administrative systems, the state commercial departments no longer undertake blindly to sell exclusively all products whether they sell well or not, but let them be put directly to the test by the customers. Whether the products sell well and agree with the customers or not determines to a great extent the future of the enterprises concerned. Therefore, launching new products one generation after the other by relying on research and development has become a matter of utmost concern to enterprises. In 1981, there were

100 scientific and technological research projects in Changzhou, among which 46 projects were for developing new products, corresponding to 45% of the funds for scientific research. Every year, this city produces about 200 kinds of new industrial products as a result of research and development. Jiangmen is a city in Guangdong Province with a population of 200,000. In recent years,the industries there have developed very rapidly due to the importance it has attached to research and development. In 1981, the whole city succeeded in developing 133 kinds of new products (99 kinds are already in production now) and 1,103 new varieties (841 are in production now) that could sell well in the market. Just from the light industry producing the daily necessities (excluding the textile industry), 50 kinds of new products and 621 new varieties were launched into the market in the first half of 1981 and many products have been selected as excellent products in the province or in the whole country. Xiangfan is a small inland city in Hubei Province. It has been very active in recent years in developing new light industrial and textile products. In 1980, it produced 86 kinds of new products and more than 300 new varieties.

3. Strengthened sense of economic and social benefits. During recent years, a higher proportion of achievements in scientific research has been disseminated or popularized due to more attention given to encouraging the research and development that can bring more economic benefits. By benefits, of course, we mean first of all such conceptions as higher output value and profit, and lower consumptions of raw materials, energy and labor, etc. However, they also include the conceptions in a wider scope, such as giving play to the local advantages (e.g. the traditional products and making full use of the local resources), filling in the blanks in science and technology of the country, substituting the imported products, entry into the international market, etc. or the economic benefits viewed from a higher level. For instance, developing the products of shortage to substitute the imported products with them do not bring prominent economic benefits to the enterprise and the area concerned, but its economic benefits to the whole country are certainly of no doubt. In this connection, the following five points suggested by the ministries of machine building are representative to a certain degree; improving the economic results of the enterprise itself; improving both the economic results of the enterprise and the social and economic results having no economic benefits to the enterprise itself but great economic benefits to the whole country; promising no immediate benefits but great future benefits; having no big benefits in the form of economic value but great benefits in the form of social welfare. This way of overall and forward-looking consideration of course originates in the socialist planning system. It is dependent on the overall planning, balance and control by the various levels higher than the enterprise.

The factors consisting of the economic benefits and their order of priorities can be different due to the different conditions in different areas and departments. For instance, the provinces in East and South China are short of energy, so it is an important problem to develop energy-saving technologies, processes and products there. The results shown in the form of currency are often insufficient to reflect their real meaning. Considering, in particular, certain characteristics of the present price system in China such as the frequent failure of price to reflect the relation between supply and demand, the insensitivity of price to cost and quality, etc., it becomes more important to take into serious account the benefits in forms other than currency.

4. Serving the technical modernization of our national economy. In the period of adjusting the country's economy, one of our strategic tasks is to carry out the technical modernization of the national economy. The technical modernization of industries is an important component part. The technical modernization mainly means to equip enterprises with new technologies, new processes and new equipment, to raise the technical accomplishments of the staff and workers of enterprises accordingly and to organize and reasonably manage enterprises according to modern technical requirements for production so as to raise the technical level of enterprises and yield greater economic and social benefits.

The task of technical modernization is set and decided according to the technical conditions of the industries in China. Looking at the industries of our country as a whole, they are furnished with old equipment and backward processes, high in energy consumption, low in proportion of technical personnel and poor in technology and management. For instance, the country's 3 million or so machine tools are mostly in one machine-one cutter-one operator condition; equipment has served for many years, e.g. the fixed assets of half of the enterprises in the whole country are of over ten years service; technologies are backward, e.g. founding is mostly done by hand, forging is mainly free forging with only a few mould forging operations; the utilization ratio of materials for cutting is only 40%; the average heat efficiency of industrial boilers is only 55-60%; the technical personnel in the machine-building industry is only around 5% (lower in other industries), etc. The consequence of all these is poor product quality and slow regeneration of products. For example, the trucks and lorries made in China are heavy and high in gasoline consumption and there has been no regneration for more than twenty years.

The technical modernization of industries, in fact, is a strategic measure to improve fundamentally the quality of enterprises and the industrial capability. In the Fourth Session of the Fifth People's Congress, Premier Zhao Ziyang pointed out, "The technical modernization and the equipment renewal of the enterprises in industry and communications not only can change the situation of insufficient workload of the heavy industry to keep the present economic development at a certain speed and increase new production capacity, but also raise the production technology of the industries of our country to a new level to create conditions and accumulate forces for the future modernization of the entire national economy. It is a matter of key importance to make the economy of the country advance toward a smooth development." In the technical modernization of industries, the machine-building industry plays a role of key importance. It is estimated that in the next five years, about two-thirds of the output value of machine-building industry will be used for this purpose and there will correspondingly be a considerable proportion of subjects and funds for scientific research devoted to it, too. This will also be the case for local scientific research. For example, the technical modernization of the enterprises is one of the measures emphasized and supported by Changzhou Municipality. Between 1978 and 1981, the research and development projects for the new processes and new technologies that could be used for the technical modernization amounted to 31.4% of the total funds for scientific research there.

Our country is at present in a period of adjusting the national economy. The scientific and technological policies in industry are not perfect, substantial enough and systematized yet, and there are still many problems to be solved.

There are still many weak links in making research and development serve the production of the commodities that can sell well and particularly in quickly putting the achievements in scientific research into use. The policy of encouraging technical innovations has not been satisfactorily embodied in various tax systems for appraising the performance of enterprises. Products of poor technology can still be seen everywhere, and quite often even get higher profits than new products.

Due to the lack of effective ways for coordination, the cooperation between the different forces of scientific research is not good enough. The work for passing the achievements made in scientific research in national defense to the civilian use is pretty poor. The research institutions that do not belong to enterprises need to have closer relationship with production. And so on and so forth.

We are convinced, however, that along with the progress of the adjustment and the reform of the system of national economy, these problems will gradually be solved without any doubt.

POLICIES OF THE UNITED STATES TOWARDS INDUSTRIAL INNOVATION: WHAT WORKS AND WHAT DOES NOT

Richard R. Nelson

This paper summarizes conclusions drawn from a study, just completed, of the public policies which have influenced the pace and pattern of industrial innovation in seven American industries. The industries are civil aviation, semi-conductors, computers, agriculture, pharmaceuticals, automobiles, and residential construction.[1] That study considered a wide range of government policies; the focus in this paper, however, is on direct and indirect support of R&D. While that study was concerned specifically with the American experience, the experience of the European market economies is similar in many respects.[2]

The economic systems of the United States and the People's Republic of China differ in various fundamental and superficial ways. It is an open question how much of the US experience is relevant to China. However, at the least, it may be of interest to Chinese scholars to better understand how governments influence industrial R&D in basically market economies and to comprehend the basic limitations on government action in these systems. And there may be some lessons that are applicable to a fundamentally different system. While some of the limitations on government action discussed in this paper may be specific to market economies, others may be quite general. While some of the guidelines for effective governmental policy toward industrial R&D may be economic system specific, some may be more general. Also, to the extent that the People's Republic of China continues to experiment with a degree of decentralization of economic decision making, and with market-like incentives, the American experience of government policies may be particularly relevant.

ESSENTIAL CHARACTERISTICS OF INDUSTRIAL INNOVATION

While the details of technological innovation differed among the seven sectors considered here, there are several common properties that ought to be noted. These would appear to be generic and, therefore, as important to recognize in a socialist economy as a capitalist one.

First, it is important to recognize the essential uncertainties which surround efforts to significantly advance a technology. There generally are a wide number of possible objectives and approaches to any of these. Ex-ante it is unsure which of these objectives is most worthwhile pursuing and which approaches will prove most successful. Before the fact, aviation experts disagreed on the relative promise of the turboprop and turbojet engines. In the early 1950s experts differed on whether there was sufficient knowledge and experience to warrant introducing a commercial jet airliner. Most companies vastly underestimated the potential commercial demands for computers. Whether or when computers should be transistorized was a topic on which computer designers disagreed; later the extent and timing of adoption of integrated circuit technology in computers was a subject that divided the industry. Texas Instruments got a jump on the rest of the semi-conductor industry by betting on silicon as the best substance for transisitors and later on the integrated circuit. The history of the search for efficacious pharmaceuticals is replete with false starts and lucky happenings. The development of better seed varieties and animal breed is a history marked by chance events, as well as systematic intelligent strategies.

With a clear vision of hindsight, technological advance leaves a litter of abandoned ideas and projects, some of which cost plenty. Hindsight suggests that there ought to be ways to tidy up the process, to avoid marching down false paths, to figure out in advance which technology will be best. But hindsight is better than foresight. The case studies do not reveal R&D and follow-on technological work as activities that can be plannned in any neat and tidy sense. The uncertainties seem to be innate. From a social point of view, effective pursuit of technological advance seems to call for the exploration of a wide variety of alternatives and the selective screening of these, after their characteristics have been better revealed.

Second, in making R&D allocation decisions, the producer of the product or service in question and the consumer, or user, each has important informational and motivational advantages over other parties. Producers live with the prevailing process and product technology and know things about it--its strengths, its weaknesses, certain potentialities for change--that people without that experience cannot easily know. Users have similar special knowledge about the products and services they employ. It is natural, and socially valuable, that this special knowledge and immediate motivation for improvement play a central role in inducing and guiding R&D allocation. Moreover, in a market setting it is the users who will ultimately determine whether a product will be demanded and producers, whether it will be produced and how.

It sometimes has been argued that the disorderly pattern of industrial innovation in market economies can be straightened out by planning in a socialist economy. That probably is so, but straightening it out inevitably means, I think, slowing it down. Efficiency in industrial R&D in a socialist economy would appear to call for planning to assure that a variety of approaches are explored. Similarly, while in a socialist society governments are in a stronger position to persuade producers to adopt certain new technologies and consumers often have little choice about what they can buy, the lesson from the capitalist experience still seems relevant. The basic fact is that consumers have better knowledge about what they want and producers have better knowledge about their own production technologies than any distant bureaucrat. Well directed industrial innovation in socialist societies, as market guided ones, would appear to require strong participation in decision making from the firms who will produce the product and from the parties who ultimately will use it.

There are certain aspects of the American system for generating industrial innovation that at first thought, at least, may not apply in the Chinese, or may apply to a considerably lessened degree. In a capitalist economy much of research and development is proprietary. In many industries innovation is the central competitive weapon. Competition generates both stimulus and waste. One potential advantage of a socialist system for generating industrial R&D is that it can avoid some of the waste of duplicative R&D efforts, of R&D done by one firm because another firm will not grant it access to its technology, etc. It is an open question, of course, whether this can be achieved and at the same time real R&D pluralism encouraged and preserved. Also, to the extent that the People's Republic of China attempts to encourage competition among firms, some of the waste, as well as some of the stimulus, of the capitalist system is inevitable. I should also remark, and this theme will be developed later in this paper, that while the bulk of industrial R&D in a capitalist system is proprietary, an important portion of it is public, and the results of such research openly shared. Indeed governments can have a lot to say about the degree of publicity of the research that is done in a particular area.

The case studies discussed later reveal significant constraints, which differ, however, from industry to industry on what government is able to do. In the first place, in many instances government agencies simply are not in the position to gather the information necessary to make appropriate decisions. Second, the roles open to the government in a capitalist economy are limited by general ideological beliefs that the government does not have legitimate business doing certain kinds of things; in particular, unless there is an important public purpose, a government policy, which runs the risk of benefiting one group of firms as compared with another, should not be undertaken. In the People's Republic of China, in principle at least, there are fewer blocks to government agencies gaining information they need to guide R&D allocation. There are far fewer constraints on the range of actions it is deemed legitimate for governments to undertake. However, the differences here may be of degree rather than kind. In the People's Republic of China, as in the United States, there are information blocks, and in socialist societies, as capitalist ones, governments are constrained to behavior that is judged to be "fair." The American situation may be less dissimlar to the Chinese than appears at first glance.

THE DIFFERENT KINDS OF GOVERNMENT R&D SUPPORT PROGRAMS

There were four identifiably different kinds of government R&D support programs in the industries studied. First, those associated with government procurement. Second, a number of government programs supported basic research and work on the generic aspects of certain technologies. Third, there was one successful instance of government support of what could be considered a users' applied R&D cooperative. Finally, there are several instances where the government tried to "pick winners" in commercial competition. The first three of these represent different ways of accommodating informational and political constraints. Their feasibility and effectiveness certainly vary from industry to industry. The approach of trying to pick winners looks like a policy that generally is a loser. For detailed discussion of the various policies working (or not working) in the several industries, see the book reporting the complete study.

Direct and Indirect R&D Support Associated with Procurement

In three of the industries studied--aviation, computers, and semi-conductors--there was a strong and recognized governmental demand for the products produced by the industry in question, which led to a focused public interest in certain kinds of technological advances. A recognized public sector demand for certain technological improvements lends two important features to the policy context. First, it means that the government (or the relevant government agency) is in a position to define technological targets according to its own criteria and that it has or can get access to expertise about the technologies in question. Second, a recognized governmental need lends legitimacy to government attempts to stimulate and guide the evolution of the relevant technologies.

One should note that public procurement does not inevitably lead to active public sector effort to mold or stimulate technological advance. Governments procure typewriters, office calculators, automobiles, and a wide variety of products that are identical (or virtually so) to those purchased by non-governmental users. In these cases the government usually has chosen simply to act as an informed shopper. In the three industries in question, however, the relevant government agencies deliberately tried to induce the development of products that were suited for their purposes. The vehicles employed included procurement contracts which compensated firms for their earlier R&D funding (a form of indirect R&D support), direct R&D support associated with the procurement contract, and support of basic and generic research.

The details of the policy differed somewhat in the three instances. In the case of computers, direct government R&D support, both basic and applied, played a central role in the early stages of the industry. Some of this support was directly associated with particular procurement objectives, some was aimed to explore and advance quite broadly the frontiers of the evolving technology. The potentialities of a government market were visible to the companies and induced them to invest some of their own funds, long before any had confidence in a large non-governmental market.

In the semi-conductor case, most of the early work that laid the foundations for the industry was privately funded. Government procurement and R&D financing came later. After the early stages, however, the expectation of a large governmental market provided much of the thrust and direction to technological advance. The armed services and NASA provided clear-cut statements as to the kinds of devices they wanted, gave R&D support in search of these and, perhaps even more importantly, inducement to private companies to hazard their own funds.

Government support of technological advance in aviation has proceeded along several different routes. In the inter-war period, the National Advisory Commission on Aeronautics provided public funds for R&D and testing facilities that advanced general aviation technology. As stated earlier, prior to World War II the procurement of paricular new aircraft generally proceeded through the articulation of certain desired performance characteristics, with the purpose of inducing the companies to invest their own R&D in at least the early stages of the efforts. Of course there was, as well, some direct R&D support of the companies. During and following World War II the armed services largely shifted to a strategy of providing direct R&D support, sometimes prior to the signing of a procurement contract.

If public sector needs and private sector needs differed sharply, the procurement and applied research and development funding aspects of such policies would not facilitate the evolution of technology for the private sector. At least three cases suggest, however, that governmental efforts to advance technology for public sector purposes can also enhance technological capabilities to meet private needs. In the early days of these technologies R&D aimed for a governmental purpose that almost always had some commercial spillover. As these technologies matured, the governmental (military) market and the civilian market began to separate. Government financed applied research and development associated with public procurement, and R&D financed by the companies themselves and aimed for products in the civilian market, became dissimlar. At the present time, the principal impact of the government on the evolution of civilian technology in these industries would appear to come via public support of basic and generic research. This fall off in "spillover" has led to proposals that the government consciously fund projects that have likely civilian benefits. The supersonic transport ought to warn against this strategy.

Modern governments procure an enormous range of items. If one considers, as well, goods and services in activities subsidized by governments, for example, medical care in the United States, one can argue that there are government "procurement" interests in virtually every industry of the modern economy. As stated, for most of these the government has left R&D virtually to the market place. I suspect that in many cases the government has been too passive and has relied too heavily on market mechanisms alone.

It is understandable why discussion of the appropriate role of the government in stimulating industrial innovation has focused largely on products sold in private markets. However, public sector demands are large and broad, and many of these receive little R&D attention. The question of the range of public demands for which the government ought to play a significant role in R&D support, merits more attention than it has received.

In the United States certainly, and probably in most other countries as well, procurement related government R&D support has gone mostly for national defense. In recent years a trickle of funds has gone to support the development of better technologies for the provision of public services, like mass transport, garbage collection, repairing city streets, etc. But one wonders if these funds are large enough, given the potential payoffs. There are some important questions, also, about the manner in which these programs have been organized and guided. The federal agencies involved often have neglected to recognize that the potential users of new technologies are state and local governmental units and that Washington may be in a poor position to judge priorities. The study from which this article is drawn did not address these questions.

The emphasis here is on R&D to permit public demands to be met more efficiently, not spillover from that R&D to enhance capability to meet private demands. The strongest case for procurement related government R&D support can be made in circumstances where governments have strong interest in aspects of a technology that are less important to non-governmental customers. Government R&D funding to achieve these special attributes is not going to have automatic spillover, unless government demands in some sense anticipate or lead non-governmental demands for performance in certain dimensions; then non-governmental users in effect piggyback on governmental users.

I think it is a mistake, however, to try to justify procurement related R&D by assigning heavy weight to anticipated spillover. Among other things, if anticipated spillover is the target, criteria for project selection becomes diffuse, and the advantages that a government agency has in at least knowing what it wants are not adequately exploited. Programs aimed largely at advancing the generic aspects of technology, not associated with particular government procurement, are something else again. I turn now to these kinds of programs.

Support of Basic and Generic Research

Without a recognized public interest in the evolution of a particular technology, the government's ability to fund R&D efficiently faces certain constraints. In the first place, a government agency has no paricular claim to be able to determine R&D priorities and may be blocked from access to the information necessary to do so. Second, the legitimacy of publicly financed R&D programs, which may upset the status quo within an industry, may be questioned and such programs politically stymied. The case studies reveal these constraints to be quite stringent regarding government support of applied R&D aimed to achieve particular new products and processes. They appear to be less confining for public support of basic and generic research, a step or two away from specific application.

Our case studes show the government actively involved in support of such research not only in the three industries in which there was a strong procurement interest--aviation, computers, and semi-conductors--but also in agriculture and the scientific fields relating to pharmaceutical developments. The aborted Cooperative Automotive Research Program represented an attempt to extend this type of public program to the automobile industry.

To understand the nature and importance of these public programs, it is important to recognize that technological knowledge inevitably involves a public as well as a proprietary component. The public part of technological knowledge generally does not relate to the design or operational details of a particular product or process but to broad design concepts, general working characteristics of processes, properties of materials that are used, testing techniques, etc. Such knowledge often is not patentable. Much of it is openly shared among scientists and engineers working in the field, whether they are located at universities, government laboratories, or corporate laboratories.

The kind of research that leads to such knowledge is not generally the sort that an academic scholar, pursuing fashionable questions in a standard scientific field, would explore. Rather the research questions are posed by technological problems and opportunities, and the objective is to enhance their understanding and the capability to solve practical problems. In some industries progressive private companies themselves support some of this type of research. While some secrecy is involved, it is recognized that the findings from this type of research ought to flow into the public domain. As our case study illustrates, often the funding is public, at least in part. Such a research system fits in between more fundamental research defined by the traditional sciences and the applied research and development of the firms in the industry. To be effective, the system has to make good contact with both sides but avoid much overlap and duplication.

Farming and pharmaceuticals have benefited greatly from government funding of basic and generic research. The agricultural sciences appear to have managed to define their niches appropriately. The research they encompass lies in between, on the one side, the basic academic sciences like chemistry and biology, and, on the other, the research that goes on in public experimentation stations and private companies to develop better seeds or fertilizers, etc. Parties on both sides influence the kind of research that is done and monitor quality and efficacy. The bio-medical research community is a similar system. It too is pulled from one side by the interests of practitioners (physicians) and private companies in having practical problems illuminated and is disciplined from the other side by scientists in the more basic sciences. It is interesting that both the agricultural sciences and the bio-medical sciences tend to find their home in universities, but in professional schools rather than in colleges of arts and sciences.

The government provides the bulk of support for these two research communities. The allocation of research resources, however, is guided only loosely by government agencies. The Department of Agriculture, the state legislatures, and the National Institutes of Health--the principal support agencies--leave the details of allocation to machinery operated by the research communities themselves. However, in political deliberations about the level of funding and broad research strategies, the focus is very much on the practical benefits that have flowed from the programs and the practical problems that future research promises to resolve.

The old National Advisory Commission on Aeronautics also fits this mold. Unlike the agricultural experimentation stations and the medical schools, NACA was a free-standing organizational entity not affiliated with a university or universities. Nonetheless, NACA undertook many experiments and studies that were relevant to aviation technology in general, rather than concentrating on particular aircraft designs that were being contemplated or were on the drawing board. In that sense, NACA certainly did support generic research and, as history testifies, to strong positive effect. The role of NACA diminished after World War II. In the post-war era the armed services increasingly funded their principal contractors to do the kind of research that NACA used to do.

The key question is the efficacy of such programs. When private companies support little generic research, the case for public support seems especially strong. When private companies support such research, the case for public funding may be diminished, but certainly not eliminated. Thus, in the computer industry and in semi-conductors, where the companies themselves do engage in significant funding of generic research, there is advocacy for, not opposition to government funding of research at universities. While there is a risk that public funds in such cases largely replace private funds rather than adding to them, I do not think that risk is particularly great.

I offer the following conjecture. Government funding of basic and generic research not only enhances the amount of work undertaken, even when the companies themselves are spending significant amounts. When the government funds such work, particularly at universities, the research is more "public" than when business finances it. Moreover, when a considerable amount is publicly financed, the treatment of research results as public is contagious. Business hired or supported scientists are part of the communications network and behave according to its canons.

In all of the industries studied there were networks of communication among scientists and engineers as well as industrial secrecy. However, in the industries where public support of basic and generic research is significant, the information exchange seems to be wider and deeper. It is interesting that in all five such industries technological advance has been especially rapid.

Unlike procurement related R&D support, government programs in support of basic and generic research seem, in principle at least, extendable to any industry. The aborted experience with the Cooperative Automotive Research Program provides mixed evidence and perhaps some guidance as to how and how not to proceed. That experience might be read as confirming that government programs in support of basic and generic research are politically acceptable in virtually any industry. Companies do not perceive such programs as posing sharp threats to their commercial positions, or the threats, if perceived, are seen as diffuse and not readily identifiable as dangerous to any particular portion of the industry. Since proprietary knowledge is not needed to guide allocation, mechanisms can be established to allocate resources sensibly. Yet, General Motors was worried about the anti-trust implications. More important, the industry never was particularly supportive of the program, perhaps because they played so little a role in its initiation. It is clear enough that such programs require industry support and participation to be politically viable.

Recently, associations of firms in high technology industries have begun to show marked interest in cooperative arrangements to support basic and generic research. The program currently being put together by the Semi-Conductor Industry Association is an important case in point, and other industries may follow the example. Questions certainly will be raised as to the extent to which governmental funds should be blended with private funds. Under recently provided tax credit arrangements, the public is in fact paying for a large share of the industry contributions anyway. An interesting question is whether the tax credit route is more or less effective or politically palatable than the direct funding route.

Support of Clientele Oriented Applied Research

Public support of basic and generic research does not require that program officers form judgements about which particular commercial developments will be most profitable. Rather, the objective is to enhance understanding of relatively basic principles, to explore certain potential widely applicable technological routes, etc. The research community itself can be tapped to guide fund allocation. Furthermore, this kind of research seldom poses an immediate perceived threat to the proprietary interests of particular groups of firms. In contrast, government programs of support of applied research and development for an industry, whose products are evaluated largely on commercial markets, requires a mechanism to make commercial judgements. Such a program also may appear threatening to certain firms.

The case of public support for applied research and development for agriculture indicates that, even with these constraints, a government program may be feasible and effective. Governmental support of agricultural R&D has gone considerably beyond the funding of the basic sciences relevant to agriculture and generic aspects of agricultural technologies. Public monies have gone into the development of particular kinds of seeds, fertilizers, insect control methods, planting practices, etc. It is interesting to consider which aspects of the industry and the program have made such a policy feasible and effective.

In the first place, farming is an atomistic industry, and farmers are not in rivalrous competition with each other. Differential access to certain kinds of technological knowledge of property rights in certain technologies are not important to individual farmers. This fact at once means that farmers have little incentive to engage in R&D on their own behalf and opens the possibility that the farming community itself might provide a political constituency for public support of R&D.

The federal/state agricultural experimentation system established under the Hatch Act and subsequent acts marshalled that support and put the farmers in a position of evaluation and influencing the publicly funded applied R&D. The system is highly decentralized. The regional nature of agricultural technology means that farmers in individual states see it to their advantage that their particular technologies be advanced as rapidly as possible.

Historians of technical change in agriculture have argued that the applied research and development efforts of the experimentation stations did not yield particularly high rates of return until a body of more scientific and technological understanding was developed. It was this combination of an evolving set of agricultural sciences that made public support of agricultural technology as successful as it has been. The agricultural sciences were based in the universities and supported publicly while applied research and development was also funded publicly but monitored politically by the farming community. Where private companies are funding significant amounts of innovative work and the industry is reasonably competitive, it is in the interest of the farmers, as well as the companies, that public R&D money be allocated to other things. A reasonably well-defined division of labor has emerged between publicly funded and privately funded applied research.

Can the experience in agriculture be duplicated elsewhere? It is apparent that many people have seen housing and agriculture as quite similar. Henry Wallace, who earlier served as Roosevelt's Secretary of Agriculture, clearly drew the analogy when, after the war, he tried (and failed) as Secretary of Commerce to initiate a major program of federal funding of building research. Under the Kennedy administration a building research program was proposed again, and again based on the agricultural analogy. The idea drew little support. The analogy also was drawn in "Operation Breakthrough" (discussed in more detail shortly). It is obvious that there are important differences.

In the first place, while the building industry is atomistic, construction markets are local and therefore individual builders are, to some extent, in rivalrous competition with one another. However, since individual builders possess little in the way of proprietary knowledge, this was not a particularly important obstacle. What was more important was that suppliers of inputs and equipment to builders produce different and rivalrous products. Direct government support of applied research and development was viewed by many of them as potentially threatening. Had the builders of houses formed a strong constituency for government support of R&D, these resistances of input suppliers might have been overcome. However, no such constituency developed. Unlike the case in agriculture where farmers in a particular region saw it to their competitive advantage (as a group) to have their technologies advanced relative to the technologies employed by farmers in other regions, builders apparently saw no such advantages for them. It might be remarked that no special efforts were made to develop an industry constituency.

Nor did there exist in housing, as there came to exist in agriculture, a scientific community who could point persuasively to promising areas for applied research and development. Residential construction lacks a broad scientific base from which an effective applied research and development endeavor can evolve.

Thus agriculture had both a constituency interested in getting applied research and development relevant to their needs undertaken and, ultimately at least, a sound scientific basis beneath its technologies. Residential construction has neither. My conjecture is that programs in support of residential construction technology will not be politically feasible until the clientele is established to support and guard them and will not be effective in the absence of some sort of underlying scientific base.

It is uncertain, therefore, just how far the agricultural model of public support of applied R&D can be extended, and there are reasons to be cautious. There may be a number of industries to which such a program may be applicable. Some of these may be atomistic private industries like agriculture, although the housing case and the recent disappointing attempts to mount a program in support of R&D for the furniture industry suggest that, at the least, the scientific and political bases need to be established before an applied R&D program can fruitfully go forward. Another class of industries is the regulated local public utilities. The Electric Power Research Institute has been put together by the electric utilities for the collective undertaking of relevant applied research and development. The gas utilities have established the Gas Research Institute. Funds are provided by the individual utilities who, in turn, have been permitted by the regulatory commissions to build these costs into their rates. Again, the key ingredient here would appear to be a group of users of a technology who are not in rivalrous competition with each other but who, together, have a significant interest in getting their technologies advanced and a scientific base strong enough so that applied research and development can be fruitful.

It might be noted that these are the conditions under which one might think of establishing industry cooperative research and development associations. Of course, EPRI and GRI are just that. And, the agricultural experimentation stations might be regarded as an industry R&D cooperative, except for one important difference. Much of the policy discussions about cooperative research and development has presumed that public funds should account for only a small portion of total R&D monies and that the industry should contribute the bulk of the funds save for, perhaps, the first few years of the program. Under such terms it has proven hard to get much cooperative R&D underway and sustained. The agricultural case suggests that the requirement for industry financing may be a mistake. In industries like agriculture, where such programs are plausible, prices tend to follow costs. The returns to successful R&D go largely to consumers, not to producers. The limit to extending the agricultural model is not that the public at large would not benefit but that the conditions under which this model is applicable would appear to be rather special.

Government Guided Applied R&D With Commercial Ends

In Operation Breakthrough and in the Supersonic Transport Project, the government got itself into the business of trying to identify or develop products that would sell well on complex commercial markets. In Operation Breakthrough the Department of Housing and Urban Development attempted to evaluate the commercial promise of various proposed housing designs. However, the Department of Housing and Urban Development was neither a major builder of houses nor a buyer of non-subsidized housing. It thus did not have any particular technological or managerial expertise to enable it to assess the economics of particular designs nor any basis for judging their appeal to consumers. It was easy, therefore, for the Department and Congress to lose track of the objectives as the program was debated politically. Similarly, the Government was not in the business of building or procuring commercial airplanes. The commercial airlines were singularly discouraging when asked about their interest in supersonic transport. The aircraft producers showed no particular interest in designing and building such a vehicle until the subsidies grew very large.

Very few of the housing designs created through Operation Breakthrough proved viable commercially, nor did they serve as significant basis for follow-up design work. The British/French experience with their supersonic transport indicates how fortunate the United States was that the program was stopped before it resulted in a technologically (thought not commercially) viable aircraft.

The lesson here is a general one, not particular to these two cases. There are many other cases, most of these European, in which the government has tried to identify and support particular products that they hoped ultimately would prove to be commercial successes. While there are few successes, the batting average has been very low, except when the government in question has been willing to subsidize or require the procurement of the completed product as well as fund the R&D on it.

This should not be suprising. In many of the industries in which this has been attempted (in Europe), the private companies also were investing in R&D, and the government was in a position either of duplicating private effort, subsidizing that effort and probably therefore replacing private R&D monies, or investing in a design that the private companies had decided to leave alone. In the last case it might be argued that there is a legitimate public role in supporting work on designs that are a generation ahead of those that the companies themselves are exploring. However, as the supersonic transport and a number of other similar examples indicate, the sensible way to explore the next generation of technologies is through doing generic research, building, and studying prototypes, etc. The appropriate research program is one modeled after NACA, not one modeled after the supersonic transport project.

If the United States were to drop its anti-trust laws and the objectives of preserving intra U.S. competition that those laws are supposed to embody, then it might be possible to mount a policy to help industry search for "winners." In various European countries and Japan, competition is viewed not so much in terms of rivalry among domestic companies as in terms of competition from abroad. In these circumstances it is possible for the government to work with industry as a whole and to participate in laying the bets and in dividing the market. The European record of public policies to identify and support winners is not encouraging. The experience in Japan may or may not be different. At the present time not enough is known about what the Japanese actually do to make a judgement on this.

LESSONS

I suggest that there are some lessons relevant to China. First, while the range of goods and services procured by governments, as contrasted with enterprises, cooperatives, and households, is somewhat different in the two societies, in socialist societies, as in capitalist ones, one can distinguish between governmental and other demands. And the distinction is an important one. When a government agency is the principal demander or producer, it has direct access to special information relevant to guiding R&D decisions that it does not have if it is not the demander or the producer. The importance of having the users of the technology play an important role in guiding the R&D seems as important in a socialist country as in a capitalist one. And it may be easy to forget about that fact or ignore it in a socialist society.

Second, the importance of two-sided influence on generic research does not seem system specific. In the People's Republic of China as in the United States the generic research system of an industry can benefit from pressures from the users of the technology as well as from ideas of the scientific community. Again, the importance of involving users may be easier to overlook in a socialist country than in a capitalist one.

The cooperative applied R&D model may be much more widely applicable in a socialist society than in a capitalist one. But the lesson about the importance of involvement of users in guiding R&D allocation certainly is relevant in thinking about policy in the People's Republic of China. Also, it ought to be recognized that, to the extent that policy encourages firms to compete with each other, this will cut down on the areas of R&D where the firms are willing to treat the work as cooperative. There is a real trade-off here.

Fourth, the lesson that governments should not try to "pick winners" in market competition obviously is much less relevant where market competition does not exist or is far weaker. However, the lesson would seem to apply in more subtle form. There is the danger that government officials or scientists or technicians may decide to push a large project without being careful to assure that the project, if successful, will be of real practical value to the users. Socialist societies are at least as vulnerable to spending money on things like supersonic transports as are capitalist ones, perhaps more vulnerable. And the fact that these kinds of big projects tend to proceed as if there were no major uncertainties and as if the best approach to the problem could be identified in advance is not a disease of government of capitalist countries alone. Again, this type of thinking may be less checked by pluralism in a socialist system than in a capitalist one.

In short, there is no denying the great differences between the People's Republic of China and the United States. Each system must find its own best way of stimulating industrial technological innovation. However, I suspect that China can learn from the American experience, both where it has been successful and where it has not.

FOOTNOTES

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will be published under the title Government Support of Technical Progress: A Cross Industry Analysis by the Pergamon Press.

This particular paper, prepared for a visiting group from the People's Republic of China, draws extensively from an earlier ISPS paper summarizing the study: "Government Support of Technical Progress: Lessons from American History," ISPS Working Paper #850, May 1982.

2. Much of what scholars now know about the European experience has been summarized in a recent book by Roy Rothwell and Walter Zegveld, Industrial Innovation and Public Policy, Frances Pinter, Ltd., London, 1981.

CHINA'S PROGRAMS FOR SCIENTIFIC AND TECHNICAL DEVELOPMENT

Luo Wei

Scientific and technical programs and plans have played an important role in developing China's science and technology. However, different views exist over the advantages and disadvantages of centralized planning. Some also doubt if such plans would dampen free thinking in science. This paper is intended to discuss methods of planning for scientific and technical development and their efforts. Since these programs embody a series of goal selection processes, we can see from them the process of policymaking for major R&D projects.

THREE LONG-TERM PROGRAMS FOR SCIENTIFIC AND TECHNICAL DEVELOPMENT

China has had three long-term programs for the nation's scientific and technical development ---- first drawn up in 1956 for the period 1956-67; second drawn up in 1963 for the period 1963-72; third drawn up in 1978 for the period 1978-85.

By the end of 1955, the first Five-year Plan for the national economy had almost been fulfilled, and the second and third ones were beginning to be taken into consideration. A 12-year program for agricultural development had also been mapped out. Recognizing that economic development depends heavily on the development of science and technology, the Party and the government put forward the task of working out a long-term program for scientific and technical development. At the second session of the second Chinese people's Political Consultative Congress, the late Premier Zhou En-lai pointed out," The starting point of such long-range planning is to introduce the most advanced achievements of the world's science into our country in the shortest possible time, according to need and possibility, so as to make up as early as possible the aspects which are short of and most urgently needed in China's science. We should have our scientific research arranged and strive to make the scientific disciplines which are mostly needed here approach the world's advanced levels in the period of the third Five-year Plan."

The whole process of planning was directly under the leadership of three Vice Premiers, and the Premier also took up the matter personnally. At the same time, a leading group (later developed into the Committee on Scientific Planning under the State Council) composed of ten persons from appropriate departments of the State Council was organized. In more than half a year of concentrated discussions by several hundred scientists, documents such as " The Outline of 1956-1967 Program for Scientific and Technical Development," as well as " Specifications for the State's Important Scientific and Technical Tasks and for Major Problems" and "Emergency Measures for 1956 and Essentials of Research Programs for 1957" were finally formed with a total of six million words. The program contained 13 fields, 57 projects and 616 major problems.

The program was characterized by the following points:

1. Close integration with the need for development of national construction. The need includes: setting up of important and urgently needed blank and weak branches of learning, which must be treated as top priorities; solving of important problems of key and compare offensive nature in economic construction and in science and technology; and solving of important scientific and technical problems needed to be done by industrial sectors during their present and near future production and capital construction. In order to make clear the situation of China's resources and to develop all undertakings of this country in a planned way, the first 10 of the 57 projects were concerned with investigations and surveys of our natural conditions and natural resources.

2. Significant planning for the development of new technology. Emergency measures were taken particularly to speed up the development of or to improve new technologies which would greatly affect such spheres as semiconductors, computing technology, electronics, automation, as well as atomic energy and jet technology.

3. Proper attention paid to basic science and basic research. Besides the project of "Research on A Number of Basic Theoretical Problems in Modern Natural Science" among 57 tasks, a program for the development of disciplines in basic science was specially worked out.

4. The program put forward not only tasks and subjects but also general stipulations for the system of the nation's scientific research for policy of utilizing the available qualified manpower, for assignment proportion and general plan of personnel training, for principles of setting up scientific establishments, as well as for plans for international cooperation. Relatively concrete measures were taken for the implementation of a certain number of major and urgent tasks.

After working out the program, the State Council decided that the Committee on Scientific Planning, which was the predecessor of the present State Scientific and Technological Commission, would be made a permanent organization of the government, in order to solve problems such as yearly scheduling of implementation of the program; division of labor and cooperation among all scientific sectors; rational distribution, management and use of research funds; guarantee of working conditions; training and rational utilization of scientific and technical personnel; heightening the quality of international cooperation and exchanges in science and technology, etc.

By 1961, the major aspects of this program had been basically fulfilled five years ahead of schedule with joint efforts of both scientific and managerial personnel throughout the country.

During the conference on scientific work convened at Guangzhou in March, 1962, the tasks of drawing up the 1963-72 Program for Scientific and Technical Development were put forward. The long range plan for 10-year development of basic science was prepared by scientists concerned called together by the Chinese Academy of Sciences and the Ministry of Education. Plans for specialized trades were worked out by various industrial sectors according to their own goals. Finally, the State Scientific and Technological Commission drew up the plan for priority subjects. Later, it was decided that a plan for certain disciplines of science and technology would also be prepared.

The whole process of planning lasted five months with a total of more than 900 scientists participating in the work.

The plan for basic science covered seven disciplines, 41 priority subjects and 380 major problems. The plan for technical science covered 13 disciplines, 32 key subjects and 145 major problems. The plan for specialized trades covered 39 fields and 301 key subjects. The total number of above mentioned subjects is 374.

The 1963-1972 Program paid much attention to agriculture, because the knowledge about the importance of developing agriculture was greatly upgraded after the three-year natural calamity. In the plan for specialized trades, the key subjects related to agriculture, forestry, water conservancy, farm machinery, as well as desert reforms and tropical crops, etc. totaled 111, making up more than one-third of all key subjects listed in the plan. In basic science, there were also reforms in agriculture.

Another feature of this program was the emphasis on technical science, for the development of which a plan was specially prepared for the first time. The urgent need for such plan appeared after the production had developed and the technical level upgraded.

This program was not able to be well implemented because of the "Cultural Revolution" which occurred soon afterwards. We should say, however, that China's prosperous situation in science and technology in 1964 and 1965 was atrributed in some degree to this program.

After the smashing of the "Gang of Four", the Party and the Government formulated quite a number of important policies and strategies for the development of science and technology and for the realization of the four modernizations while clearing away the disasterous results caused by the gang's sabotage. Starting from June 1977, all departments under the State Council, as well as all the organizations concerned, carried out a huge amount of work aiming at preparing a new program for the development of science and technology. In September and October, a conference on disciplinary planning in natural sciences was convened, and then a conference on national scientific and technological planning at the end of that year. After repeated discussions and revisions, "The National program for Scientific and Technological Development" was formed. The program specified in an overall way the scientific and technical research tasks in 27 domains, such as natural resources, agriculture, industry, national defence, communication and transportation, marine, environmental protection, medicine, finance and trade, culture and education, etc.: for the two major departments of basic science and technical science. Among them, 108 projects were defined as priorities. The program particularly required emphasis and concentration of efforts on eight comprehensive and newly emerging major fields of science and technology affecting the overall situation, which includes agriculture, energy, material science, electronic computer, laser, space, high energy physics and genetic engineering, for the promotion of overall development of science and technology and national economy as a whole. Because of an inadequate estimate of the seriousness of the sabotage caused by the "Gang of Four" and of an overly optimistic estimate of the economic situation at that time, the program had such shortcomings as overly high and urgent demands and too many large projects of construction, which have been continuously adjusted in the last two years to the actual situation. Nevertheless, with numerous problems to be solved and all neglected tasks to be undertaken at the time, the Party and the government still put science and tehnology at the top of their agenda. This indeed reflected their determination to realize the four modernizations in the country. Even from the present point of view, the orientation of development of priorities defined then was generally correct and of significance in mobilizing and uniting China's scientific and technical personnel to make their efforts energetic.

PROGRAMS AND PLANS

National plans refer to three different kinds: long-term programs (over 10 years), medium-term plans (around 5 years) and annual plans. The three dovetail one another, having both definite long-range orientation and phased plan of action and necessary material guarantee.

A program includes: scientific and technical tasks and major problems, as well as their significance, contents and goals; analysis of domestic and international situations, contents and goals; projects of international cooperation; responsible organizations; and short-term research subjects. The so called organizational measures include: setting up of needed research institutions and deployment of required scientific and technical personnel, requirement for student training in colleges and universities, etc. The plan also includes the investment on capital construction and allocation of research funds. For example, emergency measures taken for the implementation of several important scientific and technical tasks in 1956 included: setting up of urgently needed research institutions; assignment of univeristy and college graduates for that summer; a few training courses in immediate need; adjustment of specialties in schools of higher learning which should be carried out at once; carrying out projects of international cooperation of great need; and solving some other problems with the same urgency.

There are programs and plans on all administrative levels and for all branches. Generally speaking, preliminary ideas of the program come from branches and localities first. They form the basis of the program. Then, experts of all specialties, together with leading members of departments concerned, prepare a draft national program, synthesizing the needs of national construction, the trends of international development and the preliminary ideas of each branch and locality into the draft for the approval of the government. At the same time, the planning departments are reponsible for the coordination among such aspects as capital construction, expenditure, personnel and material supplies. The program finally approved serves as a guideline for branch and locality planning, in which the projects designated to their repsonsibility or their participation by the national program are to be treated as top priorities and be fulfilled with great efforts. In addition to these, there are also priorities and general projects of their own.

The advantages of such a planning system are as follows: (1) it combines scientific research of all branches and localities under a unified goal of the nation and enhances cooperation and coordination among them; (2) it facilitates the overall consideration of the nation's allocation of resources of manpower, materials and finance, so as to support the top priorities and to make an overall arrangement at the same time; (3) it facilitates the linking up of short-term plans with long- term ones so that significant long-range development will not be neglected because of a large amount of immediate problems or the other way round; (4) as a result of repeated planning processes from bottom to top, the relationship between the whole and its parts is established. Absorbing opinions from all branches and localities, and repeatedly weighing and adjusting the funding between demands and possibilities, between top and bottom, the national plan is nothing of an imposed and borrowed feature, yet it breaks through the limitations of branches and regions.

Owing to the continuous development of science and technology, the situation has changed a great deal. During the 1956 planning process, for instance, local research capabilities were rather weak. Scientific contingent had not even been established in some of the localities and industries. The Chinese Academy of Sciences was the main center for scientific research then and research work in the institutions of higher learning was primarily concentrated on a few top colleges and universities. Therefore, the planning process then was relatively simple. Even so, the program covered too broad range and too many items so that it was rather difficult to coordinate, supervise and examine in an overall way. Having developed up to the present, scientific research capabilities of five major branches: industry, defence, institutions of higher learning, Chinese Academy of Sciences, and provincial and municipal research institutions have become comparatively strong. But it is not appropriate for a country to take on too much. Therefore, its main efforts should be concentrated on those priorities with a comprehensive, exploratory and key nature and with strategic significance.

The integration of research plans with operational plans (including capital construction, funds, organization and personnel) provides a reliable basis for planning to obtain necessary material supplies. But from the present point of view, this is not enough. The two should also be combined with the plan of social economic development. First, scientific and technical plans should take the need of social economic development into consideration. Secondly, the scale and speed of scientific and technical development are restricted by conditions of social and economic development. For instance, if the economic situation is excellent, scientific research would get more financial support. If the economy is in difficulty, financial support would inevitably be limited. Thirdly, to successfully transfer research into production so as to promote social and economic development, such aspects as, for instance, the introduction of new technology, investment on production of new products, and funding for technical transformation, etc. should be included in the economic plan. Efficient and flexible coordination is needed in this repsect.

Planning is a decision-making process of a series of problems, which is not only limited to making decisions, but also includes actions necessary for making these decions. However, planning cannot cover the whole of scientific and technical development which should also be guaranteed and supported by a set of policies, systems and laws. For example, the problems of repetition and dispression of subjects can be solved primarily by perfect system of evaluations and other measures. Planning is only part of the solution. The problems of waste and under utilization of equipment should also depend on other solutions. It is unfair to attribute all these problems caused imperfection and incompletion of other aspects to planning itself, and that is not a right way to really find out where the crux of the problem lies.

TASKS AND DISCIPLINES

It has always been important to properly handle the relationship between tasks and branches of learning in the planning process. Some advocate that the planning is based on discipline. But this point of view does not get much support and understanding from the society, as it is not closely related to the needs of the national construction and development. Meanwhile, most of the scientists do not completely realize what the country needs from science and technology, and this makes the view even less reasonable. On the other hand, some suggest that a program be based on tasks. However, such a program cannot show the orientation of disciplinary development and is hard to link with personnel training which is basically arranged according to branches of learning. Some scientists, in particular, have the worry that to make the fulfillment of tasks the only goal would affect the systematic accumulation of knowledge of various disciplines. Analysing the advantages and disadvantages of the two aspects, the program is generally made according to scientific and technical requirements put forward by national construction. And there are, at the same time, programs for basic science and technical science respectively. That is to say, "Tasks primary, disciplines secondary", with the two intersecting. Related research subjects of basic theories are required in the tasks, and subjects needed by the national construction are taken into consideration in each discipline. Take the 1963 program for example, in basic science, subjects which clearly served the need of the national construction amounted to 70 percent and theoretical subjects of exploratory nature for the disciplinary needs accounted for the rest. In technical science, the former kinds of subjects accounted for about 90 percent.

The relationship between tasks and disciplines has not always been very well handled, but experience indicates that it is possible to have a better one. It is known to all that the base for the development of China's atomic science and technology was the Institute of Modern Physics of the Chinese Academy of Sciences. When new China was first founded, some scientifically talented people in nuclear physics, small in number, yet important for the country, were gathered together there. Although the foundation was not solid enough, it was indispensable. The reason that China's first transistors, first integrated circuits, first electronic computers, first laser, etc, could be developed in the research institutes of the Chinese Academy of Sciences was just because of the accumulation of knowledge in various branches of learning and a contingent of scientific and technical personnel with a strong background in basic knowledge. This indicates that accumulation of knowledge in disciplines is necessary in serving newly emerging demands in science and technology. At the same time, in solving scientific and technical problems appeared in national construction, personnel training and development of disciplines are both realized. In pedology, for example, the Chinese Academy of Sciences has gradually developed many disciplines starting from only one soil survey team in its earliest period. If due attention is paid in the process of developing various disciplines, multiple ways of their application can also be found. For instance, the research on protein and nucleic acid brought about the development of biochemical reagents and a number of pharmaceuticals such as polypeptide and nucleic acid.

Some people maintain that since developing countries' scientific and technical strengths are lacking, they should concentrate their research efforts on solving many presently existing problems rather than making attempts to develop basic science. This point of view has been proven groundless. According to our experiences, the development of disciplines plays an important role in the following aspects: 1. training of scientific and technical personnel; 2. accumulation of scientific knowledge; 3. facilitating international exchanges in science and technology which is extremely important to all countries' development in these fields; 4. the most important one, helping solve our own problems in science and technology through our own efforts. It is true that developing countires need not start everything all by themselves, they can not follow others in all aspects either. Even for the introduction of a technology, taking in and absorbing it are not easy jobs without a foundation of one's own, to say nothing of inventions.

Certainly, we have also noticed that some developing countries pay little attention to the solving of scientific and technical problems actually existing in their own construction. This results in the under-utilization of scientific and technical personnel, which then leads to serious brain drain. For this reason, we may conclude that developing countries, in particular, must always treat the solution of scientific and technical problems appearing in their development as their primary task.

There is always a gap between an ideal model and the reality. There is also a gap between things that the scientists consider as a must and things that the social opinion and leaders at various administrative levels expect them to do. As a nation which is underdeveloped in science, technology and economy, and is determined to bring about fast development, it would always require science and technology to do more in solving immediate problems, particularly when its economy is in a rather difficult situation. Such eagerness is understandable, yet the results are not always satisfactory. Although there are many other factors, this is one of the major reasons for the low quality of our semiconductor components and devices, and less rapid development of our computers and devices, and less rapid development of our computers, as well as the lack of originality and our own ideas in many fields.

In addition to the proper arrangement of disciplines and tasks specified in the programs and plans, there should also be appropriate division of labor. For instance, the Chinese Academy of Sciences and schools of higher learning should devote more of their efforts to basic research. To set a rough proportion is one of the methods io facilitate supervision and coordination. For instance, the Chinese Academy of Sciences once stipulated that basic research accounted for 15-20%, applied research around 65%, and the rest for development.

Centralization and Decentralization, Unification and Flexibility

The centralized plan of the government is often criticized by some people as having too much control and too little freedom, and therefore unfavorable for scientific development. Considering China's actual situation, however, to change its underdeveloped position calls for efficient utilization of its limited strength on its most key aspects. This means that, generally speaking, our resources of manpower, materials and finance are inadequate, and a large gap exists in this connection when compared with the developed countries. But, by such planning, much of our manpower, material supplies and funds can be concentrated on certain aspects which greatly affect the destiny and future of the nation. This explains to a great extent why we were able to develop the atom bomb, hydrogen bomb and man-made satellite under the economic and scientific and technical oonditions of the 1960s. This also explains why we could complete some important projects of economic construction mainly by our own efforts when the international situation was unfavorable to us. We should say that there are always some people who underestimate our strength because they do not see this point.

Of course, we have problems in doing so. Breakthroughs are easy to achieve, but expansions come across many difficulties. This is usually related to the entire industrial basis and technical capabilities. Inadequate knowledge of this point often leads to our overestimating our own strength and being too eager for results in certain areas.

There is always a misunderstanding about centralized planning of the government, considering it a process of demanding from above with very little flexibility and freedom of exploration. In fact, the ideas for centralized planning come from below. That is to say, the ideas are from every branch and loyalty and are then synthesized into a draft plan through collective discussions by leaders of departments concerned and experts in all fields. Such discussions are to give an overall examination to see whether there is any important ommission, to avoid mutual repetitions, and to coordinate cooperation between departments.

Of course, for major engineering projects, establishment of organizations and allocation of funds, there is a need for the governmental departments' general balancing. This process does not dampen the enthusiasm of the lower levels. As for basic research, the roles of the government and of such planning are to: (1) guide the orientation; (2) to offer support (but only after general balancing); and (3) to coordinate among all departments. There is not such a problem as intervention in specific contents and some key problems in science and technology in the national construction, they are usually well planned and well managed in almost all other coutnries. Comparing with them, it has not been overdone in China, but has not been done enough.

This does not mean that our present plan in perfect. The major problems are:

1. The scale of scientific and technical development depends heavily on the economic situation. Agricultural production greatly affects the national economy as a whole in a country like China where agriculture makes up a very large proportion of the economy. Since our agricultural production in turn greatly depends on whether, China's economic situation sometimes fluctuates. There are also influences of the political situation. In science and technology, generally speaking, there have been great changes over the past 30 years, but the development is not a steady one. It fluctuates very widely.

2. The plan covers too broad a range and therefore becomes too clumsy and too complicated. It includes all the major activities of every department and locality. Now, some experts are considering, and also trying out, letting the government be responsible for the major and comprehensive projects and, at the same time, encourage industrial institutions. The method of establishing foundations is also being tried out. For example, the Chinese Academy of Sciences has set up a science foundation for supporting basic work in basic research and applied research. The three kinds of expenses (i.e. cost for intermediate tests and subsidies for key scientific research projects) managed by the State Scientific and Technological Commission will become part of the funds for key projects. How fast these reforms occur will depend on the progress of the reform in the economic system as a whole. The reforms aim at enabling the national programs and plans to focus on a number of priorities, giving more autonomy and flexibility to all departments, localities and grass-root units, and integrating scientific research more closely with production.

3. Present programs and plans for scientific research deal mainly with scientific research carried out in the departments of the central government, and it is impossible for them to include entire R&D carried out in enterprises which, however, is considered an important base. This weakness will inevitably affect the introduction of research results or compel those specialized research institutions to devote many efforts into studying specific problems of production techniques. With the reform in the economic system in recent years, a gratifying phenomenon begins to prevail: the R&D capabilities in some industries and medium- and small-scaled cities have experienced rapid growth, greatly encouraging the utilization of new technology in production and changing the siiuation in production.

4. Generally speaking, the need for social and economic develop- ment is taken into consideration in our scientific and technical programs. But the abilities of the society and economy are inadequete in assimilating and applying scientific and technical achievements. How to integrate scientific and technical programs closely with the programs for social and economic development so that science and technology will better serve economic construction and vitalization is still a problem that is to be explored. It seems that the immediate emphasis should be put on dissemination and application of scientific results and to encourage scientists to take part in planning on national, regional and large enterprise levels. The medium-term task is to tackle the key problems. And the long-term goal is a well-integrated program for development of science and technology, economy, and society.

Division of Responsibility and Collaboration

China's scientific and technical policy and programs are not pluralistic, but unified and multi-layered. That is, there are different responsibilities under a unified leadership. Among the five major scientific and technical forces of the country, the Chinese Academy of Sciences puts emphasis on basic research and exploring new domains. Its primary responsibility in national economic construction is to solve comprehensive and key problems of significance in science and technology. To put it briefly, it is China's research center in natural sciences, and is characterized by its basic, exploratory, and comprehensive natures. Comprehensive universities are also primarily engaged in basic research and partly in applied research. Engineering colleges undertake more of the applied research for the development of technical science. Major research institutions in industries devote their main efforts in applied research and development, and a small amount of basic research is also carried out at the same time. Local research institutions, including R&D departments in the enterprises, serve primarily present and local needs involved in development and products research. Certainly, such a division of responsibility is only a rough one. There will surely be many intersections and overlaps. The major problem existing today is decentralization and repetition. There are different views on them which are now being studied and discussed.

In order to organize scientific research efficiently and to upgrade its level and bring its role into full play, in basic research, peer review system will be strengthened. And, more foundations will be established for the government's grants. According to experiences over the years, organized implementation of scientific and technical key projects is a relatively good way in solving the problems of national construction, and it is made into a special scientific and technical plan for the special projects. Its charatereistics are: 1. the goal is definite and the timing is scheduled; 2. all departments and specialties are organized under a unified goal with a division of responsibility and collaboration; and, 3. the integration of research, development and production is improved.

At present, key projects of national importance include: electronic computers; large-scale integrated circuits; comprehensive arrangements and rational exploitation of Huang Huai Hai Plain in North China; construction of the energy base in Shanxi Province; the application of remote-sensing technology, etc. Take the construction of coal base in Shanxi Province for example, more than twenty research institutions affiliated with the Chinese Academy of Sciences, and many other departments communication and transportation, electric power, geology, water conservancy, etc., as well as some universities and colleges concerned participate in the activities.

All governmental departments and localities have key projects of their own to tackle. For instance, in 1978, a campaign was organized in Shanghai to solve problems in technology including photocommunication, etc., which yielded very satisfactory results.

We must say, the organized implementation of scientific and technical key projects is only one important form of division of responsibilities. There is a variety of many others, such as establishment of industrial centers for technical development, and integration of scientific research and production.

A Brief Summary

1. China, as a socialist country, needs to develop its economy in a planned way. This inevitably enables it, and makes it feel necessary, to develop science and technology also in a planned way.

2. To change its poor and backward situation and to proceed in modernization, China, as a developing country, has to concentrate its limited scientific and technical strength on the key aspects through planning.

3. Our planning is in itself not perfect and should be improved by learning the previous lessons in economics.

4. Now, countries of different social systems are exploring their own policies of developing science and technology. Western countries are also trying the practice of developing science and teohnology in a planned way through government's intervention. Some work out medium and long-term national plans, or plans for specific areas or industries. Others offer advice of guiding nature or formulate policies to draw investment of private enterprises on certain areas. Though a country of planned economy, China is engaging in reforms and adjustments for the purpose of giving more independence to various departments, localities and grassroot units. In that case, countries of different social systems can exchange experiences and learn from each other's specific practices. We need to learn from other countries' strong points, but will have to explore the future all by ourselves according to China's own situation.

RESEARCH DEVELOPMENT AND ECONOMIC BENEFIT OF INDUSTRY IN SHANGHAI

Xia Yulong, Gu Wenxing, Zhang Nienchun

Shanghai is the largest industrial city in China and is also a city with advanced science and technology. In the last 33 years, the economic benefit of industry is relatively higher.

The total number of staff and workers on the job in Shanghai is 4.645 million, (of which 3.233 million in industrial sector) amounting to 4.26 per cent of the staff and workers of the whole nation. The original value of fixed assets in enterprises of state ownership is 202.7 hundred million yuan, accounting for 5.06 per cent of the national one. However, in 1981 the gross value of industrial output in Shanghai reached 647.5 hundred million yuan, according to the fixed price of 1970 (the same below), which is 12.5 per cent of 5,199 hundred million yuan, the total value of the national industrial output. The local financial revenue is 174.3 hundred million yuan, making up 16.4 per cent of 1,064.3 hundred million yuan of the national financial income. Shanghai is also doing well in fulfilling main economic targets. According to 1981 statistics, per hundred yuan of fixed assets achieves 77.5 yuan of taxation income and profit; per hundred yuan of capital attains 70.3 yuan of taxation income and profit; per hundred yuan of output value provides 27.5 yuan of taxation income and profit. Among the fifteen large cities, with a non-agricultural population over a million, in China, the average output value per capita (non-agricultural population) in Shanghai is the highest (9,685 yuan per capita in 1980), and the taxation income and profit achieved by per hundred yuan fixed assets is the second to the highest only lower than Tianjin).

Shanghai has achieved great economic benefit in industrial production. This is the result of various factors, including the processing industry which makes up an important part in the general industrial structure, the high efficiency of management and administration, the level of education and technique among workers and staff members is comparatively high, Shanghai has various categories of specific technologies, and the city is supported by and cooperates with other regions throughout the country. This article will only discuss the effect of science and technology when full attention is paid to them.

Shanghai is strong in doing research work. According to the statistics made at the end of October 1981, there are 213 independent research institutes*, with a staff of 73,800, among whom 31,500 are technical personnel; there are 375 non-independent research institutes** with a staff of more than 19,100, of whom 10,300 are technical personnel. In these institutes the proportion of advanced, intermediate, and elementary research workers is 3.2%, 45.4% and 51.4% respectively. There are 124,200 technical personnel altogether in Shanghai. In some heavy industries, such as metallurgy, machinery, and electricity, instrument and meter, technical personnel make up 7 to 10%, or at most, 20% of the total number of the staff and workers of those industries. In light and textile industries, the percentage is 3 to 4%. Besides, each industry possesses a large number of skilled workers. All of these technicians and skilled workers consist of the basic labour force for Shanghai's industrial production and research development.

It is because Shanghai is strong in carrying out scientific research work and consciously links research work with industrial production, that science and technology play an excellent role in achieving better economic benefit of Shanghai's industry. This is particularly true of the textile industry, which has, in recent years, while setting up some new research institues, attached great importance to its 17,000 technical personnel (making up 3.5% of the total number of staff and workers of that industry). From 1977 to 1980, more than 20,000 items of technical innovation have been done

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* An independent institute which engages in scientific research work, should be qualified with three conditions:

1. it is an administratively independent organization;
2. it is a financially independent accounting unit;
3. it is authorized to sign contracts with other organizations and to open an account in the bank.

** Non-independent institute indicates those which do not have the above three conditions and are affiliated with a factory, a school, a hospital or other enterprise. Nevertheless, it should:

1. be approved by the authority concerned;
2. have a clear research direction and task;
3. have certain facilities for making experiments and doing research work.

and 258 achievements in scientific research have been transferred to direct productive force. The rate of materialization in the Shanghai Institute of Textile Technology is 85%. As a result, the output value of the textile industry has increased at the rate of 10% for four years running. There are five characteristics, at large, in promoting production by attaching importance to research and development:

I. CARRYING OUT TECHNICAL TRANSFORMATION AND TAPPING THE LATENT POWER ON THE EXISTING FOUNDATION

Shanghai is an old industrial base. For its old foundation, we cannot rely too much on it and do nothing to improve it, nor shall we make a fresh start from naught. What we should do is to make full use of it and greatly carry out technical transformation and develop all kinds of techniques with every effort, so as to change the present state of techniques and raise the production level.

More than 30 years' practice in Shanghai industry has proved that greater economic benefit is obtained by building fewer new enterprises and carrying out technical transformation in the existing enterprises, and by adopting advanced techniques and extending the scale of reproduction. The total municipal financial revenue of the past 31 years is 12.5 times as much as the investment of capital construction. The figure is much greater in bureaus of light, textile, and handicraft industries. They have given the state nearly 1,000 hundred million yuan of taxation income and profit which is 83 times as much as the capital the state invested in them. The investigation of 103 items of technical transformation from 1978 to 1980 in ten industrial bureaus shows that 15.9 hundred million yuan was attained from the 4.9 hundred million yuan of taxation income and profit being realized each year and this is 1.8 times as much as the total investment in these items. The average recouping period of investment is six and a half months, which is one and a half years shorter than the recouping period of investment of capital construction, the recouping period of the latter being two years and one month.

Shanghai shows great concern in employing modern technologies and processes. Take the Shanghai Minibearing Factory, for example. This factory was set up by combining a textile mill and an electrical machinery plant in the early 1960s and found difficult to produce even the simple bearings, then. However, in recent years, the factory has paid attention to science and technology.

They have applied many modern technologies such as pneumatics, hydraulic pressure, electronics, automatic measurement, vacuum-quench thus achieving 12 important items of innovations in processes such as double end grinding super finishing, finishing of balls, etc., renewed 212 specific equipments with individual automation (making up 44.4% of the main equipment in the factory) and scrapped 191 pieces of old equipment. In this way, this factory has made a great step forward in its productive level. Its bearing output has reached 81.2 times as much as that of the year when it was set up and the quality of its products has got the first place in the country. Its "SW" product is now well sold out to more than 30 countries and regions. That demand exceeds supply of its products in the international market has emerged.

In carrying out technical transformation, various forms for solving technical problems, as seeking technical advice and exchanging technology, have been fully used, so that the initiative of technical personnel and skilled workers is brought to full play.

To improve weak links in production, a great many technicians and skilled workers, supported by cadres, have got millions of achievements in technical innovation under practical conditions. Since 1977, more than two hundred thousand items of innovations have been accomplished, which have powerfully promoted the development of Shanghai's industry.

The mass participation of technical innovation has resulted in greater economic benefit since it is done in a practical way and closely linked with the work of technical transformation. While organising workers to carry out activities of "putting forth suggestions, getting minor knacks, making minor measurements and doing minor innovations," and linking them with the transformation of old trades, Shanghai Light Industry Bureau has accomplished 300,000 items of innovation, large or small, and renewed thousands of equipments. Consequently, the production has increased 15 times that of 1949. Take the Shanghai Hero Fountain Pen Factory for example. Through mass participation of minor innovation, more than 950 old pieces of equipment have been renewed and most processes have become automatized and mechanized. Through the innovation of five successive stages workers have created a combining machine, putting three processes together to grind nibs which were ground by hand in the past. The working efficiency has been increased by 20 times and the quality is more reliable.

The technological innovation in every industrial trade is characterised by fewer costs, taking a shorter period of time, accumulating bit by bit and persevering for a long time. According to the approximate statistical data, only in 1981, Shanghai Chemical Industry Bureau has achieved 2,290 items of innovation, creating 30 million yuan of profit from them that year. Besides the state-invested fund of 40 million yuan for new projects, Shanghai Liaoyuan Chemical Works fulfills several other items of technological innovation every year, with its own financial and material resources. Taking the caustic soda electrolyser for example, it has been improved several times, its output has increased by 157 times as compared with that of 1949. In the past 30 years, the annual increase rate of the factory is 21.5% and has accumulated 7.5 hundred million yuan of fund for the state. Shanghai No. 5 Iron and Steel Mill is another example. From July 1981 to the end of that year, 10% of the workers in a rolling workshop of more than 700 workers, put forward 116 proposals, of which, 36 were accepted after being examined. And 19 of them were put into practice before the end of 1981. The Mill invested 5,000 yuan for them but got the profit of 420,000 yuan in the same year.

In order to encourage workers, both spiritually and materially, for their initiatives in technological innovation, rewarding measures have been set up. Every year a large number of crackerjacks at technical innovation are titled as advanced workers, shock workers, or reo-banner pacesetters, and given material reward as well.

II. ORGANICALLY COMBINE THE TASKS OF DEVELOPING NEW FIELDS OF TECHNOLOGY AND REVISING AND REORGANIZING THE EXISTING INDUSTRIAL STRUCTURES

Each important stage of development in Shanghai industry is always accompanied by the vigorous adoption and development of new techniques. The revision and reorganization of industrial products and administrative structures have paved a wide way for the adoption and development of new techniques. It can be said that the course of Shanghai industrial development is also a course of widely adopting new techniques. Each period has its own distinctive character.

In the mid-1950s the first reorganization in industry occurred. More than 20,000 factories were classified into 83 professional companies in terms of the similarity in products and processes and according to the principle of convenience for cooperation. In that period, Shanghai mainly developed its watch, camera, film, automobile, tractor and synthesized perfume industries, on the basis of its original light and mechanical repairing industries.

The second reorganization occurred in the late 1950s and early 1960s. After the first reorganization, new productive capacities (including processing capacity) were formed and some research institutes for applied technology were set up, and some technical returns were obtained within a short period of time. Thus, some key enterprises appeared, mechanical and raw material industries were strengthened and a great many products with highly intensive technology were developed, such as meters and instruments, precision machine tools, high-temperature alloy, precision alloy, rare metals, and specific metal materials. With the research and development of basic raw materials of petrochemistry and coal chemistry and the study of synthetic materials of high polymers, synthetic fibers, rubber and plastic industries were greatly developed.

The third period began in 1962 when the whole country was in the course of rectification. For the purpose of improving the quality of and enriching the assortment of products, more than 300 enterprises were closed, merged into other enterprises, stopped production or changed their products because these manufactures consumed more energy, turned out products with poor quality and had no bright future. In doing so, the cooperation among specialized departments strengthened and new products, which by then had not been produced in China, were greatly developed, such as electronic products, high-power generating equipment, ocean-going vessels, and new types of materials. As a great many technologies and processes were employed in all industries, the technical level in manufacturing was raised.

The fourth one began in early 1979 and is still in process and will not be completed in a short period of time. The purpose of this reorganization is to strengthen the connection with other regions in our country, to better develop the specialized divisions in technology, and while moving out some traditional industries which consume much more energy and raw materials and are less advanced in technology, lay stress on the development of new branches of industries with a high intensive technology.

The industrial reorganization at present is of far reaching significance. On the one hand, it may solve the problem of the shortage of raw materials and energy in Shanghai, improve the situation of heavy transportation and get the city less crowded; on the other hand, Shanghai can concentrate its resources on entering international competition and extending its international market. In the view of the nation as a large system, it is very beneficial.

III. INTRODUCING ADVANCED TECHNOLOGY FROM ABROAD, DIGESTING IT WELL AND THEN DEVELOPING IT

In the passing years, taking into account the practical need, technical foundation and the resources, the city has purposefully imported some new technologies from abroad in the form of joint venture, co-manufacture, co-development and compensated trade. Since the second half of 1978, the city has introduced 334 items, of which, 240 were accomplished at the end of 1981. 135 items from the accomplished ones can bring about additional 400 million yuan of output value, turn over to the state 1.4 hundred million yuan of taxation income and profits every year. Averagely, one U.S. dollar loan increases nine yuan RMB of exporting goods and 2.7 U.S. dollars of foreign exchange.

Introducing foreign technology is done on purpose. Take Shanghai Toothpaste Plant, for example. It has set the following principles for the work: if China has or can make it, it will not be introduced; if only a part of the machinery is needed, a whole set of it will not be bought; if it is not available in China and cannot be made now, only a model machine is imported; when the foreign machine is introduced, the faccory does not just make duplications of it but tries to improve it to fit their own practice and conditions. During 1964-1974, nine pieces of equipment were introduced from abroad after matching them with appropriate machines, making duplications and innovation, ten production lines manufacturing toothpaste containers and nine automatic packing lines were formed in that factory. By doing this, the factory, from 1965 to 1977, turned over to the state 2.1 hundred million yuan of profit, 80 million yuan of taxation income and gained 20 million U.S. dollars by exporting its products.

In introducing foreign technology, the stress is laid on digesting and developing. Shanghai does not use the technology blindly, nor copy what it is but chooses the advantages for our own need, and on the basis of applying and digesting, Shanghai tries to explore and develop its own technology. For instance, the Shanghai Electric Meter Factory has imported an eight-line oscilloscope which is bulky in size, inconvenient in operation and low in efficiency. Having digested it and absorbed its advantages, the factory developed several kinds of oscilloscopes with the types of eight-line, ten-line, sixty-line, etc. These oscilloscopes, having their own character, are small in size, good in efficiency and easy in operation and are welcomed by customers.

When the technology is digested and developed, it is introduced not only to the factories concerned within the city but to the inland factories as well. In recent years, the Shanghai Institute of Printing and Dyeing Machinery Technology has studied some new printing and dyeing techniques from abroad and then quickly introduced them to the Shanghai printing and dyeing industry. For instance, this institute is helping the Shanghai Printing and Dyeing Machinery Plant develop new products. In 1981 the new products made up 20% of the whole. This Institute also introduced new technology to inland factories. Having absorbed new technology of anti-shrinking machines from Japan and East Germany, the Institute made Model LMH 751-160 anti-shrinking machines. Consequently, the shrinkage of khaki is steadied at 1 to 2% and poplin less than 1%. These products have been recognized by the international standard with the gold and silver prizes respectively. Because of the improvement gained by these products the foreign exchange has increased 15%. Now, this machine is being introduced to 21 provinces and municipalities.

IV. ORGANIZING EVERY FORCE TO COORDINATE IN SOLVING TECHNICAL PROBLEMS IN THE DEVELOPMENT

In Shanghai, the way of solving technical problems is described as the three "concentrations;" concentrating on the target--aim at the essential crux and key problems in present and future production; concentrating forces--arrange every technical force and means of research, design, teaching, trial production and manufacturing to form a powerful force; concentrating on management--combine the solution of technical problems and the transformation in technology with production planning, and put the research and production planning under a unified arrangement and practice, and adjust their relations in time.

The "three concentrations" have become a traditional way in the city. Early in 1950, during the period of economic recovery and the first five-year plan, Shanghai made its contributions to the accomplishment of 156 items of the state by solving more than ten key problems in technology; in the early 1960s, Shanghai efficiently mobilized great efforts in 18 items of six technical areas, bringing new industries into being such as electronics, plastics and chemical fibers; since the beginning of 1978, the city has, ten times, mobilized its technical resources, in which fruitful results have been achieved in optical communication. These efforts have laid the technical basis for the development of new industrial areas in the near future. In the past 30 years various kinds of technical efforts, in different trades and at different levels have been beneficial.

Take the glass bottle trade, for example. In the past all the work was done by hand, but since 1958, this trade has organized four "technical battles," solving technical problems one after another. As a result, 80% of the work in making glass bottles is mechanized and semi-automated and the gross labour productivity has increased 2.8 times. Exchanging meetings and "fairs" for technical cooperation in recent years are the more effective and comprehensive forms for solving technical problems. In these activities, research institutes may exhibit their typical achievements for application, and industrial departments may raise their present or future technical problems while some organizations concerned will bridge over between the two, introduce some important technical returns in a planned way and organize technical forces to overcome some difficulties. Besides, industrial enterprises can also employ ready-made achievements or invite research organizations or universities to help solve their difficulties. This way of spreading new achievements and solving problems is of significance in exploiting technology and developing Shanghai industry. In 1981, such activities were carried out successively in chemical, machine, and electricity, light and handicraft industries and also in universities. From February to March 1982, a municipal technical fair was held in Shanghai with 22 different departments or industries participating. At this fair more than 600 factories raised about 1,200 technical problems, of which, 33% found certain units for cooperation. All this will play an important role for Shanghai industry in transforming technologies, renewing equipment, reforming processes, changing the structure of products and improving the quality. This will also substantially influence the problems of energy, disposing of three wastes (waste water, waste gas, and industrial residue) and increasing productive efficiency.

V. CLOSELY COMBINING AND UNITING PRODUCTION DEPARTMENTS WITH RESEARCH INSTITUTES

Of several hundreds of special research and designing organizations, the majority are scattered to productive departments in different administrative levels. The application of their research returns to production reaps full benefits in the economy. From 1960 to 1979, the seven professional research institutes of the Shanghai Chemical Industry Bureau turned out 336 returns successively to production, only 11 of which created 800 million yuan of output value and 2.65 hundred million yuan of taxation income after being put into application. In the Handicraft Industry Bureau, the benefit of achievements from its own key research items since 1978 is four times as much as the investment on these items.

However, the main research power is generally concentrated in the independent institutes while the other research organizations belonging to the enterprises are either underdeveloped or weak in technical power. Recently, in order to apply research returns to production and quickly solve technical problems, Shanghai has developed various forms of unions or combinations, between research and production.

1. Pilot workshop or affiliated factories are open in research institutes for the convenience of spreading research achievements. The Shanghai Research Institute of Iron and Steel Technology and the Shanghai Research Institute of Nonferrous Metal Technology, both of which were set up in the early 1960s, have built pilot workshops and affiliated factories as well as laboratories. In the past 20 years, both institutes have had more than 630 achievements, 85% of which quickly spread and applied to production. The Shanghai Research Institute of Organic Chemistry (belonging to the Chinese Academy of Sciences) ran a factory for experiment in the late 1960s, and this factory has also played an important role in the application of the returns achieved by that institute.

2. Large-scale enterprises run their own institutes. For instance, the Shanghai No. 5 Iron and Steel Mill set up an institute in 1978 on the basis of a former experimenting center. Now, it consists of more than 200 technical personnel, the lowest ranking being an assistant engineer. In 1980 and 1981, more than 100 research and development achievements were approved and have begun to play their part in production.

3. Factories and institutes are coordinated to develop products for market. Recently, the Shanghai Institute of Building Science has coordinated and shared profits with the Shanghai Nanhui Waterproof Coating Plant. Thus, research results of the Institute can be quickly put into pilot production in that plant. This has enriched the factory's products from two kinds to 50 kinds and the annual output value has increased from 50,000 to 60,000 yuan to 5 million yuan, its products being sold well both at home and abroad.

4. Building the research institute of a professional company into a technical center of that trade. Most of the products in the Shanghai Silk Company are exported abroad. In 1978, this company set up a Silk Research Institute, which brings together the research and design forces in the company and runs an experiment factory. For three years, this institute has designed and developed 65 new products and 498 new patterns. In the national competition of patterns, the company has received "excellent" for three years running whereas in the past, it was in last place.

5. The prolonged coordination between universities and industrial enterprises. Shanghai Television and Broadcasting Company has set up such a relation with the Radio Deparment of Shanghai Science and Technology University. The technical problems of the company are considered the items of scientific research of the university. Besides, they also develop the cooperation in exchanging information and materials and training personnel.

6. The technical coordination between Shanghai and other regions by contracts. In recent years, many research institutes and universities in Shanghai have signed contracts for coordination with many enterprises of other regions, and this has achieved good economic

benefit. For instance, for many years, our country had to import flexible graphite at the high price of 4,000 U.S. dollars per kilogram. In 1979, the Shanghai Material Institute succeeded in making it and transferred the technique to its sources area--Weimin Country, Shangdong Province--and set up a graphite factory there. In 1981, the factory produced more than ten tons of the graphite, not only satisfying the domestic needs but exporting some of its products as well.

The main aim of developing various kinds of unions between science and production is to reinforce the research and development in enterprises and is the key to making science and technology perform better functions in industrial production.

China is a country with unbalanced economic development. We must take this factor into consideration and build a reasonable gradient of economy and technology in order to realize the four modernizations. Shanghai and its surrounding regions are advanced economically and technologically. This is also the case with those cities along the coast and in northeast China. Because of this, there is "potential energy" to spread advanced technology and management to inland areas and remote regions. By doing so, the gap between them will narrow. In order for this spreading to continue on a higher level, Shanghai should absorb the advanced technology of the world as much as possible, develop new industry, and improve economic benefit in industry, so as to enlarge its own "potential energy." In our opinion, this should be a prerequisite to Shanghai industrial production as well as the development of Shanghai.

GENERAL ISSUES RELATED TO R & D IN INDUSTRY

Robert A. Charpie

In order to have an appreciation of the role industry plays in U.S. R&D, including specifically the role of the individual firm, it is essential to understand the overall delicate balance among the major institutions which relate to industrial R&D--industry itself, the firm, the universities, and government.

In the United States the balance among these forces has changed dramatically since the beginning of the twentieth century when industrial research and development began to emerge as a major factor in large companies. In particular, the role of the federal government as both a large-scale user of research and development and the principal underwriter of basic research, particularly in our universities, has become important. Let us look, in turn, at each of these institutions within our society from the point of view of its impact on the course of, and the value of, industrial R&D.

The government has an enormous stake in promoting successful cooperation across the whole research and development technical community from the large-scale, long-term relationships, such as those that must necessarily exist between universities and industries in general, to the level of individual firm relationships within a single industry. In this promotional context it is required that the government be ever mindful of its often conflicting responsibility for maintaining genuine competition between individual companies and avoiding cartelization of price-fixing within any industry. We also look to our government to establish societal priorities which often have R&D components or requirements which need to be framed in cost-effective policy settings. In this activity the government often plays a regulatory role with respect to industry, which is usually managed by a specialized agency or commission--examples are the Federal Trade Commission which has responsibilities in the anti-trust area, the Environmental Protection Agency which is responsible for setting and policing standards of air and water pollution, or the Federal Food and Drug Administration which is involved in all kinds of activities from the certification of new chemical substances as drugs for human use through labelling laws and the creation of standards for purity and minimum processing standards in the food area.

Another kind of government activity which predictably has a large effect on industrial research and development priorities is the establishment of large-scale programs at the national level. Two extreme examples would be the national effort to put men on the moon in the 1960s, which mobilized enormous quantities of research and development in the aeronautic-astronautic-space arena as well as in the materials sciences, and the long-standing national program to better define the causes of heart disease, cancer, and stroke within our society and then provide drugs and new technologies to ameliorate or cure those diseases.

It is also the federal government that has the responsbility for establishing and promulgating patent policies. In the United States this is a Constitutional requirement, which dates back to the late eighteenth century, and has been, I believe, in an important way responsible for the success of industrial R&D in this century at the level of the individual company.

In all of these activities--the promotion of competition, the avoidance of cartelization, the establishment of societal priorities, and the creation and operation of a patent system--the government has the additional job and role of disseminating information about technology, about its activities, and about the results of research and development for which it has provided funding.

In U.S. society the information-dissemination activity is of pivotal importance to all of those organizations which choose to specialize technologically, whether at the level of basic research or within the most applied kinds of development work. For them the information bank available from government sources provides a way of reconnoitering fields immediately adjacent to their interests to learn if there are new developments therein which can be helpful to them and to identify novel thrusts pioneered by others which threaten their commercial security over the years ahead. This kind of information reconnaissance is difficult to conduct individually and is best managed under the ever-spreading umbrella of new technical information essential to the stimulation of R&D programs within a firm and occasionally even to the survival of the firm itself.

The other special role which the government plays in R&D, most notably since World War II, has been to provide the funding for a large proportion of the basic research work done in the universities in the United States and to own and to support directly a large network of specialized laboratories, particularly in the health sciences, space sciences, and the energy and weapons fields.

In a very real way, beginning with World War II, we have forged in the United States a remarkably successful partnership of graduate education, university research, industrial applied research and development financed by the government, and government procurement particularly within the specialized areas of national defense and space. This partnership has provided us with a large base of technological activity spanning virtually the entire range of science and engineering. The role of the government as the provider of funds and the user of services has been pivotal in this partnership. But, it must be recognized that a very large fraction, currently exceeding 50%, of all research and development in the United States goes on outside the reach of these defense and space-based partnership activities.

In order to have a look at that other 50%, most of which is in non-defense industries, it is first useful to pause and examine the roles of our universities in the science enterprise. U.S. universities are remarkably decentralized, each with its own style, management, culture, and problems. While their primary role is to educate the key people required by our society in all avenues of vocation, their primary activity in the area of research and development is to develop competent scientists and engineers in adequate numbers for our overall R&D enterprise and to conduct high quality research and development. It is a deeply rooted belief in American society that high-quality research and high-quality graduate education are natural partners, each of which prospers best in the presence of the other. Hence, our primary dependence for educated key people within the U.S. science enterprise is on the graduates of those universities which conduct the bulk of high-quality basic research in the United States.

Such universities have drawn a large proportion of their funds, well in excess of 80% of which has gone for basic research, from the government over the last twenty-five years. Increasingly now, however, as the demands for research and development are appearing primarily in new areas of technology more closely linked with industry, the universities are seeking to develop closer ties with industrial associates in order to learn more about industry's problems and ultimately in order to be able to receive and expend funds from industry in the promotion of university research. I, for one, believe that this is a trend which will increase and become more and more important over the years ahead.

Let us now take a look at the individual firm within a technological industry in the United States and focus on some of the important questions related to decision making about research and development. The most obvious first question is, "What should be the balance in a company's program between basic research and applied research?" After all, basic research has long time horizons, 5-10-20 years is not unusual, and therefore at the discount rates which U.S. industrial management generally applies to decision making, it must produce enormously important results in the out years in order to be of any value at all on a present-value basis. Applied research, on the other hand, can often have quite short-time horizons, 2 to 5 years is not unusual, and therefore it does not suffer to the same degree from the high return on investment requirement as does basic research.

What then is the argument for supporting any basic research at all in industry? The answer is very simple. It is the desirability of having within any technical complex a mix of people who represent a wide range of points of view, interests and experience, as well as levels of individual skill. Some of the very key people in an industrial setting must be those who have the capacity to think with long time horizons and contribute to the directional strategizing of the overall technical enterprise. Such people are most generally found in university settings, but every large and successful American industrial research enterprise has a few of them sprinkled through the organization. In order to keep those people content and stimulated, it is necessary to have basic research programs in the program mix of any large technical firm. There is a plus side to those basic research programs that cannot be measured simply by the discounted return on investments. It is the necessity of establishing today what I might call "seed programs" that will not mature commercially for fifteen to thirty years but when they do will become important new technologies, not simply modifications or evolutionary transformations of existing activities within the corporation. They represent completely new directions which require new understanding and a different commercial setting for success. That kind of radical transformation can never take place successfully within a company unless there are people within the organization who understand in the fullest and most sophisticated sense every detail of the underlying technology so well that they can persuade their supervisors of the depth and reliability of their understanding. And so the purpose of a basic research program within the ambit of an industrial enterprise devoted to technology is the desirability of creating constructive relationships and shared interests among the important decision makers and providing well ahead of time the long-term horizon outlook which is helpful to success and the sophisticated understanding of new revolutionary technologies in the deepest possible way.

To reach an optimum balance between money spent on basic research, as compared to applied research in an industrial setting, requires that correct assessments be made including: (1) a realistic appreciation of the time-scale on which a major industrial research and development effort can be expected to be successful; and (2) the recognition that applied research in a commercial setting will require multi-disciplinary involvements which for major projects can become significantly large management efforts.

A second issue which often perplexes industrial research managers is how best to select the fields in which to apply the limited basic research dollars. My suggestion is that it is wisest to choose basic research in fields that tend to open up applied research and development opportunity in high priority commercial target areas. More succinctly, I often say to people in my company, "Think commercially in the long run as well as in the short run." And so in an industrial setting one would probably choose as his research topics new feed grain hybrids not extra-terrestrial life forms; or novel catalysts not astrophysics; or finally high strength alloy development not high energy particle physics. While these all seem obvious, the persuasion of the basic research scientist is not always such that he will naturally lean to practical choices or conclusions, if I can call them that, so one role of industrial research management is to find those basic scientists who will find it easy to accommodate themselves to this kind of requirement and who will prosper in the presence of large-scale development programs and applied science intended to produce commercial results in the shortest possible time.

Through the collaboration I referred to earlier between government, industry, and university, the U.S. R&D community has had a high impact on the national agenda. However, it has not pervaded the economy. The industries that have been most affected by this collaboration have been aircraft, agriculture, nuclear energy, space, computers, semi-conductors--what has come to be called the high technology industries. Where there has been low impact of government R&D activities is in housing, steel, chemicals, drugs, autos--principally the smokestack or basic industries on which so much of our total economy depends for its vitality.

The notion that these are low technology industries simply because they are not included in the conventional wisdom definition of high technology industries however, is all wrong in my judgement. If one looks carefully he will find that something approaching 50% of all research and development is conducted within the metals, drug, automobile, and chemical industries--the basic industries sector of the United States economy.

The glamor of high technology and the presently highly visible problems of the basic industries have created a massive new problem for American research and development managements within the individual firms. This problem relates to the recruitment of key people into the most cost-effective areas of technical problem-solving. This is surely a joint responsibility of all the important institutional factors--government, university, and industry.

The special problem we have now is trying to entice some of the best young technical graduates into the automobile, steel, and chemical industries (particularly the manufacturing sectors of those industries) at a time when they are more needed than ever before. With the great success of the microcomputer, and the increasingly lower cost of producing yet another item of data in the shortest possible time, the automation of our factories, the success of which must underlie any future revival of our basic industries, has created a need for the highest possible quality people in the manufacturing sector within those industries. Traditionally, manufacturing in the United States has depended principally, but not exclusively, on the less academically able technical graduates from our engineering schools. Our oldest industries are overpopulated with engineers of the old school who initially were drawn from the bottoms of their graduating classes as far as academic performance is concerned. This is a very difficult combination of factors to work against and overcome and to do so in the shortest possible time, but it is the basic problem which must be attacked with vigor and one which must be solved if U.S.-based firms are to compete successfully with firms outside the United States whose factories have been built more recently and whose cadre of senior manufacturing-engineering people were drawn in their time from the brightest and best graduates.

When we talk about special people, one important sub-class of individuals deserves particular mention in any conference which purports to speak about the effect of science and technology on national economies. These are the entrepreneurs. Entrepreneurship in the United States has been responsible for a large percentage of the successful innnovation within our economy over a very long time. Studies now reach back more than a century to look at U.S. economic time series which suggest that between a third and a half of our economic growth measured in real terms can be traced to technological innovation. If we look for the sources of technological innovation, we find that the entrepreneur based in a small company has been responsible for an overwhelming fraction of the successful entrepreneurship that underlies that innovation which has been the principal engineer of economic growth in the United States.

Entrepreneurship in the setting of a small company and team effort supported by the technological and financial strength of a large company is the available alternative to economic growth based on innovation. These alternatives have been demonstrably compatible over a long period of time,and I, for one, do not believe they are now or will become mutually exclusive. Neither one by itself can always do the job. In the United States I claim we need both for sustained success.

The entrepreneur is a special kind of person who needs and requires a supportive climate for success. In the first place he has to be able to find adequate financial resources to launch and develop the idea to which he is committed. Those sources are available in the U.S. in the form of large pools of risk capital willing to support ideas which are judged to have extraordinarily high return on investment if they are successful. Secondly, the entrepreneur needs an incentive--in fact he needs two incentives. One is personal recognition, which comes readily with success and which I have always believed is the primary motivation which drives him ahead. The other is financial success. Venture capital support, which I have already referred to, provides the very successful entrepreneur with the opportunity to become extremely wealthy in our society. Tax laws do not make it easy for him to keep what he has earned, but they have been moderated over recent years so things are significantly better in 1982 than they were in 1972.

Finally, the successful entrepreneur needs the support of a model--the model represented by others who have gone before him and been successful. We have lots of rich entrepreneurs in the United States. Government, industry, university--each has its stake in and each has a role in the successful promotion of increased entrepreneurship. It is hard to find the ideal division of responsibilities, but it is perfectly clear that when the cooperation works out well--everybody wins.

RESEARCH AND DEVELOPMENT MANAGEMENT: TRANSFER OF TECHNOLOGY

Gerald P. Dinneen

INTRODUCTION

There are many ways to characterize the decades from the 1940s to the 1980s. I am neither a historian nor a futurist and am unskilled in making the generalizations which so often are able to capture the essence of a very complicated world environment. But I have been a participant in some of the technological developments which have created the dramatic changes in our society. Because the technology has developed at such a rapid rate, a major issue facing the country today is the transfer of this technology into useful products. The questions concerning technology transfer have therefore become as important as the questions concerning development of new technologies. In the next few paragraphs I will review some of the history of the development of technology and illustrate some of the ways in which we have attempted to transfer that technology into products.

The 1940s in the U.S. were characterized by the technological developments needed to win World War II. Specific important developments were radar, nuclear, and jet engine technology and weather forecasting technology applied to military operations. Most readers will be familiar with the crucial decisions concerning the invasion of Europe which hinged on accurate weather forecasts. Our government dealt with this latter requirement by educating a large number of young people, including me, in meteorology at our best universities. This is the most basic and essential method of technology transfer--that is, formal science and engineering education. In the cases I've cited, the system worked well. Although many more people were trained than needed, even those who did not remain in meteorology were better prepared for other technological jobs.

The methods used in weather forecasting at that time were largely manual--use of hand-plotted weather maps; manual transcription of weather information from teletype to maps; and manual reading of weather instruments. It was not until the development of the digital computer in the 1950s and satellites in the 1960s that modern technology transformed weather forecasting. The application of computers to weather forecasting illustrates a second kind of technology transfer, that is, between disciplines. The number of variables and the complexity of the equations which describe such things as heat transport and air flow require very lengthy computations. Trying to perform these numerical calculations by machine inspired John Van Neumann to lay the foundations of today's computer architectures.

If the 1940s were characterized by the demands of World War II, the 1950s witnessed the beginning of the electronic revolution and the application of technology to civilian needs. The scientists and engineers who had worked on the Manhattan Project and the Radiation Lab returned to the universities and in some cases to the emerging high technology industries. This is a third method of technology transfer, by the transfer of people.

During the 1960s, we witnessed the exploitation of rocket technology both to explore and to use space. One of the most significant technological developments of the 1960s was the use of satellites for communications. For the first time it was possible to communicate globally without undersea cables, without the vagaries of high frequency transmission, and without many intermediate ground stations. In a very real sense this was the catalyst for developments which began in the 1970s and which will dominate the 1980s: the developments associated with information processing and dissemination of information or, as some prefer, knowledge processing. These developments make possible an acceleration of the fourth method of technology transfer, namely, by meetings, seminars, periodicals, and use of teleconferencing.

During the 1970s, we observed the explosive growth of semiconductor technology which moved very rapidly from the discrete transistor to an integrated circuit, to medium-scale integration, to large-scale integration. This is a technology which progressed very rapidly from the laboratory to small industries and to large industries and in fact across national borders. Much of the transfer was accomplished by license agreements.

During the 1970s, while managing technology development as director of the Lincoln Laboratory of MIT, I strove to transfer technology from public or university laboratory to the private sector. While serving as Assistant Secretary of Defense in the Carter Administration, I was very actively involved in discussions with the People's Republic of China on technology transfer. Hence the seventh technology transfer subject will be transfer from nation to nation.

As we move further into the 1980s, I believe that the major challenge to our nation and to the world is the application of technology to increase productivity. For some, that productivity is needed to bolster their economy to conserve scarce energy resources and to develop alternate sources and to provide for national security. For others, productivity is needed to obtain higher yields in agriculture and to deliver basic health care. But in all cases it is imperative that we move technology which now exists in the university, in goverment laboratories, in industrial research laboratories into the factory, the hospital, the farm to meet the needs of society. While we must continue to develop more basic technology, the real challenge is to apply the technology already available. We will need to use all seven methods of technology transfer.

METHODS OF TECHNOLOGY TRANSFER

In this section we will offer a little more detail on the seven kinds of technology transfer.

Formal Education

Formal education is perhaps the best understood and most effective of the methods of technology transfer. Although others in this seminar will be discussing educational issues, I want to touch on just a few points. First, the creation of land grant colleges and the associated agricultural research stations has had a tremendous impact on U.S. agriculture and is probably the single most important factor in making the United States a world leader in food production.

I don't believe that we have been as successful in our engineering education. Surely we have done an outstanding job of educating scientists and theoretical engineers. But we have not had the broad impact on practical engineering that the land grant colleges have had on practical farming. Our vocational schools have not received the public support they need. In fact, many of the people who provide the service and practical engineering for our commercial equipment were trained in the military. For a nation to obtain prominence in technology, it must have a technical infrastructure. That means not only the engineers and scientists who design systems but also the technicians who build systems and build the prototypes, the people in the factories who produce them, and the people to maintain them. In this country we have done a first-rate job of training scientists and engineers; we have more Nobel prizes, we have more of the people who are the leaders in science and engineering. We have not done as good a job in providing for the maintenance and service of our equipment. Although I will come back to this later, this may be a good time to point out that one of the problems that our friends and colleagues in the People's Republic of China face is creating that infrastructure which is necessary for them to develop a very strong technological base. In summary then, a very important transfer of technology is through formal education, and this can be done within a nation as we have done in the United States where we increase the support for technological programs. An interim measure which our colleagues in the People's Republic of China are doing now is sending people to the United States and to other countries to learn technology. We in the United States did that earlier in this century when we sent our people to Europe to learn from the scientists in Germany and England and France.

Transfer from One Discipline to Another

The second technology transfer category is that between fields. I mentioned earlier the fact that the demands on numerical analysis by meteorology were an incentive for John Van Neumann and others to develop the digital computer. Another driver for computation is the requirement for very intensive calculations in order to do nuclear physics. A very current and very important example is the need for doing calculations based on seismic exploration in order to determine underground resources of oil. This is particularly pertinent to our friends from People's Republic of China who may have very large resources of oil which can only be determined by analysis and exploration.

Transfer of Technology by People

The third category of technology transfer is the transfer of people. This is a very important category. I mentioned earlier in my remarks the fact that scientists who went to work for the Radiation Lab at MIT or for the Manhattan Project returned to the universities after the war. These people brought with them new concepts in carrying out technology programs, and as a result of that we started many new, very large technological programs in the United States. This was an unusual condition. Today the transfer of technology by people must be much more immediate. What we are talking about is transferring people who have done the basic research, advance development, perhaps even the engineering development of a program, to the production facilities of an organization. An industrial organization that has a central research laboratory must encourage the transfer of people from that central research laboratory to its operating divisions or to its factories because those people can carry with them the knowledge which they acquired during the development of the process. While this is an obvious and very efficient way to transfer technology, it is also a difficult one because people don't want to move. People who have been working on fundamental research prefer to remain with fundamental research rather than move with the products of their research to a new environment. Therefore it is necessary to create environments which will encourage these people to move.

Transfer by Meetings, Seminars, Etc.

The fourth category I would like to talk about is transfer by meetings, seminars, and other similar exchanges. There is a real difficulty with this transfer because it is limited. It is mostly theoretical and informs the listener what is possible but not how to do it in practical terms such as building equipment, setting up a factory line, or deciding what kinds of test equipment are needed, and so on. Therefore, in this case, the receiver of the technology transfer will understand what is possible, but then when that person or that individual or that organization decides to move into that technology, they will need to create their own infrastructure. They will, in essence, do it all over again. Other kinds of technology transfer can be accomplished very effectively through seminars and other similar educational experiences. For example, if one wants to learn about personal computers, one can learn about them through a seminar.

Transfer by License

The fifth kind of technology transfer is that which is done by license agreements. In this, a company which has developed a process licenses that process to another company. This can be very effective if the process is not too complicated. It is even more effective if the company which is transferring the technology is willing to transfer some people, as we indicated earlier. If the company that is transferring the license is willing to transfer people, then that transfer will be very effective, as I said, and a consumer can go to either company to obtain the product.

From Public Sector to Private Sector

A sixth transfer is that from the public laboratories to industry. This is a transfer, in my opinion, that is not carried out very effectively in the United States. We have a number of very effective public laboratories sponsored by the Department of Defense, by the National Aeronautics and Space Administration (NASA), and by the Department of Energy, in such laboratories as Los Alamos and Livermore. Each of these laboratories does very advanced technology; however, when they have completed their research and have demonstrated the research through an experiment, then they try to transfer that technology into industry. Industry will come to those laboratories, listen to their presentations, and accept the results of their experiments; however, when industry decides to turn that into a product, they often start over again. When I was at Lincoln Laboratory, we built several communication satellites. These satellites, including the most advanced technology, were constructed by the laboratory, were prepared for flight, were fully tested, were launched by Air Force rockets, and were successful. After their success, the Air Force went to industry and said we would like to buy several more of these satellites so that we can create a communication satellite system. Even though we at Lincoln Laboratory were quite willing to transfer all our technology to industry, the industrial companies felt that it was necessary for them to do their own engineering, to decide on their own manufacturing technology, and in a sense, to start over again.

From Nation to Nation

The seventh technology transfer characterization that I would like to talk about is that from nation to nation. Here I would like to talk about two kinds of technology transfer--that from the United States to our NATO allies and that from the United States to the

People's Republic of China. Our transfer to our NATO allies was impeded by the fact that our NATO allies have a capability of their own; consequently, when we tried to transfer it to them, their industry was reluctant to accept it because they feared that our transfer would take jobs away from their workers. Consequently, they rejected and resisted the notion that we should have a common system because they were afraid that the common system chosen would be the U.S. system. This is quite understandable, and it would be exactly the response of the United States if it had happened the other way. Consequently, the most effective transfer between two countries with rather advanced technologies is most effectively done when the transfer is done early in the development of the product. That means that there should be common research and development. That means that we should determine that there would be a joint development of a particular system where one country or the other would take the lead and both countries would produce the output. In the absence of that, one can make license agreements so the second country can produce the output of the research from the first country.

Now the issue between ourselves and the People's Republic of China is quite different. The People's Republic of China has set very important and quite pertinent goals for themselves, goals that in earlier days were referred to as the four modernizations. Those four modernizations included modernization of agriculture, modernization of industry, modernization of production, and modernization of national security. Our colleages and friends in the People's Republic of China recognize that they did not have the infrastructure which I discussed earlier for moving into high technology. Therefore, they were anxious to arrive at agreements with other nations for transfer of technology which included the transfer of entire factory processes. My discussions with my colleagues in the People's Republic of China were concerned with the transfer of military technology. In this case, since we had a national policy which said that we would not sell arms to the People's Republic of China, we had to consider ways in which we could transfer technology which was considered to be dual use. Dual use technology is that which can be used for both civilian and military applications. Examples of this would be computers which could be used for a census, such as the People's Republic of China conducted, or could be used for command and control systems. Another example of dual use technology would be transportation where trucks could be used for transporting agricultural products but also could be used for transporting military. Another example would be communications equipment which could be used to extend communications from cities such as Beijing and Shanghai out into the rural areas and could be used for communication between military commands.

During our discussions with our friends in the People's Republic of China, we agreed on a number of examples in electronics, communications, transportation, even air transportation which were dual use and which could be considered for transfer from the United States to the People's Republic of China. We visited many of the factories in China, talked to the people who ran the factories, and observed the people in the factories. We recognized the need that existed for increasing the infrastructure in those factories. We felt that transfer of dual use technology would enable the People's Republic of China to improve their technical infrastructure because in producing dual use technology, whether it be communications equipment or trucks or certain kinds of radars, would require the same kind of engineers, technicians, and production specialists that would be required for military equipment. The needs of the People's Republic of China for military equipment are so large that it will be necessary for them to produce it themselves. While this is a somewhat lengthier transfer of technology than would be the case if we were to give the People's Republic of China a turnkey factory for producing, let's say, tanks, it is in fact a much more efficient technology transfer because it permits the People's Republic of China to become self-sufficient. A turnkey transfer such as the Soviet Union made to the Chinese in the 1950s becomes obsolete at some point. The transfer of technology by means of helping the People's Republic of China to establish capabilities for relatively high technology dual use equipment would be effective.

IMPEDIMENTS TO TRANSFER OF TECHNOLOGY

In the previous section, I've described a few of the technology developments over the last 40 years indicating some of the ways that technology is transferred and why they are important. In this section, let's look at some of the impediments to technology transfer.

I will illustrate these impediments by describing an electronic system which was tried and developed in the 1950s embodying advanced technology but which did not have an immediate major impact outside of its intended use.

The system is distributed with many remote sensors. Each of these sensors has some associated data processing which reduces the information so that it can be transmitted over digital data transmission lines.

These lines all converge on a large, advanced signal processor which integrates the inputs from the several sensors and correlates it with information received from other sources.

There are many individuals at the central computer who interact with it using man-machine interfaces such as light pens and keyboards.

After the people working in consort with the machines have made decisions, they are transmitted over digital data links to various points where they are implemented.

This could be the description of any one of many modern control systems--to control energy and provide security and fire protection in a building or to control a complex industrial process or any one of many military command and control systems. However, what I have described is the SAGE system. SAGE is an acronym for Semiautomatic Ground Environment. It was an air defense system designed and developed by MIT Lincoln Laboratory for the U.S. Air Force during the 1950s. There were initial test installations almost 30 years ago. The system performed its intended tasks very well, but the technology employed in this system was transferred at a very slow pace. In fact, it is only in the last few years that there is widespread deployment of new systems with these characteristics. I believe there are at least four factors which impeded the transfer:

Technology Not Ready

In 1950, during the cold war, there was an urgency to provide air defense against the Soviet long-range bomber. Consequently, the government was prepared to fund the development of new technology and to put it into the field. For that purpose there did not seem to be any alternative; the manual methods were too slow and could not handle the large amounts of data, and therefore the government was prepared to take the technology risk. The central computer used for the demonstration was Whirlwind. This computer filled a room perhaps 20 feet wide by 40 feet long. The capability of that machine is now duplicated in a small hand-held calculator, or reduced in size by a factor of 6400. The machine's speeds have increased by at least a factor of 1000. The active memory available has gone from perhaps a thousand words to many million. Because the machine was so large, took so much power, had to be programmed in machine language, it was natural that it would only be used for the most urgent requests.

Costs Above What the Market Is Willing to Pay

As noted above, the SAGE system was very expensive to develop; therefore commercial users could not see cost effective applications. This illustrates a most important impediment. The developer of new technology is motivated to create new ideas, methods, processes, or products. He is often frustrated because successful developments do not reach the marketplace. The public, the users, are usually more concerned with a balanced cost effective solution than with the latest technology.

Cost of Training and Maintenance

The introduction of the gasoline engine and auto transportation created an enormous infrastructure of service stations, repair stations, and supply houses. The training of mechanics by the auto companies is necessary to the continued sale of their product. We know the same is true of television, washing machines, and other appliances. It is also true of course for the computer business. The owners of machines must have programmers and operators and be able to obtain maintenance. In 1955 that infrastructure was thin and could not cope with the kind of very advanced systems that SAGE represented. An interesting development today is that despite the larger infrastructure, the users are uncomfortable with the need to provide their own programming. Hence, more and more the computer manufacturers are providing solutions. This has been spearheaded by the personal computer with its applications software. Hence, the needed training of programmers is minimal, and the transfer of this technology to a useful product is aided.

Public Acceptance of Automation

I have already discussed some of the principal factors influencing public acceptance of automation, for example, the high cost and the lack of an infrastructure. There is another aspect which is difficult to quantify. This includes such things as concern about loss of jobs, concern about dehumanization, and concern about loss of human control. Robotic technology has been introduced into many of our factories. In those areas where the introduction was successful, it was preceded by an education program. This program explained that robots would be used to do hazardous and repetitive tasks which were the least desirable on the factory floor. The threat of dehumanization is very real. Many of the early computer systems were actually quite rude, if I can apply that term to a machine. You were commanded by a recorded voice on the telephone to give your message when the buzzer sounded. How many times have you hung up, as I have, when that happened?

ORGANIZATIONAL ISSUES

I would like to close this paper on technology transfer by focusing on the technology transfer within a particular industrial organization. Research and development in an industrial organization is measured primarily by its effectiveness in increasing the profit of that company. Another way of saying this is that in an industrial organization the transfer of technology from the research laboratories to engineering to production and manufacturing and ultimately to a product is essential. It is very difficult to give a quantitative measure of the effectiveness of the research and development within a large industrial organization. Many efforts are made to do this and will continue to be made. In some few instances, one can see the results of a research activity in a product. Then one can measure the success of that product, its return on investment, and some part of that can be attributed to the research and development activity. This is rare. Usually a research and development activity provides a base technology upon which individual divisions build specific applied technologies and, consequently, products. I will not try to settle this particular problem in this paper although it may be an interesting item for discussion at the meeting. I will, however, continue in my discussion of how technology is transferred within industrial organizations. Before I do that, I should comment that in some organizations a part of their central research and development is based on secondary objectives such as providing better relationships with universities, creating an image for the company as a high technology company, or investing in the long-term future of the company. In this case, long term means something beyond five years. The conduct of research and development is a function of the size of the organization. At either extremes of industrial corporations, the situation is quite different. At one extreme are General Motors, Bell Telephone Laboratories, IBM, and a few others of the very, very large companies. Bob Frosch can speak knowledgeably about General Motors, and most of us know quite a bit about the central research activities of the Bell Telephone Laboratories and of IBM. In these three cases, and in other very, very large organizations, there are central research laboratories which are self-contained large organizations and which are pretty much vertically integrated. By that I mean the research laboratory itself works on basic research, advanced development, engineering development and, in some cases, builds prototypes or engineering models. These labs are also sufficiently large so that they can look at both long-term and short-term research. At the other extreme are the very small start-up companies. In those cases, and I am now speaking of companies, for example, that are working on very high speed integrated circuits, on speech technology, and on intelligent work stations, those organizations cannot afford any central research laboratory so that all of the R&D is product related. Theirs is also, or many times, among the most innovative research because it is conducted by people who are entrepreneurs and who are working on a very high technology. In between these extremes are the many Fortune 500 companies whose revenues range from perhaps a billion dollars up to $10 billion. These companies must do more than the small entrepreneurial companies which can afford to concentrate their limited research dollars on the niches they have cut out for themselves. On the other hand, these companies cannot afford to have the very large central research laboratories that the companies whose revenues are in excess of $25 or $30 billion. Honeywell is one of these companies. About 95% of Honeywell's research and development is devoted to product development, and 5% is allocated to central corporate research. This funding is supplemented by customer-funded research and by funding directly from divisions to the central research laboratories to carry out specific programs. This latter funding, that is, the joint funding by divisions and by corporate programs of research, is very important. There is an old adage that if you pay for something, you are most likely to be interested in it and use it, and it is a true adage. I have seen many cases where people have funded research which would in fact be very useful to an operating division and then have taken that research to that division, have offered it to them, and have been turned down. By contrast, if the division had from the start been a party to it and had been contributing to it, then it would have been much more interested in the results.

Now I would like to turn to some specifics in the organization of R&D within the firm and use Honeywell as an example. The organization is one of decentralized research and development because, as I have said earlier, about 95% of the research and development is done within the operating divisions, that is, separated or divided out among different parts of the company, and 5% is done centrally and funded by the corporate research and development fund. As a general objective, I think most would agree that a vertically integrated research and development organization is close to the ideal. A vertically integrated research organization has basic research, advanced development, engineering development, development of prototypes, production technology, and test and evaluation leading to the final product. Bell Telephone Laboratories of AT&T come rather close to this ideal, as I have already said. The advantages of vertical integration are of course that the transfer of the basic research to advanced development is much simpler because these units are part of a single organization. It is also true that because they are part of a single organization it is somewhat easier to transfer the people and to have close coordination on the establishment of priorities for research. They have close coordination between engineering development people, basic research people, and manufacturing people. However, in a decentralized organization where the individual divisions have their own profit and loss centers, it is necessary for them to have control over their expenses which include R&D, marketing, and other general and administrative expenses. In such an organization as in Honeywell we look for a way of achieving the ideal which would be attained in a truly vertically integrated organization.

Let me now describe a generic organization for R&D within a firm which is decentralized. In such a firm there would be a corporate-sponsored, corporate-managed research and development agency. This agency would be directed by a corporate vice president for science and technology. His or her budget would constitute about five to ten percent of the total research and development budget for the organization. The items which would be sponsored and funded and managed within this corporate research and development agency would be recommended by the corporate vice president for science and technology and approved by the chief executive officer with the advice and consent of the managers of the principal subsidiary divisions of the corporate body. The kinds of research and development which would be done in a corporate agency would be the following: a) Generic technology which was common to the entire corporate organization. In a high technology electronic company that might be work on silicon microelectronics. b) Another example would be a technology which was a very high risk with a potential for high payoff and also a potential for application in the long-term. Again, in a high technology electronics company, this might be work on gallium arsenide or on Josephson junctions. c) Another example would be work on a function which would support the entire organization, for example, design automation. d) Another example would be a basic research effort such as materials research which would be an underpinning for the work that goes on in the divisions. The corporate research agency would also be the agency which was involved in assessment of new technologies, and predictions on those technologies which would be important to the company in the future. e) Another example would relate to those things, tools, for the entire company--perhaps test equipment, perhaps software methodology. Roughly half of the work in a corporate research and development agency should be supported by funds other than corporate funds. These funds could come from contracts with government agencies or other funding agencies or from the operating divisions of the company. The importance of this funding as I indicated earlier is to maintain the relevance of the research to the operating divisions.

Now the operating divisions. The operating divisions which would support and manage and develop 95% of the research and development are primarily concerned with product development. These efforts would be largely concerned with specific new products--a new computer, a new control system, a particular software application program. To attempt to achieve a kind of efficiency that one would have in a truly vertically integrated organization, certain mechanisms have to be employed. One of these would be various committees to coordinate efforts. One could, for example, have a technology committee with the senior technology people from each of the operating divisions and corporate staff as members. This committee then could establish overall priorities for the entire company and establish working groups to do specific coordination of efforts. One could also have a manufacturing board which would look at manufacturing technology which is being carried out by all the operating divisions. These committees could sponsor company-wide seminars; encourage publication of company-wide reports, journals, or supporting research activities and results; offer rewards to leading technology people; make recommendations to the chairman and chief executive officer on priorities for research, on methods for carrying it out, and on funding levels. Some research dollars could be managed by working groups consisting of members from operating divisions and the corporate research centers. The advantage of this organization is that it permits decentralized control of the bulk of the research and development and therefore permits more autonomy for the general managers of the profit and loss centers. As we said early in this paper, the primary objective of research and development in an industrial organization is to turn basic technology into products. A simple, effective way of measuring this transfer of technology is through the success of the individual segment of the industry as a business entity. In other words, whether it makes a profit or a loss. The general manager who is managing this segment will manage his R&D in the same way he or she manages the rest of the organization in order to produce a product at the lowest possible cost for the widest possible market. That's the advantage, but sometimes this operation will not be in the best overall interest of the company and therefore there must be some part of the research and development which the individual components pay for out of allocations aimed at the longer term. Whether this portion is 5% or 10% or 15% is something that will vary with time and with the individual organizations. It is not likely to be much larger than 20%, and it certainly isn't going to be less than 5%. And as I have indicated earlier, that kind of central research and development agency aided by various committees and other mechanisms for communication within the company can provide a balance and identify areas of weakness, of redundancy, or of duplication. This kind of organization for R&D within the firm has been tested over the years, and while it has disadvantages as I have indicated, it has proven to be effective; it has contributed to the success of many U.S. corporations.

Let me close as I began by talking about decades. I see the decade of the 1980s as one in which the United States will be tested. It will be tested to see whether or not our advanced technology can contribute to a rebirth of our economy and permit us to be competitive with the other strong industrial nations of the world. To meet that challenge, the industries of the United States must effectively use their research and development assets to create products which are reliable, which have high quality, and which can capture places not only in the U.S. market but in the international market.

NOTES TOWARD A THEORY OF TECHNOLOGY TRANSFER

Robert A. Frosch

INTRODUCTORY CONCLUSIONS

Technology transfer, in or out of the firm, is a process carried out by consenting adults. Like other forms of intimate human intercourse it can be difficult and require constant courtship, patience, and understanding. It is a process by which people approaching a problem from different points of view learn about how to solve it. It is not a process by which what is in the head and notes of one person is simply given to another for use. This process cannot be carried out, therefore, by passing papers under the door and especially not by throwing them over the transom. The mere transmittal of patents, technical papers, and reports is not likely to be satisfactory or sufficient. The process cannot be done at "arms length" or through the use of elaborate organizational systems: it must be done person-to-person.

No organizational arrangement can make this process happen, although some arrangements make it more likely than others; many organizational arrangements can be used to discourage it, and most bureaucracies are heavily engaged in preventing it, even while saying the reverse.

THE NATURE OF THE PROBLEM

These assertions arise from a great deal of experience and from the consideration of several major problems that must be considered in working on technology transfer.

The Tidiness Problem

Technology begins with a process of research and development, mixing questions of knowledge generation and problem solving. This process is essentially an untidy creative operation in which people consider possibilities and ideas, struggle with them, continually revise, invent, destroy what they have done and begin again, engage in arguments, experiment, and generate theories. It is of the nature of a creative and poetic process; it cannot be done systematically; indeed, systematics are likely to be the enemy of the most creative aspects of the work. Naturally, some systematics in experimental and theoretical discipline are involved, but they are heavily embedded in a rather untidy milieu.

For these reasons most research scientists and engineers are regarded as rather peculiar, somewhat unmanageable people who work in organizations that are difficult to operate by the ordinary disciplines of the corporation or agency. This attitude is essentially correct, but in their behavior lies the strength of their ability to do things that are new; they are not bound by the failed history of previous ideas.

At the other end of the technology transfer problem lies the systematic production, probably the mass production, of a product. The essence of a productive factory is system, order, and method: things must be available on time, schedules must be met, the same activities must be carried out precisely over and over again if quality and delivery are to be met. This is the product of systematic, businesslike, detailed engineering in which as much of the process as possible is under continuous precise control. At this end of the problem there is tidiness and discipline.

The problem thus presented is the problem of creating a splice, and a relationship, between people who are inherently inclined to be rather untidy and resentful of detailed systematics and authority, and whose strength derives from these attitudes, and people whose stock in trade is the detailed, disciplined operation of precise systems. Thus some kind of communication relationship must be made among people of varying backgrounds, experiences, styles of work, and values. This can only be done if they get to know and understand each other's strengths and weaknesses well enough so they gain respect for the strengths and are willing to deal with the weaknesses, because the resulting pair of strengths is so much stronger than either alone. Such marriages are difficult to make, are very strong when made, and cannot be produced by waving a wand or commanding them to happen. They must be produced by human interactions resulting in personal relationships.

The Educational Mismatch Problem

The tidiness problem is likely to be compounded by another social mismatch: research and development scientists and engineers are usually the product of long graduate education; they are technically and educationally sophisticated. While the pattern is changing, manufacturing, industrial, and operating engineers are traditionally less formally educated; they will frequently have bachelors' degrees, but sometimes have come up through the shop floor and the factory. While the operating experience is valid and valuable education, it will not equip these people to speak the scientific and technical language of their R&D brethren, nor will the latter necessarily understand the things the operators know from long, and frequently painful experience. The education of each has strengths and weaknesses; these complement each other and can lead to a strong partnership, but the starting point is likely to be mutual misunderstanding and distrust, if not mutual contempt. This is "He doesn't even know the differential equations" versus "He doesn't even understand how the machine really works." Both may be correct, but partnership may still be indicated and profitable for both.

The Problem Misperception Problem

In my experience there is serious difficulty in matching the real needs of the customer for technology to the possibilities that technology holds for meeting those needs. "The customer is always wrong"; that is, the customer does not perceive his own requirements in terms of basic problems that must be solved. Rather he tends to perceive the requirements in terms of how he thinks the technology applies to his existing situation.

That is to say, the customer usually asks for technology not in terms of the underlying problem which is to be solved but in terms of the customer's best estimate of the final product that is visualized. This may or may not be a correct statement of the problem to be solved. The customer is likely to come and say "I would like a widget which will do thus and so," rather than saying "I have a problem which I want solved, and it is as follows." Even if the request is stated as a problem, it usually has only the dimensions of the immediate problem as seen by the customer, not the dimensions of the underlying situation which produces the problem, or in which it is embedded.

At the same time, the technologist is likely to put forward a solution which is formed from whatever recent technology has been produced that looks as though it might be applicable to the problem as stated: the laboratories' last patented success. This is likely not to be satisfactory as a solution to the problem either.

The difficulty is that the customer, not understanding the state of the technology, cannot really perceive the way in which it could change the very nature of the problem to be solved, while the technologist cannot see beyond the request to the fundamental application of technology to the customer's problem.

For example, the request for an improvement in the qualities of a metal alloy might lead to an expensive development and production process, while a shift to a plastic with a slight change in design might be cheap, easy, and even better. Accepting the request for metal development, or selling the latest super alloy from the laboratory, would be wrong. Even the use of the super alloy might require corresponding changes in the production process; the transfer involves more than just sending the new capability.

This difficulty is not rare; it is constant. It should be assumed that, at the outset, the customer and the technologist are likely to be talking at cross-purposes and not yet really communicating needs and possibilities.

The Feedback Problem

Most models of research and development leading to a product are essentially models which are sequential in time and operations. That is to say, they assume that there is a period of basic research which provides a body of knowledge, which is then used in some kind of applied research on a more or less well-defined problem, with the result of this leading toward early development work aimed at a particular product; this being followed by successive stages of advanced and engineering development, and design test prototype, and finally pilot production, and production. In actuality the process is never as neat and convenient as this; at the very least, it is frequently necessary to compress it so that some of the "later" stages are begun before the previous stages are complete. Thus one is likely to be doing design and development work even before all of the applied research may be completed and certainly building prototypes before all of the development, final design, and testing is completed.

In addition, it always turns out that not everything in a given stage has been or can really be complete before the later stages are begun, whether time telescoping is being tried or not; there are always missing pieces. Consequently there must be, and there always are, feedback connnections between later stages of the process and what are supposed to be earlier stages of the process. Things are discovered in design and development that require further elaboration in applied research and early developmental engineering. It is even the case that things arise in the course of production that require going back to engineering, development, and research for solution or improvement.

There is a body of what I called embedded basic research inside all engineering development programs. By this term I mean simply that it frequently turns out in the course of development and test that things go wrong and expose missing pieces of fairly fundamental knowledge. It is then useful, indeed sometimes necessary, to fill these gaps in before one can have a truly successful product development. At the same time, sometimes capabilities are established in the course of the engineering of the product, or of parallel products, which make it possible to do things in basic research, in laboratory technique for example, which were not previously possible, and therefore new fundamental knowledge, or applied knowledge, may be created as a result of later engineering success. In addition, during the course of development there will be new knowledge development in the laboratory which will be of advantage to the engineering development and engineering design, if the latter is in a position to use it.

Thus the process is far more complex and untidy than anybody's diagrams or budgets ever show. There is a need for continuing dialogue and working between those who know the basics and the technology of what is involved and those who are trying to embody this knowledge into a product.

Indeed, one does not really know whether a technology, or a body of knowledge, has been transferred until the job is done and the product is produced and successfully on the market. Even rather late in this process there can be a requirement for modulation and tweaking of the technology, and hence a continued need for technology transfer.

SOME ASPECTS OF DOING IT RIGHT

Given the problems that I have just stated, and the implications of my introductory conclusions, which in fact derive from the problems, there are a number of points about interactions which must be made.

Dialogue

The only approach to solving the problems of tidiness, educational mismatch, problem misperception, and feedback that I have ever found is a series of detailed discussions between those who have a problem to be solved by technology and those who have some knowledge of the technology or technologies that might be useful in solving it. Remembering that this is likely to be a dialogue between people who approach problems from rather different points of view, we can see that this may be a protracted and difficult dialogue, unless the people involved have tried this kind of communication before. It takes a good deal of digging on both sides to define and elaborate and understand the real nature of the problem, or problems, to be solved and at the same time get an understanding of what technology is available, or nearly available, to solve them.

The dialogue is likely to lead to a reassessment of the nature of the underlying problem, frequently to a redefinition of what the problem really is. This newly defined problem is likely to be different than the problem originally stated. At the same time, the definition of the technology to be used in the solution will change from what was originally proposed as the technologist gains a better understanding of the requirements and constraints of the problem.

The sequence of discussion, rather than a simple customer's request and technologist's response, will be more a dialogue of adjustments, a sequence of modifications of requests, punctuated by modified technological suggestions. As the process continues and the parties learn more about each other's problems, capabilities, and strengths, they ideally become a team working together on the simultaneous redefinition of the problem along with the technological means for its solution.

The problem the customer and technologist state together at the end of the process, as well as the proposed technological means for solution, will differ from the initial statements of the problem and proposed technological solution.

The nature of the successful dialogue approach to technology transfer and development problems is such that it must be described as a "problem-solving" rather than a "transfer" approach. The spirit of the successful process is antithetical to "arms length negotiation" and legalistic adversarial processes.

Where To Begin

There must be established some process or arrangement for making it possible for those with problems to be solved by technology to become acquainted with those who may have useful technological knowledge so that the dialogue can begin, or for those with technological knowledge to become acquainted with the problems that the technologies might solve. Indeed the real problem is even prior to this: those who are engaged in the development of technology need to have some idea of the kind of problems, processes, and products to be solved and developed, so that they can use this understanding in making intelligent choices of the research that they want to do.

This understanding of potential product direction is in fact important in deciding on the area and subjects of basic research that a laboratory with that responsibility ought to engage in, as well as in deciding on the technological research and development of a particular firm.

An Attitude Towards Relevance

This problem of knowledge of what is going on in the firm, both knowledge by research and development people of product needs and interests and knowledge by product people of research and development possibilities, is complicated by the fact that too strict a view of relevance in research and development may be merely a guarantee that no results will come out of research and development that can produce very much useful change; and it is useful change that we are aiming for. It is a paradoxical fact that adherence in research and development to what is believed to be strictly relevant to a problem is nearly a guarantee that the problem will not be solved. It is perhaps an exaggeration, but not a very great one, to say that if the solution to the problem were easily embedded in the prior knowledge in a way that was clearly relevant, the problem would probably have been solved or never arisen. It is particularly true that if important product change is desired, then a body of material other than that which is obvious will have to be involved.

It is certainly a truth of the history of science and engineering that important discoveries and inventions have a habit of being made by the wrong people. That is to say, it is someone from the next lab who becomes aware of a difficulty, a problem, or a situation, and by seeing it from a different angle than the individual who has already succeeded in not solving it, may contribute a crucial or important idea to its solution. This is perhaps the reason why students, tyros, and ingenuous newcomers are so important in the process of research: they are likely not yet to understand the full body of material which is on the wrong track. The ability to step outside of the normal framework of thinking can be crucial to successful research and development.

The Communication Problem

Thus there is a paradox in the technology transfer process in that somehow one wants enough looseness in the system so that people who can contribute, but are not working in an obviously relevant subjects, can somehow get wind of what is going on and be involved in the process. Clearly one cannot solve this by the anarchistic solution of having everyone get involved in everything, for the sheer statistical and combinatorial aspects of the situation will make it impossible to solve anything.

What one has to aim at is a situation in which a reasonable number of people, in whatever research and development divisions the organization has, are aware of the nature of product problems and situations and can hear about things both inside the research and development laboratory, and in the corporation at large, in a way which will enable them to put forward ideas that are connected with the problems being discussed.

Meanwhile, product people need to get some idea of the nature of technological developments that may be of use to them.

What is needed is an internal formal and informal rumor network about technological and scientific developments and about product ideas and problems so that concerned people become aware of technology transfer opportunities.

Some Systems

Formal schemes that have some use include the establishment of brokerage organizations, in which the internal broker is responsible for the outreach of his organization to other portions of the corporation. This would include a responsibility, for example, for knowing what it is that is going on inside the research establishment and, at the same time, knowing what it is that is going on elsewhere in the corporation and being a kind of marriage broker for technology transfer.

The weakness of the brokerage arrangement is that it can sometimes become a bureaucratic end in itself and become an interference rather than a brokerage establishment. The broker must also understand that it is not only the obvious people who must be informed, but unobvious people too.

It can also be useful to make sure that particular individuals or groups, both in the research and development organization and in the operating organizations, are designated as having known contact people in other parts of the organization. They should not be restricted only to the formally established contacts, but these at least provide a minimum glue for the technology transfer system.

In spite of the inadequacy of the linear model of research and development and technology transfer discussed earlier, it can be useful to have a formal system based upon it in place, that is, to designate portions of the organization which have nominal responsiblity for various parts of the problems, such as fundamental research, applied research, initiation of development, product development, etc. While it may be necessary to use other relationships, for example, direct work between a fundamental research laboratory and a manufacturing division to solve many problems, the existence of the nominal track may be useful in providing a well-greased system for moving technology along. Care must be taken, however, that gates do not become walls and that categories of activities do not become watertight compartments.

Use of such a system cannot be in lieu of all other contacts, however, or it will make the intimate knowledge and understanding between research people or between the initial development engineering staff and production people, difficult or impossible.

Another mechanism, sometimes useful, is to place parts of the research and development organizations physically in the manufacturing division. This can provide an intimacy of living together for some of the R&D people and their manufacturing counterparts. It usually leads to the difficulty that the "field groups" grow away from the other parts of the R&D organization, leading to new information and technology transfer problems.

It is sometimes useful to establish project organizations for new products; these can temporarily (weeks to years) combine people from various parts of the organization for the particular purpose. Carefully done, the project can become a medium of technology transfer, particularly as long as the members maintain communication contact roots in their home part of the corporation. By this means they may bring in irrelevant people and skills as they become relevant.

Committees may play similar cross-organizational roles, as long as they don't become formalized and dull. The process must remain exciting, even tense.

Another mechanism which can be useful is the temporary or permanent transfer of people from a part of the organization where they have developed or learned an area of science or technology to one where it is needed. Conversely, people may be sent from a place with a need to one that is a source of knowledge.

Organizational Comment

I have said little about the organization of research and development in terms of corporate laboratories, operating division laboratories, and combinations of these because to my mind these are likely to depend more upon the nature and size of the corporation than upon the details of the requirements of technology transfer. What one is trying to do is optimize the kind of communication network that I have described, and this will depend upon the product mix and organization of the corporation; various systems will be appropriate depending upon circumstances.

It must be remembered in this context that bureaucratic matrices cannot be diagonalized. By this I mean that there is no organizational arrangement which is perfectly matched to the problems it is to solve. Every organizational system distorts some portion of the important relationships.

For example, if research and development is decentralized to production centers, there will arise problems of critical mass of technical specialists in the research and development units (the groups may be too small to remain competent and up to the state of their art) and problems of communication and coordination among the research and development units. On the other hand, if research and development is centralized, there will be problems of technology transfer to the production units.

The organization should be chosen so that the problems it will inevitably give rise to are deemed by the management to be solvable.

The organization must allow, even encourage, means for breaking its own structural restrictions. There must be systems for communication across organizational barriers.

This is why no bureaucracy operates according to its organizational diagram: both because all organizational diagrams are instantly obsolete (life changes faster than organizations can, or should, reorganize) and because they are always grossly imperfect. The organization actually adjusts around them informally to produce some kind of satisfactory operating arrangement.

Thus I have emphasized the nature of the human relationships required for technology transfer rather than the organizational artifices in which these arrangements must operate.

It is important that there be a sense of responsibility for technology transfer both in the research and development part of the organization and in the production part of the organization.

Objectives

The objectives for the technology transfer network may be set in both a formal and an informal way. Formal objectives may be set by communicating product interests from the corporate level to the various portions of the organization so that a search for technology transfer opportunities may be made by all of the participants in terms of these specific product objectives. At the same time it is useful, but insufficient, to pass documentary information around concerning technological possibilities and interests.

Incentives

The most important incentive for this work is the desire of those involved to see their efforts in research and development used or to see their problems in production and product design solved, and for both groups to see the corporation succeed. In addition to these social incentives, the connection of career progress, in the promotion sense, with the transfer of technology and its use in successful product development and production can be a specific incentive, as can the awarding of prizes and money bonuses in order to produce an interest in technology transfer.

From the research and development point of view, however, it is important that these incentives specific to technology transfer and application be coupled with incentives to do good research and development for its own sake and for its value to the corporation. If both of these incentives are not pursued, then there will be a tendency for the technology transfer incentives to produce an interest in short-term research and development, since that can apparently pile up technology transfer credits, whereas we really want to give those involved incentives that will encourage some appropriate mix of long-term and short-term research and development.

It is important to note that incentives which operate only on individual performance may discourage technology transfer by not giving sufficient credit for accomplishments which involve, by their nature, other groups of people in the corporation. It is important that both individual and group contributions be recognized and encouraged and that both individual research and research transfer be encouraged if the system is not to be badly unbalanced.

The incentives are not nearly as important as the forces which exist in most organizational settings to discourage good communications and technology transfer.

DIFFICULTIES AND EMEMIES OF TECHNOLOGY TRANSFER

By far the greatest enemy of real technology transfer is systematic management and businesslike attitudes. The difficulty is an insistence that the organization operate according to its organizational structure written down. This can inhibit the creation and operation of exactly the kind of communication network that I have described as being required for technology transfer.

In addition, the same "businesslike" and "good management" attitudes lead to strictness in such things as travel, so that the people in different parts of the organization are inhibited from meeting, or even from talking to, each other by long-distance telephone.

Those who have not had experience with this process will frequently insist that the transfer of reports and the writing of letters is a suitable substitute for meetings and conversations, whether by communication system or face to face. This is simply not so. The dialogue must take place in a live and human way. It may be that communication by computer system is becoming natural enough so that it will be satisfactory, but I have a suspicion that a quiet conversation with a drink or a cup of coffee or tea will never have completely satisfactory substitutes.

An additional difficulty is that many of the obvious aspects of this process appear to be "time-wasting." They involve travel, meetings, bull sessions, and a great deal of conversation before there is final output. Thus the very things that are good for technology transfer are likely to be the first things that the auditors, budgeteers, and personnel people attack. They must be kept out of this process or they are likely to destroy it. The essence of the things is flexibility and human interaction as a way of solving problems and seizing opportunities. Those bureaucractic arrangements that destroy that kind of flexibility cannot be allowed.

A related problem may be found in budgeting and costing systems: what I call the widget-versus-system mentality. Since the essence of technology transfer may be the redissection of a problem and its redefinition along with a technological solution, a direct transfer of the previous costing arrangements may not be possible. An insistence that the new component be compared in cost to the old component may be strictly impossible because it is a new system rather than an old system, and the way in which the old and new components are embedded in their systems may be different. This may make naive costing impossible because changes have really been made in larger parts of the system, not just in component change, forcing reanalysis of system costs, not just component costs. This is a point to be watched. It is solvable, but ordinary systems are likely to do it wrong.

A related problem is the problem of early economic analysis: analysis of the cost of using a new technology before one has really gone through enough development to know what the possibilities really are. This is especially pernicious if the costing is of totally specious accuracy. This is simply a way of destroying the future for the convenience of budgetary control. (It has been my experience that accountants and economic analysts are generally naive in the matter of assessment of accuracy: they generally seem totally unaware that there is a problem.)

An important problem to be worried about is the continual battle between proprietary secrecy, which may well be necessary for product competition, and the need for lots of communication in order to facilitate technology transfer. Anything which inhibits communications is likely to be bad for technology transfer, and a sensible balance must be sought. Technology transfer takes place in an atmosphere of" "If I had known it was a problem, I could have solved it."

There can be difficulties because the time scale and phasing of research and development may simply be incompatible with the ordinary timing and phasing of business readiness for product production. This most often becomes evident when small delays in the completion of research and development or in the availability of technology for application and transfer result in a poor phase relationship to budgetary or production readiness cycles. In such cases a small lag can result in introduction of the new ideas being delayed by a whole cycle, since introduction during a cycle may be too difficult or expensive. Thus a whole annual or longer cycle of product design and production can be lost, when what was out of synchronism was merely a matter of days, weeks, or a month or two. Careful planning can sometimes help with this, but it is always a problem to be kept in mind.

An Important Caution

I have placed a great deal of emphasis on informal communication and cooperation across form organizational lines, but it is my intention that this be a means for work towards the identification of problems and their solutions, not a means for subverting the normal decision procedures of the organization. It must be clear to the participants that they are producing possibilities; the possibilities must be ratified by the organization through its normal formal means.

However, given the real communication systems, and even the formal systems that can be built around the arrangements I have described, it is likely that the formal decision system will have participated in, and been informed of, the informal processes, so that formal regeneration of the results is easily accomplished.

CONCLUSIONS

My conclusions are basically a reiteration of my introductory conclusions: technology transfer is a process carried out by consenting adults; it is a process of communication and human interaction. Those things that foster this in a useful way will be fostering technology transfer; the greatest danger arises from practices that inhibit free communication and discussion.

TECHNOLOGY ASSESSMENT AND ENVIRONMENTAL IMPACT ASSESSMENT

Harvey Brooks

The assessment of the effects of technology is an activity that has grown rapidly in the United States since the middle of the 1960s. It can be regarded both as a sociopolitical movement and as a new intellectual discipline. Its new importance derives from a number of changes that have been taking place in America, and indeed in all industrialized societies, for the last two decades. Theories of the sources of these changes are various and often conflicting. However, my own identification of the sources of pressures for the social impact of technology would be summarized roughly as follows:

1. Sociocultural changes arising from the change in the quality of life and the occupational structure.

As average incomes and material affluence have increased in all industrialized societies, particularly during the period of unprecedented and uninterrupted economic growth which took place from the end of World War II to the early 1970s, people have become less preoccupied with the satisfaction of material wants, and have become more interested in other, less tangible amenities ranging from a clean environment to less conflictual human relations. Whether or not one fully accepts Mazlow's theory of the hierarchy of human wants[1], it seems apparent that more and more people are inclined to take material welfare foregranted to give greater weight to other values. This evolution has been moderated, but not reversed, by the recent decline of economic growth rates in the West and by increasing anxiety about the performance of our economies.

Accompanying the increasing wealth of industrialized societies has been the emergence of a professional and technical class, not directly engaged in material production, with the leisure, means, and independence from daily livelihood concerns to register new values and perspectives in the political process. This class includes independent professionals, academics, employees of the private non-profit sector, officials of state, local, and federal government, the media, and a significant proportion of non-production workers in manufacturing and commerce--people whose daily work is concerned with ideas, knowledge, and human relations rather than with things and artifacts.[2] It is these people that form the backbone of support for the environmental movement, for voluntary associations and political action movements, for outdoor recreation and the enjoyment of natural amenities. It is they who are most concerned about what goes on outside their immediate sphere of daily concerns, who worry about the future and the prospects of their descendants, who are aware of the plight of people outside their sphere of immediate contact.

In part because of the growth of this class we have a society with rising expectations to the proper standards of cleanliness of the environment and as to the level of risk to which people should be exposed as a consequence of industrial and economic activity. The attitudes of this group provide a setting for the closer examination of the effects of technology and economic activity which has led to a less automatic acceptance of the byproducts of technical and economic progress throughout the whole society.

In the United States this change of mood has been reinforced by the political experiences of the late 60s and early 70s--the divisive national debate over the Vietnam War, the events of Watergate, the student movements of 1966-1972--all reinforced by the rise to leadership of a new generation which had never experienced any alternative to relative economic security, nor had any direct knowledge of war and conflict. Thus in a sense one could say that the rise of interest in technological and environmental assessment is a permanent residue of our own "cultural revolution" in the West.[3]

2. The increasingly apparent systemic effects of new technologies

While the interest in assessment and the changed, more critical attitude towards technology is in part the result of altered expectations and aspirations rather than of changes in the physical circumstances of life, there have also been real changes in the physical and technological environment which have reinforced and confirmed the changes in mood. There is an increased awareness that the large-scale deployment of both new and old technologies can have importance ramifications that their early proponents could hardly have foreseen.[4] These ramifications can extend much more widely in both space and time than was appreciated during the period of euphoria about the benefits of technology which extended from the end of World War II to the early 1960s. One of the earliest examples of this was the global radioactive fall-out from atmospheric testing of nuclear weapons, for which public concern was instrumental in bringing about the atmospheric test ban treaty of 1962. A more influential example, perhaps, was the case of the pesticide DDT. Commercialized as a by-product of World War II, DDT was at first hailed as an unmitigated boon to mankind. For the first twenty years of its use it probably was responsible for saving more than half a billion lives worldwide through its use to control insect-borne diseases such as malaria.[5] In agriculture it was a major factor responsible for the dramatic growth in agricultural productivity which occurred in the U.S., Japan, and Europe during the post war period. Initial concerns about its side effects put forward by a few entomologists and ecologists shortly before its large scale introduction into agriculture were almost completely forgotten after experiments indicated that direct hazards to health were minimal if the chemical were properly used.[6] But in

1962 the marine biologist Rachel Carson published a remarkably influential book, Silent Spring,[7] which documented some of the bad side effects of DDT and brought home for the first time to a wide public the fact that even the most apparently beneficial technologies can have serious social costs, especially if they are deployed uncritically and without a continuing ongoing process of assessment of their effects as their scale of use is increased. This book triggered almost a social movement which, in the minds of many, was an overreaction to the actual facts of the situation, but it was soon followed by numerous other examples of unintended or unforeseen side effects of technologies hitherto regarded as benign--food additives, nuclear power, automobiles and highways, commercial aircraft. In the rush of discovery of unwanted side effects the original benefits for which the technology was deployed were often forgotten.[8]

3. Shift of the burden of proof with respect to technology

The most important effect of this new consciousness of the possible side effects of technology was a gradual shift in the burden of proof with respect to technological projects and with respect to the introduction or diffusion of technology. From an era in which technology was presumed innocent until proved guilty, we were rapidly shifting to an era in which technology was presumed guilty until proved innocent. The burden of proof was shifted from the few who opposed the introduction of particular technologies to the proponents or purveyors of such technology. Also the burden tended to be shifted towards an earlier and earlier stage of the innovation process. People feared that a new technology would acquire sufficient momentum in the early development stage so that it would be impossible to stop by the time it was ready for commercialization or large scale deployment. Thus environmentalists mounted a successful campaign to stop government development of three prototype experimental supersonic civil aircraft on the grounds that a future commercial fleet of five hundred such aircraft would have unacceptable environmental effects.[9] People were much less willing than in the past to accept the notion that a technology should be developed and its adverse side effects dealt with by a "technological fix" at a later stage after some practical experience with the technology was available. One should prove that it would be harmless, or devise and prove out a suitable remedy for its possible side effects, before it should even be allowed to be developed.

Indeed many of the arguments that arose in regard to the regulation of technology were less about the magnitude and uncertainty of the actual risks than they were about who should bear the burden of proof as to the acceptability of these risks and at what stage in the sequence of decisions leading to final application of the technology.

4. Scientific progress that permitted earlier and better appreciation of potential risks

Somewhat ironically the deployment of technology was approached with greater caution because in fact scientific measurement sensitivity or theoretical understanding permitted the identification of much smaller or more subtle side effects than would have been possible earlier. During the 1960s and 1970s the analytical sensitivity of chemical and physical instruments made it possible to detect the presence of impurities in amounts which would have been undetectable before. Dramatic examples were the detection of DDT residues in Antarctic penguins,[10] of the use of the electron microscope to detect asbestos fibers in Lake Superior near the drinking water intake for the City of Duluth.[11] The mere presence of an impurity known to be carcinogenic or otherwise deleterious to health, became grounds for suspicion of a situation without the necessity of demonstration of adverse effects in the concentrations actually found. Such suspicion became plausible on scientific grounds because of increased understanding of the long latency periods that could precede the appearance of adverse health consequences from low concentrations of certain chemicals. It became conceivable that a considerable population could ingest or breathe low concentrations of a chemical for years with no apparent adverse effects, only to show up with delayed cancers of other diseases twenty or thirty years after the initial exposures. Thus trace chemicals could become a "time bomb" whose presence was simply undetectable by ordinary health surviellance techniques.

Once again, as in the case of DDT, public concern was stimulated by a few dramatic examples, mostly in connection with occupational exposures, the most poignant being the case of asbestos workers who showed up with a rare form of lung cancer several decades after their original exposure.

Similarly, the capacity to model very improbable but catastrophic events with the aid of powerful computers helped to generate valid concerns about the safety of various technologies even in the absence of any adverse operating experience. In this way doubts arose regarding the safety of nuclear power reactors, even though actual operating experience with these reactors had been almost uniquely free of actual injury or health damage to operating personnel or to the public. Without the scientific sophistication that made possible the plausible modeling of improbable but possible events, safe operating experience would probably have been sufficient to reassure the public and even critics of the safety of the technology even though a rigorous quantitative risk assessment might not have justified such complacency. Historically more new technology had been introduced with the implicit assumption that "what you don't know won't hurt you," and this assumption was usually, though not always, valid. However, it was no longer publicly acceptable, particularly with respect to novel or unfamiliar technology. The greater the power of scientific analysis the more the public insisted that its full capacity be used to assure the population against even the remotest risks.

5. Changes in the nature of the political process which made it more susceptible to the registration of wider and more subtle social concerns than in the past

The scope of this paper does not permit a detailed account of all the political changes that have made both the political and legal processes in the United States much more susceptible to influence by both new and old special interest groups. On the one hand, growth of new lobbying groups representing consumers, environmental concerns, health and safety concerns, the elderly, the handicapped, and certain minority groups and other underprivileged subpopulations has brought a whole new set of actors onto the political scene. On the other hand, the traditional economic interest groups such as industry and labor unions have redoubled their activity, partly in self-defense. What is important, however, is not the existence of such groups, always important in U.S. politics, but the fact that they have better access to decision making processes than ever before.

Institutional and Political Response to the New Climate Towards Technology

The last decade has seen a proliferation of laws designed to regulate and control the social costs of economic growth and the introduction and diffusion of technology in American society. All of these laws have as a necessary by-product the development of analytical capacity within government and outside it to anticipate, assess, monitor, and analyze the effects of technology on the environment and on society. The broad objectives of these laws as expressed in their preambles are extraordinarily ambitious and presume a knowledge base and an analytical capability which often far transcends what science is as yet in a state to provide.[14] Much of this legislation is thus either "technology forcing," i.e., requiring the development of new technology before it can be fully implemented, or "science forcing," requiring the development of a much expanded base of data and scientific understanding than now exists before one could even know whether its objectives were being realized. For example the Toxic Substances Control Act (TSCA) presumes a degree of knowledge of the biological effects of thousands of new chemical entities introduced in commerce each year which present testing techniques are incapable of providing except with very large margins of uncertainty. The subjects covered by new regulatory legislation in the late 60s and the 70s include auto safety, occupational health and safety, consumer product safety, toxic substances, hazardous waste management and disposal, the identification and clean-up of past hazardous waste depositories, clean water, clean air, the management of solid wastes, the registration and control of new pesticides and herbicides. In addition the government management and surveillance of nuclear energy has been reorganized to give much greater prominence to environmental and safety concerns with a complex and detailed system of licensing and overseeing the operation of nuclear power reactors.

With the new laws have also come a host of new regulatory agencies to implement these laws, including the Environmental Protection Agency (EPA), the National Highway Safety Administration, the Consumer Product Safety Commission (CPSC), the Occupational Safety and Health Administration (OSHA), and numerous specialized sub-offices within each of these agencies responsible for implementation of various subsections of the original legislation.

As economic stagnation set in after 1973, and unemployment began to increase, some of the extreme enthusiasm for environmental regulation began to wane, first towards the end of the Carter administration, and then more dramatically with the election of the Reagan administration. However, public opinion polls still indicate that the majority of the American people remain very supportive of the goals of this legislation and assign high priority to the protection of the environment and public health and the minimization of risks arising from technology. Thus the introduction and diffusion of technology still bears a much heavier burden of proof to demonstrate its harmlessness than was true before 1970. If anything the lobbying groups supporting environmental, health, and safety goals have redoubled their efforts and are still able to attract adherents and financial support. Despite a less receptive administration, environmental and consumer groups still find strong supporters in the Congress, and are frequently able to make their views felt through the judicial system.

Thus, in the opinion of most observers, the new emphasis on the assessment of technology and its environmental impacts is a permanent feature of the American political landscape, moderated only slightly by a greater public appreciation of the economic costs of achieving some environmental goals.

The National Environmental Policy Act and the Technology Assessment Act

Probably the two most important pieces of legislation affecting the social assessment of technology have been the National Environmental Policy Act enacted in 1969[15] and the Technology Assessment Act enacted in 1972.[16] These two acts are important because, unlike the specific regulatory legislation mentioned in the preceding section, they cover the assessment of technology in all its aspects and address themselves specifically to the data and analytical requirements for such assessment. In the case of the regulatory legislation, assessment is necessary because in practice each regulatory agency has to produce a plausible case for its decisions if they are to withstand challenge from the regulated industries in the American court system. Under the provisions of the Administrative Procedures Act, which governs the relations between regulated groups and the agencies applying the regulations, the decisions of such agencies can be appealed to the Court system, and the agency must show that its application of the regulations was not "arbitrary and capricious."

This provides that every agency of the federal government shall "include in every recommendation or report on proposals for legislation and other major federal actions signficantly affecting the quality of the human environment, a detailed statement by the responsible offical" on the environmental impact of the proposed action. As a result of legislative history and particularly judicial interpretation both "human environment" and "major federal action" have been construed in very broad terms. In the law itself environment includes: "Any adverse environmental effects which cannot be avoided should the proposal be implemented," "alternatives to the proposed action," "the relationship between local short term uses of man's environment and the maintenance and enhancement of long term productivity," and "any irreversible and irretrievable commitment of resources which would be involved in the proposed action should it be implemented."[17] However, the law has usually been interpreted by the courts to include almost any effect whether strictly environmental or largely social or individual. An interesting recent example is the decision of the United States Court of Appeals reviewing an action of the Nuclear Regulatory Commission to permit restart of the undamaged Three Mile Island unit No. 2 reactor. The majority of the court held that NRC in its EIS should be required to consider "psychological stress" as an impact on the "human environment" under the provisions of section 102 (C) of NEPA. Similarly the term "major federal action" has been interpreted by the courts to mean any action in which a federal decision is involved such as the licensing of an electric generating plant, which is required to be done both by the Federal Energy Regulator Commission (FERC) and by the Nuclear Regulatory Commission (NRC) if the plant is nuclear. The courts have also interpreted the phrase "alternatives to the proposed action" in the broadest terms, in some instances to include community energy conservation as an alternative to the licensing of a new power plant, despite the fact that energy conservation could not be mandated or carried out by the same agency that licensed the plant.

Thus, as a practical matter, the EIS requirement of NEPA is a requirement for a comprehensive technology assessment involving all aspects of the social and environmental impact of a proposed project whether it be initiated and funded, or merely consented to, by a federal agency. Furthermore, the courts have insisted that the agency not only prepare an adequately comprehensive and balanced assessment but that it be able to show that it actually took into account all aspects of this assessment, including comments from the public, in arriving at its decision.[18]

In most EIS preparation, particularly when the government role lies primarily in giving permission for a private action, consultant firm and other outside groups are heavily involved in the actual preparation of the EIS. Following the preparation of a draft EIS the responsible agency is required to "obtain the comments of any federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved." Part of the purpose of the EIS procedure was to secure broader public involvement in the planning process. Executive Order #11514, part of the implementation of NEPA, required that agencies "develop procedures to insure that fullest practicable provision of timely public information and understanding of federal plans and programs with environmental impact in order to obtain the views of interested parties." This included public hearings where practicable. In practice it has proved difficult to provide sufficient lead time between the issuance of a draft EIS and the deadline for receipt of public comments to obtain truly meaningful participation of all the relevant interest groups. The courts have held that agencies must allow private individuals and interest groups to review impact statements even though this is not specifically provided for in the legislation. The degree and timing of public participation have continued to be contentious issues in the implementation of NEPA, in part because there is a fine line between the representation of legitimate interests and concerns in the EIS review and the use of the EIS procedure as a pretense for delaying actions on the part of small groups unalterably opposed to a particular project or technology on other grounds. The difference between genuine participation and small group veto of a program which is on balance in the public interest is often a matter of the values of the observer.

The NEPA also provided for the creation of a Council on Environmental Quality in the Executive Office of the President, one of whose important functions was to devise guidelines for the content and format of EIS's. One of the important purposes of the EIS procedure was to force a comprehensive assessment of proposed actions of federal agencies even when the impacts of the action lay outside the jurisdiction of the agency. Environmental groups had been frustrated by the fact that agencies frequently made decisions on narrow grounds which simply ignored those ramifications of a decision over which the agency had no control but which lay within the jurisdiction of another agency or another level of government. Part of the purpose of Section 102 (C) was to undercut the defense "that's not my business," which had sometimes been used as a pretext for not confronting the systemic effects of an agency program in a comprehensive manner. Thus this provision of the law was explicity aimed at forcing all decision makers, inside and outside of government, to recognize these systemic effects in their decisions.

The problem withthe EIS procedure from the viewpoint of environmentalists was that it provided no guidance to agencies as to the relative weights to be given various factors in arriving at a final course of action. For example, Congress provided no guidance as to how economic benefits of a program were to be traded off against environmental quality or how various kinds of intangible values such as the preservation of pristine wilderness were to be balanced against more tangible economic or social benefits to defined groups. While the procedure implied a kind of overall cost/benefit analysis, a balancing of aggregate costs against aggregate benefits, this was never explicit, nor was there indication of how distributional considerations were to be weighed in the balance if costs and benefits were experienced by different groups. The reason behind this lack of legislative guidance was, of course, that Congress itself could not agree on anything beyond the fact that some balancing was desirable, and hence left the matter vague, in practice to be resolved in administrative hearings and in a series of confrontations between environmentalists and project proponents in the federal courts. Because of this lack of guidance EIS's often tended to become catalogues of conceivable environmental and other effects with inadequate effort to quantify them or evaluate their relative importance.

Technology Assessment

The EIS prodedure was designed primarily to be an Executive Branch affair. Although agencies were required to prepare an EIS when they proposed legislation, Congress itself was under no such requirement if the legislation was initiated there, even though the ultimate implementation of the legislation would surely meet the test of a federal action "significantly affecting the human environment." Thus, even after the enactment of NEPA in 1969, there was a felt need for a mechanism for assessing technology and the consequences of legislative initiatives directly within the province of the Congress itself. The Technology Assessment Act of 1972 provided such a mechanism directly under the control of Congress, with the capability to provide assessments to its own contemplated legislative actions. Unlike the EIS procedure technology assessment if not mandatory. The projects, programs, and issues to be assessed are carefully selected from a very large agenda by the Technology Assessment Board, the non-partisan joint House-Senate Board which governs the activities of the Office of Technology Assessment (OTA). In fact the studies undertaken by OTA do not necessarily have to relate to specific proposed legislation, although the reports of these studies usually include a list of possible legislative actions by Congress in response to their findings.

The idea for an Office of Technology Assessment is said to have originated in conversation in 1964 bewteen the famous aviator Charles Lindbergh and Congressman Daddario, the chairman of the Subcommittee on Science, Research, and Technology of the then Committee on Science and Astronautics of the U.S. House of Representatives. That committee had been set up originally to oversee the burgeoning U.S. space program, and its interest in wider issues relating to science and technology grew only gradually. In fact, whereas the origins of NEPA and EIS's lay primarily in the environmental movement and environmental concerns, the origins of Technology Assessment and OTA lay more in the broader field of science policy. It was only gradually that the two themes converged, but whereas NEPA and the EIS procedure had a more or less anti-technology flavor, stressing the negative and unintended consequences of technology, TA was more evenhanded in its attitude towards technology, aiming not only to identify negative side effects but also to identify hitherto unrecognized benefits of new technologies and to stimulate the development of technologies which its studies indicated were being overlooked or underemphasized.

Congressman Daddario took up the issue of TA as a personal crusade. He held a series of hearings through the late 1960s and commissioned several reports by various outside technical groups to further define and characterize what was meant by technology assessment, and to examine various organizational options for implementing the process as an integral part of legislative oversight and Congressional deliberations on legislation. The concept of TA matured more slowly than that of environmental assessment, which was swept up in the mounting political enthusiasm for environmental regulation and the ecology movement. Thus legislation was not passed until 1972, and Congress was persuaded to support it more as an independent instrument of Congressional consideration of science policy issues than as a way of regulating technology as such. Only after President Nixon in 1973 abolished the President's Science Advisory Committee (PSAC) and the Office of Science and Technology (OST) in the Executive Branch did Congress take up the OTA idea with enthusiasm as a kind of Congressional counterpart of PSAC and the now moribund Executive Branch science adivsory apparatus. Indeed OTA has always suffered from ambiguity in the definition of TA. Was it in fact simply a source of technical advice for the Congress, of which the assessment of specific technologies was only a small part, or was it to concern itself with the evaluation of specific proposed technological projects? In fact it has remained a little of both, never fully resolving the ambiguity of definition. In practice more studies undertaken by OTA have their origins in requests from specific Congressional committees or subcommittees, although they are frequently recast as the result of informal interactions between the Congressional proposers and OTA staff. Final approval of the project and its general work statement have to be approved by the TAB, the governing body of OTA, which includes six members from the House and six from the Senate with three each from the majority and minority parties from each house.

Whereas the prinicipal outside constituency group for NEPA and the EIS process was the environmental movement, the constituency for OTA and the TA process was the broad U.S. technical community, which included environmentalists, ecologists, and specialists on consumer affairs, but also included natural scientists and engineers from both academic and industrial backgrounds. The Technology Assessment Advisory Council (TAAC), created by the law to advise the TAB, has a balanced representation of both expertise and institutional background. The present Council includes one engineer from industry, but two others with former industrial backgrounds, for example. In connection with each study undertaken, OTA creates an advisory committee in which an effort is made to secure a wide and balanced representation of various points of view and interests related to the issue under discussion. While the advisory committee has no responsibility for the final product its comments and inputs are taken very seriously by the project staff. To a degree the project advisory committee mechanism serves as a form of public input or participation, which is supplemented by special workshops and conferences preparatory to report preparation. As a result of these mechanisms OTA report benefit from a wide range of inputs from both the public and the non-government professional communities and have acquired a reputation for balance and disinterestedness which has brought them increasing acceptability in the Congress as well as increasing attention and respect from both a domestic and foreign public and the general professional community.

TA in Other Settings

While the EIS procedures and the OTA have been principal sources of technology assessments, the activity has gained importance in many other settings as well. The Technology Assessment Act of 1972 called for close cooperation between the National Science Foundation and the OTA, and the NSF has responded to this direction by supporting more than a hundred technology assessments under contract to academic and private consulting groups. The purpose of these assessments has been in part to stimulate evolution of the state of the art and the formation of a national cadre of experts with experience in conducting multidisciplinary technology assessments.

Nor is the OTA the only Congressional agency that carries out technology assessments. The General Accounting Office, a much larger agency than OTA with a staff of more than 5,000 has increasingly shifted its emphasis from pure accounting and program evaluation towards conduct of technology assessments and policy studies involving scientific and technological considerations. For example, the GAO published a whole series of reports assessing plans for the Clinch River Breeder project and provided analytical support for the efforts of certain Congressional subcommittees to preserve that program over the objections of the Carter administration which was trying to cancel it. In this case and others the GAO has played somewhat more of an active policy advocacy role than the OTA, which tends more to lay out a range of policy options for the Congress with their pros and cons without recommending any single best policy. This is sometimes frustrating to politicians who prefer clearcut answers from experts, but has helped to enhance the reputation of OTA for fairness and balance.

In contrast to the GAO, the Congressional Research Service, another staff arm of the Congress, tends to play an even more neutral and non-committal role than the OTA. Responding mostly to requests from individual Congressmen, it issues reports which tend to be based mainly on a meticulous review of existing literature and opinion with relatively little interpretation or judgement injected by the staff. While the reports of CRS may usually be described as "policy analysis" rather than technology assessment in the narrow sense, many of them are in effect technology assessments.

In addition, the Congressional Budget Office (CBO), created in 1973 to provide a central analytical capability to the Congress in evaluating issues arising in the annual budget, has conducted many studies that can appropriately be described as technology assessments.

Both environmental impact assessment and technology assessment (frequently indistinguishable from each other in fact) have become respectable academic subjects with their own professional associations, professional conferences and meetings, and a scholarly literature. As one views this activity one is struck with the difficulty of drawing meaningful boundaries between various activites described as technology assessment, environmental impact analysis, policy analysis, social assessment of technology, technological forecasting, program evaluation, or cost benefit studies. Often such activities differ only in the degree of technical content, or the extent to which the multidisciplinary staffs performing the analysis include engineers and natural scientists as well as economists, lawyers, and social scientists. In the next section I will sketch a typology of kinds of technology assessments which may be helpful in distinguishing among the variety of activities that actually go on under the rubric of TA and related subjects.

A Typology of Technology Assessment and Policy Analysis

Assessments of technology may be classified along several dimensions, such as:

1. The degree of specificity of the program being assessed, e.g., a specific project vs. a generic technology.
2. The scope of the sociotechnical system included in the assessment, e.g., the automobile vs. the whole transportation system, or the supporting technologies such as highways, fuel distribution systems, maintenance and inspection systems, inc.
3. The degree to which assessment is restricted to the technical aspects of a system vs. the inclusion of regulation, institutional support systems, managerial arrangements, insurance, legal systems, etc.
4. The scope of the types of impacts considered, e.g., environmental, health, and safety vs. economic, social, and psychological effects.
5. The geographical and temporal scope of the impacts being considered, e.g., global vs. regional or local effects, short term impacts vs. effects on future generations or long term ecological productivity, etc.
6. The degree to which the response of the sociotechnical system being assessed to alternative policy prescriptions is explicitly taken into account, i.e., does the assessment aim only to describe the existing system and its impacts or to estimate how the system and its impacts may be altered as a result of various alternative policies?
7. The degree of "neutrality" aimed at in the assessment, i.e., whether the assessment is aimed at supporting a preferred policy prescription, or whether it aims at exploring the consequence of a variety of possible policy alternatives, or whether it merely aims at exploring the consequences of continuation of existing trends or forecasting emerging trends without indicating how to channel or control them.
8. The stage of development at which the technology being considered is, e.g., whether it is in the R&D stage, and the issue is

how much to invest in R&D, or whether it is already deployed, and the question is how to regulate its future deployment, or how to modify it or its supporting system to reduce undesired impacts.

Taking all these aspects into account I have found it convenient to classify technology assessments into five main groupings as follows:

1. Project assessments. Here we are dealing with a specific project such as a highway, a shopping center, a pipeline, a prototype of a new aircraft or power plant. EIS's most frequently deal with such specific projects. Project assessments may be further subdivided according to the novelty of the technologies to be employed in them, or the degree of novelty of the environmental circumstances in which they are to be carried out. Many projects involve quite standard technology, and the assessment may focus on the particular environment in which the project is to be deployed, e.g., whether a highway involves filling in a wetland or destroying a residential neighborhood, or whether a particular proposed dam threatens a valuable ecological resource or an endangered species. Some projects may involve fairly standard technology, but the environment in which they are to be carried out is so novel or unprecedented that novel technological considerations are involved; a classic example is the Alaska pipeline, where the arctic environment posed many novel and unusual problems, and potential ecological risks which would not have been present under more usual conditions. Project assessments of this type are the most usual ones encountered, and the ones for which NEPA was primarily designed.

2. Generic technology assessments. Here the focus is on a class of technologies without reference to the circumstances of a particular project or location. An example would be a generic assessment of the automobile and its long term social and environmental impacts, or the assessment of breeder reactor technology in general in contrast to the EIS for the Clinch River Breeder Reactor Project, which would be a project assessment. Generic TA is what is most frequently in mind when one refers to TA. There is an ambiguity, however, in that in specific project assessments opponents frequently attempt to broaden the assessment to consider the generic aspects of the technology involved and the potential consequences of ultimate large scale deployment of the technology. Thus in fact the EIS for Clinch River was forced to consider the implications of the commercialization of liquid metal breeder reactors and the development of a so-called "plutonium economy," not just the local impact and safety of the Clinch River experimental reactor itself. It is in the case of generic TA that the issue of the proper scope of the system to be assessed most frequently arises. For example, in an assessment of automobile technology there is a question of how the assessment should include the highway system and all the supporting systems of the automobile such as law enforcement systems, insurance systems, repair and maintenance technologies, the supplier industries and technologies, the petroleum supply and distribution system and its social and environmental effects, etc.

3. Problem assessments. Here the approach is to examine a broad problem area and assess a variety of alternative or complimentary technologies designed to deal with this problem area, rather than to look at a single class of technology and examine all its potential impacts. For example, instead of assessing the technology of

commercial supersonic flight, one might perform an assessment of the air transportation system and consider the SST as one of several alternative technologies for meeting air transportation needs. Or instead of assessing the breeder reactor as a technology, one might examine the problem of long term, indefinitely sustainable energy sources, and consider the breeder as one possible component of such a system, treating its advantages and disadvantages in comparison with other alternatives such as "hard" and "soft" solar technologies, fusion, "hard rock" geothermal energy, etc. Actually there should be no sharp line between problem and generic technology assessments because it would be hard to make a sensible assessment of a single technology without considering alternative technologies serving the same general objectives. NEPA, for example, requires the consideration of "alternatives to the proposed action" in preparing an EIS for a project. The difference between the two approaches to assessment is a matter of emphasis; in generic TA the focus is on exploring all the possible secondary and higher order consequences of a given technology, while in problem assessment the focus if on the problem, with less intensive or focused examination of indirect consequences of each of the alternative technologies considered.

4. Policy assessment. In this type of assessment there is less emphasis on technology and more consideration of alternatives to technology including non-technological regulatory actions or restructuring of economic and social incentives to achieve a different outcome in a given social problem area. An example might be the use of various kinds of peak load pricing of electricity in order to smooth out the load curve as an alternative to building a new generating plant, or the use of staggered working hours to reduce traffic peaks on urban freeways as a way of avoiding new highway construction or of reducing the need for investments in public transportation. In a certain sense these "software" measures can themselves be considered as forms of technology--social technology--but again the distinction is one of emphasis. Policy assessment blends over into policy analysis, where the emphasis shifts almost entirely away from technology to focus on social and political measures, with technology being only an incidental ingredient or by-product of socially driven policies.

5. Global "problematique" Since the publication of "Limits to Growth" under the auspices of the Club of Rome in 1972 there has been increasing interest in the development of computer models of the entire world designed to assess trends and the effects of various policies regarding energy, food, environment, population, resources, etc. In a way these models are the logical extension of the assessment of sociotechnical systems of increasingly comprehensive scope until the whole world is treated as a single coupled system. Any TA of smaller scope must inevitably treat the world outside the scope of the system being assessed as "exogenous," i.e., as an environment which influences the system but is not influenced by it. While there is much debate as to the feasibility and realism of these types of comprehensive models, they do constitute a form of technology assessment and indeed involve, explicity or implicitly, an evaluation of the influence of various technologies and policies on the evolution of the world environment and multinational production system. One can thus regard a "problematique" as a cluster of problem assessments in which the mutual interactions between different problem areas are

taken into account. For example, one could make an assessment of the problem of U.S. energy supplies and demand, but its realism would depend upon the assumptions used about interaction with the rest of the global energy system, and with other sociotechnical systems such as the food production system, the extraction and processin of raw materials, the environment, etc. Alternatively, one could regard global modeling itself as a technology to be assessed, although what would be assessed is not its side effects or its consequences but its validity and realism. The OTA has in fact published such an assessment under the title, "Global Models, World Futures, and Public Policy: A Critique." In the foreward to this report the Director of OTA, Dr. Gibbons states:

> the purpose of this report is neither to confirm nor disprove the sometimes rosy but more often dire predictions derived from global modeling studies, but rather to examine the present use and potential usefulness of this rapidly developing technology as a powerful tool for a long range strategic analysis and policy development...the report focuses...on how to improve this capability and make its projections more useful to analysts, planners, decision makers, and the broader public.

The report was a response to a request from TAB for "an evaluation of the methods, findings, and implications of Global 2000 and other global modeling studies."

The concept of a global problematique, however, can be more restricted than this, and could, for example, be confined to a single sociotechnical system such as the food or energy system, but global in scope. What makes the concept a meaningful aspect of technology assessment is that there now exist many technologies which are global in their reach and ramifications. For example, several human activities, such as the burning of fossil fuels, are capable of appreciably altering the natural chemical and biochemical cycles of the earth as a whole. The world oil production and distribution system and the rapidly growing worldwide system of telecommunications and information processing are examples of what we have called "global technologies." Because of the implications of global trade in fissionable materials and the handling of spent fuels and nuclear wastes nuclear power can also be viewed as a global technology. The difficulty, of course, is that as the system being assessed becomes more extensive and inclusive, the conclusions of the assessment become more speculative and uncertain, and there is a danger that the use of the computer will lend to its projections a specious impression of an exact science which will mislead the public and policmakers not familiar with its detailed assumptions and approximations. Indeed, the question of uncertainty in the projection of the consequences of any technology or policy arises in all environmental impact of technology assessments, and the issue of how to incorporate such uncertainties in translating assessments into policy prescriptions is one of the central dilemmas of technology assessment and policy analysis. The fact is that these uncertainties grow with the scope of the system being assessed, and the conclusions become more susceptible to conscious or unconscious manipulation to fit various ideological preconceptions or policy references.[19]

The Future of TA

Technology assessment is more of an art than a science despite the fact that it must make heavy use of science and knowledge of the detailed characteristics of various technologies. It is an art which is still at a very early stage of difficult social learning process. There is a constant temptation to claim more for it than it can deliver, or to allow apparently scientific techniques to override informed judgment and common sense. Yet our world has become so interactive, with even trivial events and decisions having such a long chain of systemic consequences extending more widely than intuition or conventional experience would lead us to expect, that we cannot afford to depend on judgment and experience alone to develop intelligent policies for the development and use of new technologies, or the further diffusion of old ones. It seems likely that concern over the impacts of new or expanded technologies will increasingly preoccupy the industrialized countries and, in growing measure, the developing nations as well and they more and more seek to employ technology to accelerate their own modernization.

Both environmental impact assessment (EIA) and technology assessment (TA) have made a difference, but their impact on policy has not reached its potential, and in some instances, has probably been perverse. In the case of EIA as implemented under the EIS procedures of NEPA both public and private decision makers have been compelled to take a larger view of the consequences of their decisions and policies and to expose their decisions to a much wider range of constituencies and professional perspectives than fall within the scope of their traditional responsibilities. At the same time the EIA procedure has frequently been a source of delay and frustration to the proponents and managers of major technological projects, and has occasionally increased the cost and delayed the timing of such projects to a perhaps unnecessary degree. The quality of EIS's has steadily improved, but the problem of developing uniform and consistent criteria and standards has taken a long time and is still not fully solved.[20] The particular prominence assumed by EIA in the American situation owes a great deal to the unique role of judicial processes and the courts in the American political system. EIA and the preparation of an EIS might be a valuable tool in the Chinese situation, but would doubtless take a somewhat different form because of the differences in the political systems. Nevertheless, the notion of comprehensively considering the systemic effects of major projects is valuable and important in any political system.

As regards TA, there is a feeling that it has not yet reached its full potential as a tool of policy in part because there is still much to be learned about the proper interfacing between analyses and political decisions, particularly in the legislative context. Many observers feel, for example, that the Technology Assessment Board of the U.S. Congress should take a much stronger role in the translation of OTA reports into concrete recommendations for legislation. In addition there is a widespread feeling that the "early warning" functions of OTA as envisioned in the original act have not been fulfilled as successfully as was originally hoped.[21] In the Chinese context it is possible that the sharp separation between EIA and TA which exists in the U.S. would be inappropriate and that some blend of the two would suit China's needs better.

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TECHNOLOGY ASSESSMENT AND GOVERNANCE IN A TECHNOLOGICAL AGE: THE ROLE OF THE CONGRESSIONAL OFFICE OF TECHNOLOGY ASSESSMENT

John H. Gibbons

The world is not what it used to be. Over the past several decades human activities, by virtue of both size and the evolution of technology, have created a highly interdependent world. Actions taken in one place and time can affect events and conditions in many other places, over long periods of time. Most of these interrelationships are regionally confined, but many are international and even global. This reality contains both good and bad news. On the positive side, the evolution of technology has enabled billions of people to be better assured of unprecedented access to basic amenities such as food, shelter, health, mobility, and communication. But those same technologies have also fouled water, despoiled land, accelerated population growth, consumed resources in a way that is not sustainable, and uprooted social and cultural patterns. Technological advance has also brought forth awesome means of destruction. As the development and use of technology intensifies our global and intergenerational linkages, the need for more thoughtful anticipation and social guidance of the process also grows. Growing interdependence implies changes in the need for governance.

In the United States, where the assumption exists that more thoughtful analysis will improve the chance for wise decisions, there are several approaches to scientific and technological analysis:

Industry analysts apply their tools to the tasks of anticipating and identifying potential markets for new products and learning how to increase their competitiveness.

Public interest groups use analytic tools to estimate the various costs and benefits of activities that interest them (e.g., public projects, environmental regulations).

The National Science Foundation (NSF) supports research on methods of analysis of technology and its impacts, including attention to improved ability to project future developments that can arise from advances in science and engineering.

The National Academy of Sciences (NAS), including its academies in engineering and medicine, carries out a wide variety of studies, mostly for the Federal Executive Branch Agencies. These range in scope from highly focused studies of specific equipment to broad overviews (e.g., science and research policy) and require six months to four years to complete. The Academy reports represent the consensus--or lack of it--of an expert group. Typically NAS reports contain both findings and recommendations for action.

The Office of Science and Technology Policy (OSTP), located within the Executive Branch, also conducts studies related to technology. It draws mostly upon the resources of the other Executive Branch agencies. OSTP's work is generally not publicly available but is carried out and delivered to the White House for its consideration.

The Congressional Office of Technology Assessment (OTA) is the organization within the Legislative Branch responsible for studies in technology. The purpose of this paper is to review the purposes and activities of the OTA, as an example of U.S. efforts to improve governance.

OTA was established as an agency of the U.S. Congress in the early 1970's, after several years of debate, study, and discussion. Congress was in the wake of debates about controversial technologies such as the proposed commercial supersonic airplane and sensed that in the future such issues would become more frequent, more expensive, and more controversial. The process of receiving information and advice in public hearings from various interested parties was viewed as insufficient and increasingly confounding to Congress, as one "expert" after another provided conflicting claims. It was decided that Congress should have its own source of technical advice which was removed from special interests and advocacy.

OTA was charged with providing Congress with expert, unbiased, and timely information concerning the potential impacts of technologies, programs, and policies relating to science and technology. OTA's role is increasingly important as the United States relies more heavily on technological innovation to strengthen national security, foster economic growth, and assure human health and a healthful, safe environment. OTA's responsibility is two-fold: (a) to analyze current important issues in technology and policy--for example, air traffic control; nuclear and non-nuclear waste disposal; sustainability of agricultural production; air pollutant transport and control; and (b) to provide foresight on emerging issues--for example, the looming shortage of affordable, dependable, high-quality water; or potential impacts of continued technical advances in micro-electronics, genetic engineering, and robotics.

The Office is guided by a Congressional Technology Assessment Board of Directors (TAB) that consists of Senators and Congressmen who equally represent the Senate and House and both political parties. Rather than establishing broad analytic strengths throughout various House and Senate Committee staffs, Congress created OTA to act as a common analytical resource on socio-technical issues that could be shared by all Congressional Committees.

The choice of projects undertaken at OTA is largely determined by the interests of Committees. Most proposals are based on specific requests from one or more Committees, but TAB can also authorize projects on its own request, or at the request of the Director. Every major assessment must be proposed to and approved by the OTA's Technology Assessment Board before it can begin. Several criteria are considered in deciding whether or not to undertake a project. These include the following:

Is the subject associated with major federal expenditures?

Is there considerable controversy about the subject, with conflicting claims being made by different advocates?

Are the consequences of various choices irreversible or long lasting?

Can a study by OTA make a substantial contribution to the debate?

About two-thirds of OTA's professional staff are trained in science, engineering, mathematics, and medicine. The remainder have backgrounds in social and political sciences, finance, economics, law, humanities, and business. OTA is staffed with a sufficient number of professionals (about 90) to carry out 15-20 major studies each year using in-house analysis supplemented by contracted studies (e.g., universities, industry) and extensive external review.

This combination of in-house and outside contributions is very unusual and represents a form of participatory analysis that helps focus and raise the level of Congressional debate over pressing national issues. OTA has procedures which require routine checking of other institutions, both in government (Legislative and Executive Branches) and in the private sector to assure that OTA remains knowledgeable and takes the fullest advantage of the works of others. OTA synthesizes and integrates national wisdom about key issues and then translates and delivers this wisdom in ways that best meet the particular needs of Congress.

For example, in its work in disposal of high-level nuclear waste, OTA used many detailed studies and analyses (e.g., from NSF, NAS, U.S. Department of Energy) of various aspects of the problem (e.g.

solidification technology, geological sites, safety analyses). Only this thorough search enabled OTA to carry out its responsibility of providing a comprehensive, workable solution for the nation that takes into account not only the relevant science and technology but also incorporates appropriate federal, state, and local jurisdiction and assurances of public safety and environmental quality.

The most complicated and costly issues on our national agenda merit thoughtful analysis from different perspectives. Therefore, it is important that several independent studies be made of some issues. Because the studies take different approaches and usually deal with less-than-absolutely certain data, it should not be surprising that sometimes different studies have different, if not conflicting, outcomes. OTA's job is not to decide which is "correct" but to make it clear <u>why</u> the outcomes are different; to help the decisionmaker understand what his options are; and, as a consequence, to help improve the wisdom of public policy decisions.

The broad issue areas in which OTA works (e.g., resources, health, defense) change only very slowly, even though the specific subjects of assessment projects can change markedly. In response to this, OTA is organized into Programs that specialize in major issue areas. This helps OTA maintain a degree of institutional memory and expertise on certain issues and yet be able to accommodate the relatively high turnover rate of professional employees (about 30% per year) that is necessary to carry out projects that require different kinds of expertise.

Once a project is approved by the board, OTA assembles a project team consisting of (typically) 3 to 5 professionals. An advisory panel is drawn together to provide guidance and oversight. The panel consists of 10 to 20 individuals chosen to represent the points of view of the parties-at-interest. Members for the panels are drawn from outside the federal government. Some are technical experts; some are from business, others are from academia and public interest groups. The Panels meet several times during the course of the project (one to two years). Their role is to assure that the work is accurate, complete, objective, and free of bias. In addition to the advisory panels, OTA utilizes other individuals as contractors (e.g., to carry out a particular analysis) or temporary employees. When the study nears completion, additional individuals experts from both the public and private sectors are called upon to review and comment on the draft report.

While each assessment study is different, they all have certain characteristics in common. First, the relevant information is gathered and critically examined. This includes technological, economic, environmental, and social factors. Past and current conditions are studies to gain a perspective on what future conditions might be. The future is not predicted; rather the factors that can <u>affect</u> the future are identified and then used to project alternative or "conditional" futures. The impacts--good and bad--of the technology are examined in terms of their magnitude and identity of affected parties. Means are explored to take fullest advantage of the desired effects while minimizing the undesired impacts. The roles and influence of existing and possible new policies are then analyzed in order to provide Congress and the public with a carefully considered discussion about the full nature of the technology and the choices the nation has in dealing with it. The methods of analysis used by OTA are not unique, but the relative comprehensiveness of the studies, as well as the process of carrying out assessments and communicating the results, is unique.

The products of OTA assessment projects take a variety of forms and appear at various times during the process of the work. Early in the course of a study, the specific work is shaped by several forces including the expressed desires of the requesting Committees, the advice of the Advisory Panel, and OTA's own sense of what is--or will be--most important to think about. As work progresses, OTA provides briefings, memos, and testimony on the status of the work and any preliminary results that are pertinent to pending Congressional decisions. OTA is explicitly organized to make its agenda of work a matter of public record.

When the project is formally concluded with publication of the Report, it is delivered to the requesting Committees and all other Members of Congress. It is simultaneously released to the public and sold through the Government Printing Office. The print media usually report on OTA's work, and commercial publishers in the U.S. and abroad have reprinted and sold many of the Reports. Following release, and frequently for several years later, OTA continues to provide testimony, memoranda, and briefings on the issue to Congress.

OTA's responsibility is not to try to tell Members of Congress how or what to legislate but rather to provide the data that will help Members to make more informed judgements on issues related to science and technology. OTA does not recommend a specific legislative action; rather it seeks to clarify the issues, develop viable policy alternatives, and spell out the consequences of the various choices. Thus, OTA's most valuable contribution is to help Congress establish the terms of reference, narrow the focus of the debate, explain technical controversies that cannot be resolved with existing data, and distinguish what is feasible and factual from what is impractical and incorrect.

There are two broad categories of use of OTA's studies by Congress: strategic and substantive. In cases of strategic use, material is selectively drawn from the analyses that best sustain or reinforce the argument that is being made. Substantive use refers to situations where the findings of OTA analyses are directly used as a basis to change existing or proposed legislation. In either case, if OTA's analyses become part of the language of discourse in the Congress and at senior levels elsewhere in the government as major issues are addressed, OTA has done its job. Since OTA's studies generally focus on major, controversial issues, it is natural that other studies and analyses are also carried out elsewhere. Thus, it is normally very difficult to uniquely or quantitatively identify the particular impact of OTA's work on the legislative process.

Ultimately, a more interesting question is the following: Can objective, nonpartisan analysis and consensus development, such as practiced at OTA, have a permanent role in the political process--which by its nature is partisan and adversial? OTA's work to date tends to support the thesis that such an activity is helpful in the political process because it helps elevate the level of the debate. If so, then the cost of such work (in OTA's case, about one-thousandth of one percent of the federal budget) seems well worth the price, especially in an era when even small mistakes can have disastrous consequences.

Up to this point we have written about OTA's work in very general terms. It seems appropriate to illustrate this discussion with an example. We have chosen for this purpose to discuss our work on Energy from Biological Processes and, in a separate paper, our work on Biotechnology.

THE APPROACH TO THE SCIENTIFIC AND TECHNICAL POLICY OF ENVIRONMENTAL PROTECTION IN OUR COUNTRY

Guo Fang and Peng Tianjie

The environment and natural resources are the basic conditions on which the human race lives and are material sources for developing production and a prosperous economy. The pollution and destruction of the environment is a new problem which occurs with the development of modern agriculture and industry. A fundamental task of modern construction is to manage the environment of our country and to rationally exploit and use natural resources.

The settlement of environmental issues needs manpower, material resources, scientific technology, the common effort of all trades and professions, and everyone's concern and cherishing; but fundamentally, it needs national environmental policies and prompt and effective measures. The content of the environmental policy is many-sided, it involves administrative policy, economic policy, educational policy, scientific and technical policy, and so on. The scientific and technical policy of the environment is very important in the settlement of environmental issues, since the state uses it to organize scientific and technical strength and adopts the best scientific and technical line and the policy of technical economy to deal with environmental issues. Now, taking the settlement of the problem of atmospheric pollution for example. At the beginning, our objective was the elimination of smoke and dust in existing furnaces, with the encouragement of policy, the broad masses of scientific and technical workers thought of many methods and achieved certain success; but people gradually discovered that improved furnaces had less pollution or even no pollution at all, while many unimproved furnaces with pollution were turned out and put into use. Obviously, the problem of atmospheric pollution could not be settled in this way. Therefore, the state announced that the new furnaces, which did not cause atmospheric pollution, should be produced, and that the furnaces, which pollute the environment, would not be permitted to be produced. Those furnaces, which do not conform to the quality standards of products set by the state, would not be allowed to leave the factories.

Atmospheric pollution is mainly caused by fuel combustion. The people further realize that we should ultimately consider the structure of energy, and we should have a scientific and technical policy encouraging and arranging scientific research work on energy which creates little or no pollution. Consequently, studying the origin and development of each country's scientific and technical policy of environmental protection, and drawing from it the experience and lessons which are useful to us, is an important scientific research task with strategic significance. This article attempts to approach the important issues on the scientific and technical policy of environmental protection in our country and to give some views and suggestions.

BASIC REQUIREMENTS FOR THE DEVELOPMENT OF ENVIRONMENTAL SCIENTIFIC RESEARCH IN OUR COUNTRY

The scientific and technical policy of environmental protection in our country is gradually defined and perfected on the basis of environmental guiding principles and policies. The basic requirements for developing environmental scientific research in our country are:

First of all, the correct aim of settlement of environmental issues is needed: we had a process of cognition for this matter, with the industrial development of our country, the harm of the industrial "three wastes," waste, gas, waste water, and waste residues, was gradually realized by the people. Therefore, at the beginning of the 1970s, many provinces, municipalities, autonomous regions and factories, mines and enterprises began to set up offices for the "three wastes." We took charge of the disposal of individual events. We assumed that the environmental issues would be settled as long as the "three wastes" had been harnessed. The environmental aim then was small local environment, one technique, one workshop, and one factory. The practice of many years shows that to take charge of the disposal of the "three wastes" alone cannot completely settle the problem, that means our environmental aim should be enlarged. Consequently, since the middle of the 1970s, we have begun to pay great attention to the regional environment and to stress regional comprehensive prevention and control. The result is fairly obvious. At the end of the 1970s and the beginning of the 1980s, the people further realized that the scope of the destruction of the ecological environment caused by improper activities of agricultural production is also very broad, the whole country should be regarded as a whole. The whole country is a big environment; we should consider issues from the ecological balance of the whole nature; the whole country's resources and ecological environment should be well protected. Then, the aim of environmental studies is clearer. The scientific and technical policy of the environment is just for the realization of this stragetic aim.

Secondly, the major direction of environmental scientific research would be needed: the major direction of environmental scientific research is not the same because of different realization of the environmental aim. At the beginning of the 1970s, the major direction of scientific research was single control technique, for example, the improvement of furnaces; in the middle of the 1970s, the direction was comprehensive prevention and control techniques and the environmental quality assessment; while in the 1980s, the workers of natural science and social science make common efforts to deal with certain environmental problems. We consider matters emphatically from the ecological balance and the environmental realignment.

Thirdly, we need a certain amount of specialized research institutions on environmental science. For over the last ten years , and especially in recent years, a certain number of environmental research institutions which have particular emphases have been gradually set up. They can be roughly divided into four systems:

1. Academia Sinica As early as the 1950s, the research institutions of water and soil conservation, and forestry and soil, as well as the committee of comprehensive investigation of the natural resources of the whole country were set up within Academia Sinica. They laid down a foundation for the investigation of our country's natural resources and the protection of the natural environment. At the beginning of 1975, the Institute of Environmental Chemistry was also specially set up by Academia Sinica in order to meet the needs of environmental work. Furthermore, there are some research divisions and groups of 26 institutes in Academia Sinica, which engage in environmental studies. Their work contents integrate with practice, and they pay particular attention to applied foundations and new techniques. In order to strengthen the scientific direction of the whole Academy's environmental science and the inter-institute coordination of the scientific research work, the Committee of Environmental Science of Academia Sinica was set up in 1980, according to scientists' advice.

2. Research Divisions of Universities From the 1970s, Beijing Normal University, Zhongshan University, Tongji University, Beijing university, Qinghua University, Nanjing University, Shanghai Normal University, Beijing Medical College, Nankai University, and more than a dozen other universities and colleges all set up special research divisions of certain branches of environmental science, or engage in scientific research of some aspect, and some of them set up research institutes of environmental science. The stress of their work is basic theory and engineering. Emphasis is on environmental education and the training of talents.

3. The environmental protection system Since the 1970s, the environmental protection system from the State Council to the provinces, municipalities and autonomous regions all have established the research institutes of the environmental protection or the monitoring stations, in order to deal with the local problems of environmental protection. The Beijing Municipal Research Institute of Environmental Protection was established earlier, and its research capability, especially for waste water treatment, is comparatively

strong. Furthermore, the Shenyang Municipal Research Institute of Environmental Protection, the Shanghai Municipal Research Institute of Environmental Protection, the Hunan Provincial Research Institute of Environmental Protection, and the Gansu Provincial Research Insitute of Environmental Protection also have certain scientific research capabilities. The large part of this system's efforts concentrates on the investigation of environmental quality, pollution prevention and control, and environmental monitoring. There are now more than 600 environmental monitoring stations. Since 1979, the China Environmental Science Research Institute and the General Environmental Monitoring Station of China have been prepared.

4. The system of government ministries and commissions: Ministries of industry, agriculture, and communication as well as big enterprises all command the research institutes of environmental protection. Early in the 1950s, the work of the sanitation and antiepidemic stations, which belong to the Ministry of Public Health, involved a lot of the environmental work. The beginning of the establishment of the observational stations of the departments of meteorology, water conservancy and geology is earlier than that of the environmental system. These monitoring stations are fairly large in scale. There are 156 monitoring points within the river system of the Yangzi River alone. The specialized research organs are established by some large enterprises in order to deal with the environmental problems in their own industries.

Fourthly, a contingent of scientific and technical workers, which engages in the research of environmental issues of all aspects, with certain amount and quality is needed. Academia Sinica has preliminarily formed a comprehensive contingent of multidisciplinary environmental research. There are nearly 800 scientific and technical workers who engage in the scientific and technical research work of environmental chemistry, environmental biology, environmental geography and environmental acoustics, etc. There are also several hundred persons in colleges and universities who engage in environmental education and scientific research work. Since 1977, the graduates of the specialty of environmental science have been distributed to every front of endeavour every year. There are several thousand scientific and technical workers in organizations of the environmental protection system from the central government to the county level. There are also some thousand environmental scientific and technical workers in all ministries and commissions. According to incomplete statistics, our country already owns an environmental scientific and research contingent with about 5,000 persons.

Fifthly, we should prop up and develop environmental science as a new and developing discipline.

The practice of the past ten years of our country shows that in order to solve environmental problems, we should carry out a lot of scientific research work in various areas. Therefore, the workers of geography, chemistry, biology, physics, mathematics, engineering techniques, economics, science of law, and sociology all use the theory methods, techniques and knowledge of their own disciplines to solve some environmental problems and to infiltrate environmental science. Thus in our country, a new and developing, highly comprehensive environmental science, which includes some branch disciplines of social sciences, is developing vigorously. Some workers of natural sciences and social sciences are studying these new disciplines in theory, for example, the concept, objects, category, methodology and branch disciplines of the environmental science are studying. The state takes all measures to promote the development of environmental science, for example, to establish special research organs, to ensure a certain number of people, equipment and funds, and to establish the Chinese Publishing House of Environmental Science.

Sixthly, the environmental scientific research work needs both long-range plans and short-term arrangements of plans. The proper proportion of basic research, applied research and development should be maintained. At the National Meeting on the disciplinary program of natural sciences held in 1977, the scientists of Academia Sinica and univeristies and colleges jointly mapped out the first ten-year developmental program for environmental science in our country. In 1978, the National Commission of Science and Technology took charge of working out "the National Developmental Program of Sciences and Technologies during the period of 1978-1985," in which there was a special item about the development of environmental science and technology, and made arrangements for basic research, applied research, and developmental work. The content of environmental engineering was also placed in the item of technical science of the program. It pointed out: "Within eight years, a fairly comprehensive system of environmental engineering in our country will be established preliminarily to develop environmental engineering in our country." The state allocates a certain amount of funds to environmental scientific and technical research every year.

Seventhly, the popularization of environmental scientific and technical knowledge: environmental protection not only needs a lot of environmental scientists, but also needs broad masses. Only when the masses have grasped environmental scientific and technical knowledge, and everyone has set to work and has cared for it, can the objective of environmental protection work be really realized. At present, many departments and units are still short of environmental scientific knowledge and ecological viewpoints. This is a main reason for which the environmental protection work cannot be successfully carried out. This also shows the importance of the propaganda and popularization of environmental scientific and technical knowledge. The state has established environmental protection schools in Qinhuongdao and Changsha and has conducted the cadre training class many times. The Chinese Society of Environmental Science was set up in 1979. The commissions of scientific propaganda and environmental education were specially established within the society. Some journals of scientific propaganda, for example, the "Journal of Environmental Protection," the "Journal of Environment," the "Journal of Environmental Pollution and Prevention," and the "Journal of Nature," are published in all parts of the country. Scientific propaganda work is being carried out.

2. Several items of Important Economic and Technical Policy of the Environmental Protection

With the summary of many years' practice of our country, we think that the following ten items of economic technical policy of environmental protection are very important to the good settlement of environmental issues.

Carry out the research of the rational distribution of industry, agriculture, and forestry with the combination with the territorial realignment and the construction of cities and the countryside:

The task of the territorial realignment in our country is to comprehensively investigate territorial resources, to map up plans and to comprehensively exploit, use, control, and protect the territory. One of its aims is to ensure that the forests, grasslands, farmlands, waters, and cities will no longer be polluted and destroyed. In order to realize this aim, to enable coordination the environmental protection and the economic development and to establish an environment with ecological balance, developed production and pleasant life, the state is organizing the comprehensive research organs of geography, economics, ecology, environmental science and natural resources to carry out investigations and to put out the scientific and technical policy and organizational measures which suit our national conditions.

The distribution of the construction of cities and the countryside should be more rational. The improper distribution of industries in our country and the arbitrary construction of factories regardless of the environmental conditions are one of the causes of environmental pollution. During the initial post-liberation period, large-or medium-sized enterprises in our country basically concentrated in large-or middle-sized cities. The high concentration of the population added pound to the environment of cities, at the same time, it also formed the pernicious concentration of pollutant sources. Later on, in order to develop the inland industries, some large enterprises were established in canyons of mountain areas, thus causing the smoke of factories to be difficult to diffuse which resulted in water source pollution. The very rapid development of the enterprises run by communes and production brigades also caused the transfer and diffusion of pollution and destroyed the ecological environment. The environmental policymakers have realized the importance of the rational distribution of functional regions and have taken measures. For example, seven chemical plants in the city Jinan, Shandong Province, which were situated in the windward of the urban district and on the upper reaches of water sources, have been changed for their products, therefore, the pollutant destruction of the chemical enterprises in the urban district has been basically received. 236 plants of electroplating in the city of Shenyang have been merged into 120 plants. These examples show that the rational distribution must be taken as an important scientific and technical issue which should be studied early. The development of village towns as well as the development of newly built cities, residential areas, industrial and mining districts or other large projects shall be comprehensively programmed and rationally distributed by reference to the local features of the natural geography. On the long-term point of view of the overall situation, prejudged assessments of the environmental effects should be made by analysis of profit and loss, thus to draw up the best program which aims to protect the environmental resources and to develop production. This is an important policy of sciences and technology. Therefore, we carry out more and more scientific research work in this aspect.

2. Control industrial pollution by technical reformation, renewal of equipment and improvement of process

There are now more than 400,000 factories, mines, and enterprises in our country. Only 20% of them are with advanced equipment and techniques, the enterprises, which are with general equipment and techniques account for 30%, about half of them are with old equipment and techniques. The consumption of energy and raw material is high, while the quality of products are poor. There are a lot of pollution problems. The general utilization ratio of energy in our country is less than 30%. According to the survey in more than 200 enterprises under the Ministry of Chemical Industry, one-third of the raw material, which is put into production, is converted into products, the other two-thirds is turned into "three wastes" and is discharged into the environment. Therefore, the technical reformation, rental of equipment and improvement of technique in enterprises are fundamental ways both to increase production and to improve the environment. Taking Shenyang Chemical Plant for example, after the first national meeting on the environment held in 1973, the plant began to pay great attention to environmental protection. It has achieved remarkable success. It was named the "Advanced Unit of the Environmental Protection of Liaoning Province" by the Government of Liaoning Province in August 1981. The following are its concrete practice: 1) renewing the old equipment and carrying on the technical innovation. Three well sealed bleaching powder machines, which hermetically produce and each only covers 12 square meters, are made by itself. An old absorption column, which is 22 meters high and with a diameter of 5 meters, and covers an area of 120 square meters, has been removed, and the chlorine content in waste gas has been reduced from 0.5% to 0.02%. The hydrochloric acid produced before was packed by ceramic pots, thus the acid gas spread everywhere and affected workers, staff members, and local residents. More than 3,000 tons of hydrochloric acid were lost each year before. During the period 1974-1975, they built an 800 m^3 large tank of reinforced concrete with glass fibre reinforced plastic lining, and used wax to cover the surface of hydrochloric acid and applied the hermetic tank car to transport hydrochloric acid. So that the pollution problem has been resolved. 2) Innovating the productive process, reducing the consumption and saving energy. In the past, the tail gas, which was produced from the process of hexachlorocyclohexane, was absorbed by a film absorption column. The ratio of absorption was only 30-40%, 2% of the chlorine, which did not join in the reaction, was lost with waste water, and polluted the sewer and the air. In order to perfect the technical processes, one stop of absorption has been changed into three stops of absorption, the ration of absorption has reached more than 99%, the acid content in the sewer stream has been reduced to zero. Therefore, they not only completely eliminate the pollution of the tail gas, but also recover more than 4,000 tons of hydrochloric acid from the sewer and the air every year. The recovered hydrochloric acid is worth more than 100,000 yuan every year.

Furthermore, the new technology, such as the electroplating without cyanogen chromium-plating without discharge chromium, antichromium fog agents in the electroplating industry and moulting with acid in leather industry, have been spread and applied by many enterprises.

3) Putting prevention first, developing new techniques and processes with little or no pollution. The stipulations of our country on that in planning new construction, reconstruction, and extension to construction, as well as in innovational construction tapping the latent power of old enterprises to increase the productive capabilities, the installations for the prevention of pollution and other hazards to the public should be designed, built, and put into operation at the same time with the main project ("three same time"). This is an important policy of preventing the development of pollution and controlling new pollutant sources. It reflects the policy of putting prevention first, just as the sanitation department handles diseases.

The practice of many years shows that the correct policy is gradually accepted by the people. For example, of 308 large or medium-sized projects newly built in 1977, 132 projects basically implemented the stipulation of the "three same times," they accounted for 42.8% of the total; the percentage increased to 53% in 1980, and 66% in 1981. The large or medium-sized construction in Beijing, Shantong and so on, which was put into production in 1981, all implemented the stipulation of the "three same times." There are some reasons in science and technology besides the reasons in management, for which a few enterprises are still unable to implement the "three same times." Therefore, the research on new techniques and processes with little or no pollution and harmless treatments should be carried on. Great attention should be paid to the replacement of the toxic and harmful raw material by the harmless raw material with low toxicity. Government at all levels should make a certain investment each year to support the scientific research work in this aspect. For example, the process with mercury is applied in soda manufacturing industry for a long time, and the mercury pollution is serious. The Institute of Organic Chemistry of the Academia Sinica and other units have successfully prepared a new process for soda manufacturing without mercury which has been put into practical production in the soda industry. Another example is the Calcium Carbide Plant of Jiling Chemical Industrial Company which applies the alkali-chlorination method to treat the waste water containing cyanogen. Thus the cyanogen decreased to less than 0.5 mg per kg. and that is in accord with the standards of discharge.

4) The comprehensive prevention of regional environment. Environmental pollution generally has obvious regional features. The concrete measurement of comprehensive prevention of regional pollution is to base the environmental quality assessment on the overall investigation of the regional environment, the main pollutant sources,

pollutants and environmental problems. Then, to counter these problems, research of the comprehensive prevention of the regional environment is launched. Now, take the regional work of Beijing, Tianjin and the Bohai Sea, which is carried on with the organization of the Environmental Sinica Committee of Academia Sinica, for example. Since 1972, Academia Sinica has cooperated with a lot of units to jointly carry on a series of regional environmental works, such as: research on the protection of water resources of the Guanting river system, Baiyangding, and Ji Canal; research in preventing the pollution of the Bohai Sea and the Yellow Sea; the investigation of oil pollution in the northern part of the South Yellow Sea; research on the environmental quality assessment of the west suburb of Beijing; the research on the comprehensive prevention of environmental pollution in the southeast suburb of Beijing; research in the comprehensive assessment of the environmental quality of the city of Tianjin and its Hedong District. Since 1980, under the support of the National Committee of Sciences and Technology and the former Office of the Environmental Protection Leading Group of the State Council, and on the basis of the above scientific research work, the Environmental Sinica Committee of Academia Sinica has organized more than a dozen institutes and more than 200 scientific and technical workers within the disciplinary areas of geography, biology, chemistry, physics and new technology to cooperate with the concerned departments and the localities to carry out research in the comprehensive prevention of the regional environment of Beijing, Tianjin, and the Bohai Sea. It has been found that the pollution of the aquatic oxygen-consuming organisms in the region of Beijing, Tianjin, and the Bohai Sea is a main and popular pollutant; the pollution of heavy metals is a secondary and partial one. Research on the relation between water resources and the environment in the region of Beijing and Tianjin has been finished, and six new techniques for industrial waste water treatment have been put into effect. In the area of air quality research, the 325 meter high meteorological tower , which is the highest one in Asia, and the automatic remote monitoring system have been established. The temperature measuring system of acoustic radar and the hypervelocity wind gauge have been developed. The purifying technique of the waste gases of NO_x and acelylene dioxide in factories has been raised. The comprehensive analysis of the energy resources and air pollution in the region of Beijing and Tianjin has been conducted. Two comprehensive field experiments of the atmosphere in Beijing have been carried out before and in the heating period. It has been found by applying the new measuring approaches such as the high-altitude balloon, that the zinc, lead, and sulfur in the atmospheric dust of Beijing and Tianjin mainly comes from human activities. In the area of pollution ecology, the environmental purification capacity of heavy metals has been studied. The test of cadmium effect on the photosynthesis of the rice leaf has been conducted. In the aspect of pesticide pollution, BHC is the main pollutant of the environment in the region of Beijing and Tianjin. The research in the background of certain elements in the soil of the region of Beijing and related phenological observations have been conducted. The maps of the soil types and vegetable types have been drawn. The analysis of the environmental function of the nearsuburbs of Beijing has been conducted. The separate areas with potential function of the human exploiting activities have been determined. Since the city noise standards and its measuring standards based on our research have been formulated, the noise management has been strengthened, and the city traffic noise of Beijing has been reduced to some extent. In order to work out the city construction program and to improve the environment, it is advised that:

a) Nearly half of the atmospheric dust comes from the soil and the sand blown by the wind, the other half is the result of human activities. In order to improve the environment, the elimination of smoke and dust, the afforestation of barren hills and the enhancement of city management should all be combined.

b) The tree species of preventing pollution and afforestation with high sulfur absorptivity and great ability of obstructing dust should be selected.

c) According to the investigating result of the water quality and quantity in the region of Beijing and Tianjin, the water sources should be divided into three management areas: the water source protection area, water pollution control area, and water quality harnessing area.

By the comprehensive prevention and control work of the Guanting Reservoir in the past seven years, the average contents of the toxic materials in the water do not exceed the standard. This means that the water quality of the reservoir is generally good.

The work of preventing and eliminating the pollution in the Bohai Sea and the Yellow Sea has achieved initial results through the effort of more than two years. At present, the oil pollution has basically been controlled. The floating oil of large areas in the north of the South Yellow Sea has basically been eliminated. The water quality of Liaotong Bay, Bohai Bay, Laizhou Bay, and Jiaozhou Bay, where the oil pollution has been relatively serious, has now been considerably improved.

5. Encourage the Study on the Natural Purification Capacity. There are physical, chemical, and biological effects in nature which can dilute and disperse pollutants so that their concentrations are reduced to a level that is not harmful to man. It is also possible to turn them from toxic substances into nontoxic ones by changing their existing state or chemical properties. Physical purification effect: for example, a strong air stream can disperse SO_2 emitted from a point source (stack), thus lowering its concentration. Chemical purification effects include chemical reactions such as combination, decomposition, complexation, adsorption, evaporation, precipitation, oxidation and reduction in the air, rivers, lakes, seas, and soil. It can restrain the activity of pollutants or reduce their toxicity. The biological purification effect is a very active factor. Some microorganism, algae, bryophyte and higher plants have the capacity to purify pollutants to a different extent. And they can conserve water and soil, regulate the climate, pretify the environment, reduce noise, etc. Some animals can also purify the environment. For instance, the

earthworm cannot only turn acidic or basic soil into neutral soil, but also can turn complex toxic substances into simple and nontoxic substances that can be absorbed by crops.

Since these purification capacities of different kinds and different approaches exist, we must make full use of them. In accordance with our country's situation, it is not practical economically to solve environmental pollution entirely by relying on technical measures for the treatment of the "three wastes." Therefore, we should make full use of the natural purification capacity as an important component of the policies in environmental science and technology and combine it with technical control of pollution. The two then complement each other while achieving double results. It has been suggested that the three measures, i.e. treatment by waste treating plants, land disposal and self purification of the river should be organically combined in water treatment. We think this is a good suggestion. In so doing, investment and energy consumption will be saved. This should be considered as an important policy of the country.

The study on the dilution and self purification capacity of the river is a topic which should be dealt with urgently in the protection of water sources. The biggest project which has ever been carried out in the study of the dilution capacity of a river is the investigation along the Zhenjiang section of the Changjiang (Yangtze) River made in 1975. Some studies and explorations have been made on the laws of self purification of organic pollutants in certain river sections, such as in rivers in the outskirts of Beijing, estuary of the Changjiang River at its lower reach, Lanzhou section of Huanghe River (Yellow River), etc. At present, the study on the self purification capacity of the river is being carried out so as to determine the maximum permissible carrying capacity and to formulate reasonable environmental standards.

The Institute of Hydrobiology, Chinese Academy of Sciences has succeeded in treating waste water containing organic pesticides by adopting biological purification methods with oxidation ponds in Yaer Lake. This method does not consume electricity and does not need operation fees, thus 3.06 million watts of electricity and 2.10 million yuan of transportation fees are saved every year. Only a small amount of fees for repairing the dikes is needed. After being purified, the water of the lake can be used for fish breeding and irrigation. Every year 250,000 kilograms of fish are produced, and there is an increase of 15,000,000 kilograms in grain output.

6. Strengthen the Study on Environmental Administration Science, to Promote Control By Administration. We regard environmental administration science as an important subdiscipline in environmental science. It includes environmental policies and systems, environmental monitoring, enviromental standards, environmental evaluation, environmental economics, environmental law, etc. Since the middle of the 1970s, we have strengthened the research work in this area, e.g. the study on the environmental administration system, the study on the standardization of environmental analytical methods, the study on environmental quality evaluation and predication, the

study on basic environmental laws and various specific laws (on water, air, soil, forest, mineral resources, etc.), the study on environmental economic effects and so on. Based on a lot of scientific research, THE ENVIRONMENTAL LAW OF THE PEOPLE'S REPUBLIC OF CHINA (for trial implementation) was promulgated in 1979 and in the Constitution of our country, there are articles on the protection of the environment. The promulgation of the Environmental law is an event of great significance in the history of our country's environmental protection cause. It is a basic law which specifies the tasks, guidelines, policies, sphere of work and organization of environmental protection in our country. It points out that the State Council and its subordinate bodies, and the local people's governments at all levels shall make overall plans for the protection and improvement of the environment in planning for national economic development and take practical measures for its implementation; where pollution of the environment and other hazards to the public have already been caused, plans should be worked out to eliminate these in a systematic and orderly manner. Environmental protection is then no longer a general call or persuasion, but is guaranteed by the law thus entering the stage of legal control. In order to implement the decision made by the Central Committee of the Communist Party of China and the Environmental Protection Law, to educate the cadres and mobilize the masses to do a good job in environmental protection, the State Council and the department concerned approved the activity "National Environmental Protection Propaganda Month" which was carried out twice in March 1980 and 1981. Leaders in most of the provinces, municipalities, and autonomous regions did propaganda work during the month. They went to grass-roots levels to make investigations and to advance environmental management work. In February 1982, the State Council issued a notice stipulating that emission fee regulation be implemented in the whole country, and also concretely specifying the standards for the collection of emission fees, the sources of funds, and the use of emission fees. In May 1982, the Ministry of Rural and Urban Construction and Environmental Protection was established.

The strengthening of environmental administration has direct practical significance in enhancing the control of three industrial wastes. An investigation of some heavily polluted industries, such as the chemical industry, metallurgical industry, and light industry shows that 50% of the pollution problems can be solved through scientific management of the environment. For example, the well-known Jilin Chemical Industrial Cooperation has rectified the enterprises and waged a campaign to create non-leakage sections, workshops, pipelines, factories and mines, thus reducing the pollution of hazardous substances to the environment. The percentage of the equipment in good condition increased from 49% in 1977 to 95.3% at the end of 1980. The leakage rate at the static sealing points was reduced from 0.7% to 0.04%. Of 63 chemical workshops, 60 have met the standards set for the non-leakage workshops. The Calcium Carbide Factory became a non-leakage factory in 1979, and furthermore in 1980 by improving the sealing of machines, leakage was less than 0.05% in the Dyestuff Factory, the Chemical Plant, the Oil Refinery, and the

Reagents Factory. After being checked, they are named as "non-leakage factories." Their environment has greatly improved. It is the same with some cities. For instance, scientific management has played a big role in the improvement of the environment in Shengyang and Suzhou.

Comprehensive Utilization of Resources There are many paragenetic minerals and lean ores in China. The comprehensive utilization of resources can reduce wastes and pollution and is of special importance to the protection of the environment. Since 1952 the Changchun Institute of Applied Chemistry, Chinese Academy of Sciences has carried out research on the extraction, separation, analysis and application of rare earth elements contained in the iron ore in Baotou. Many results have been applied to industrial production.

On the basis of scientific research, the Baotou Iron and Steel Mill has applied the flocculation process in ore dressing. With this process, 80% of fluorine can be collected, pollution is greatly reduced and resources are used. Research has also been made on the rare and noble metals in the nickle ore in Jinchuan and titanium and vanadium in the iron ore in Panzhihua. A comprehensive utilization of resources has been achieved. The state encourages the comprehensive utilization of resources and makes sure that a certain amount of funds and equipment are put into it.

Industrial "three wastes" are actually waste of energy and resources. The fundamental approach to eliminate pollution and protect the environment is to make use of energy and resources comprehensively to the fullest extent. The control of the "three wastes" in old enterprises must be combined with comprehensive utilization. Our country has organized on a wide scale the prevention and control of industrial pollution with comprehensive utilization and conversion of hazard into benefit as the main content and has achieved good results. The total value of the products from comprehensive utilization is more than 800 million yuan in 1980. Over 50,000 tons of non-ferrous metals, noble metals and rare recovered every year. More than 800,000 tons of sulfuric acid are produced every year by using a high concentration of SO_2 recovered from non-ferrous metallurgical plants. Take the metallurgical industry as an example. If we do a good job in making use of large amounts of resources such as associated metals, waste energy, industrial water, sulfur dioxide, metallurgical slag etc. we will not only reduce pollution but also provide more noble and rare metals such as vanadium, titanium, cobalt, nickle, rare earth, niobium, platinum, palladum, and other metals and non-metal resources for the modernization of our country and for the accumulation of capital. The methods are:

1. Raise the efficiency of comprehensive utilization and minimize the loss of metals;
2. Make full use of waste and lost energy, reduce the consumption of fuels and cut down the emission of pollutants caused by the burning of fuel;
3. Raise the utilization ratio of sulfur in non-ferrous metallurgical plants so as to increase the production of sulfuric acid and minimize the hazard of SO_2;
4. Reuse of industrial water by recycling;

5. Fully recover dust and sludge containing iron to increase the raw material for iron and steel production;

6. Comprehensive utilization of metallurgical slag.

Take the coal industry for another example. Large quantities of gangue produced in coal mining have caused waste of energy and pollution. It has become a serious environmental problem. According to statistics, more than 1,000 million tons of gangue have been piled up in our country. Since coal will continue to play a main role in China's energy structure, the coal industry will keep on developing. Therefore, the research on the comprehensive utilization of gangue becomes an important part of our country's policies on environmental science and technology. Comprehensive utilization of gangue has been developed in many mines such as the Jiaozuo Mine in Henan Province. In Nanpiao Mine which has made outstanding achievements in this respect, over 3 million tons of gangue have been utilized with a value of 62 million yuan and a profit of 17 million yuan. The types of utilization are:

1. Extract chemicals from gangue;
2. Use gangue as fuel with low heat value;
3. Use gangue in the building material industry.

Energy Policy for Reducing Pollution

The characteristics in the utilization of energy in China are:

1. Coal consumption makes up a large percentage of the total consumption of energy. In 1978, coal composed 70.9%, petroleum 22.4% and hydroelectricity 3.5%. Furthermore, over 80% of the consumption is the direct burning of coal in various furnaces and boilers. This is not good for the prevention and control of air pollution;

2. The average consumption of energy per the population and area of the country is low. It will increase in the future;

3. The distribution of energy resources is uneven geographically. In areas that lack energy, energy sources will be developed.

4. The energy consumption rate of industrial equipment is high. There is the potential for saving energy and eliminating pollution;

5. There are many small and dispersed coal-burning stoves which are important pollution sources in cities and towns;

6. The oil consumption rate of automobiles is high and the amount of pollution caused by their emission is large;

7. Rural areas mainly depend on biological energy sources and consume very little commercial coal and oil. Biological energy sources include plant stalks, firewood, human and animal excrement amounts to 290×10^{16} tons every year. China is the first in the world to popularize biogas on a large scale. By 1978, 35 million people mainly depend on biogas for fuel in daily life.

According to our country's circumstances, coal consumption makes up a very large percentage of the total energy consumption in the past, at present and also in the future. (It is higher now than that in Japan, West Germany and the United States as well as the average of the world.) Therefore, it is of special importance to carry out the scientific research on coal resources. The Institute of Coal Chemistry, Chinese Academy of Sciences was set up in the early 1970s, which is a special institute working in this area. The Institute of Environmental Chemistry, Chinese Academy of Sciences is working on the analysis of various pollutants emitted during the burning of coal. Our strategies are:

a. Take technical measures to eliminate smoke and remove dust, e.g. to improve the combustion techniques of boilers, to make use of surplus heat, radiator heating, central heating, combined production of heat and electricity, gasification of coal, cleaning of coal with low sulfur content and ash first to people for daily use (mainly urban residents). The techniques of industrial boilers in our country are backward. They waste a lot of fuels and seriously pollute the environment. The state has decided to renew and renovate these boilers. A 10 year renewal programme has been worked out. Research, trial production and manufacture of new boilers will be enhanced. Boilers needed for renewal will be put into the plan of the state and arrangements will be made for this production. From now on central heating systems will be installed in the newly-built industrial and residential areas;

b. In rural areas there are certain experiences in biogas generation. It should be further popularized. It has been planned that by 1990 the number of biogas pits will be increased to 20 million. The biogas produced will make up 5% of the total energy consumption in daily use in China's rural areas. In addition, trees should be planted on a large scale, firewood sources should be increased and stoves that save firewood should be popularized;

c. Since China is a very big country and conditions in different areas vary greatly, in some areas electricity can be generated by making use of hydraulic power, terrestrial heat, high-speed wind, tide. Solar energy can also be developed. China's energy policy is that development and economization are of equal importance. The emphasis of development in the future will be placed on hydroelectric power. In the rural areas where there is hydraulic power, hydroelectric power stations should be developed so as to reduce environmental pollution.

8. Comprehensive Control and Rational Utilization of Land Resources China is a populous country and land resources are scarce. The land use situation is as follows:

Use	Area (Km_2)	Percentage of Total
Cultivated Land	1,000,000	10.4%
Pasture	3,560,000	37.2%
Desert, Barren, and glacier of high mountains	1,720,000	17.9%
Forest	1,220,000	12.7%
Terrestrial Water	380,000	4.0%
Urban and Transportation	670,000	6.9%
Others	1,040,000	10.9%

About the utilization of land, there are five environmental problems in general:

1. Increase in population and extention of cultivated land.
2. Damage of vegetation and erosion of soil. For example, the middle reaches of the Yellow River has most serious soil erosion. In some areas of the southwest, soil erosion has also appeared as a result of over cultivating.
3. Degeneration of pasture and deserting of land. Some northern pastures are deserting by over herd and, unchecked cultivating. Some pasture areas are reducing, degenerating, deserting and alkalifying.
4. Secondary salting out by misusage of land.
5. Conservation and rational utilization of seashore and its resources.

To control the soil erosion, to conserve and rationally utilize land and water are the principal measures, which can improve features of mountainous areas, hilly areas, and windy and dusty areas, can establish balanced ecological environment, can promote production, and can raise living standards. Party and government pay great attention to the conservation of land and water, and set out a policy which includes paying equal attention to conservation and rehabilitation and integrating recovery and maintenance.

The Scientific Academy of China strengthened studies on land and water conservation, and established the Institute of Land and Water Conservation in Northwestern China. Government recovered the Commission of Land and Water Conservation of Middle Reaches of the Yellow River. More than 290 units responsible for land and water conservation, such as the Land and Water Conservation Agency, the Land and Water Conservation Institute, and the Land and Water Conservation Stations have been rebuilt and new built in provinces, counties, and other local areas. Now, the research work on land and water conservation is one of the most important items in the national scientific programs. Relating units at all levels carry land and water conservation as an important task.

In February 1979, the National Scientific Committee, Department of Agriculture, and the Department of Water and Power convened a conference on the conservation of land and water in clay plateau areas, and on unified development of agriculture, forest, and animal husbandry. In September, the Water Conservancy Committee of the Yellow River convened a conference on land and water conservation of the middle reaches of the Yellow River. In April 1980, the National Scientific Committee, National Agricultural Committee, and Scientific Academy of China convened a symposium on integral control of the soil and water loss at clay plateau areas. This symposium promoted combining biological measures and engineering measures.

In order to prevent and control land deserting, the Scientific Academy of China especially established the Institute of Desert. This institute carries on a series of studies about the desert, and proposed different control measures in three kinds of deserting areas:

1) In potentially deserting areas, which are half humid and spread some individual sand dunes, should act in accordance with the

local special natural laws, protect the ecological system strictly, control the utilization ratio of land, and prevent the damage before it happens.

2) In half arid pasture and deserting barren, except protect the existing natural vegetation and facilitate revegetation in deserting barren and discarded farmland, should also establish a stable agricultural system which combines the agriculture and forestry, i.e. establish a series of forest belt net. Beside this also should establish artificial livestock raising bases, to reduce the burden of pasture.

3) In areas which have deserted and sandy deserts have been stable or half stable, should use the land and water resources rationally, fix moving sand dunes by plantation and establish a protection system of oases.

In order to control the soil pollution caused by pesticides and chemical fertilizers, we have decided to stop the use of organic chloride pesticides, such as hexachlorocyclohexan (BHC), and to develop pesticides with high efficiency, low toxicity, and low residual effects. We also utilize some techniques to prevent and control pests and diseases synthetically. In order to protect the soil, we promote regulation the ratio of nitrogen, phosphorus, and potassium in chemical fertilizer and combination of inorganic and organic manure. Recently, we also pay attention to rationally irrigating with waste water.

10) To Establish Stable Artificial Ecological System by Plantation and Other Biological Measures.

Forests are the most important resource of a country. Forests are rightly called: the general regulation department of the great nature. Forests have the ability of preventing and controlling air pollution, and the ability of protecting and beautifying the environment. They also play an important role in improving the ecological environment.

The forest cover rate in China is 12.5% now. Apparently it is too low. The government encourages scientists to extend plantation areas in every possible way, to match demands on environmental conservation. Article thirteen of the "Environmental Protection Act of PRC" clearly states: "Effort to plantation and afforestation, planting arid mountains and barrens, planting desert and half desert areas. Inside and/or outside factories, mining areas, schools and offices, fully utilizing roadside and waterside, planting trees and grasses, to realize the land becoming garden-style." In March 1980 the Central Government issued a "Guide of energetically launched plantation and afforestation."

In our country plantation in plain areas is a main strategy for improving the natural environment and agricultural ecology. In recent years, we plant forest belt net in farmland areas about 100,000,000 mu (6,666,666 ha); cultivate alternative by mixed farmland of paulownia and crops about 15,000,000 mu (1,000,000 ha); and plant about 3,200,000,000 trees. To match this, the Department of Forestry and relating scientific organs unfold many studies. For example, many institutes of the Scientific Academy of China, such as the Institute of Vegetable Physiology, the Institute of Forest and Soil, and Peking Botanical Garden, the Southern China Botanical Garden, and the Jiansu Botanical Garden studied antipollutional plants and pollutant sensible plants many years ago, and screened out a lot of antipollutional species of plants provided to the plantation of cities and industrial and mining areas. They also use their studies for the vegetation of factories, scenic spots, historical sites and traffic lines, especially propose mixed plantation, such as mixing coniferous and broadleaf trees, mixing arbors and bushes, mixing the pulse family and non-pulse family plants. The Institute of Land and Water Conservation of Northwest cooperating with Shanxi Province's spreaded grass seed, "Sadawang" (a kind of bush) seed, Chinese pine seed and ning tiao seed by airplane, controlled the soil erosion effectively. Forestry organs positively support the afforestation of plain areas in Middle and West China. Counties within "The Protection Forest System of Three-North" were provided with a lot of new planting machines. Recently, the Agriculture and Cultivation Agency of Ningxia Province successfully developed a ditching and planting combined machine, which can plant 1,200 trees in an hour.

China also has plentiful biological resources. There are about 30,000 species of higher plants, about 3,000 species of vertebrates, and 2,145 species of birds over China. How to develop and utilize these biological resources is an important scientific problem of our country. There are about 300 species of rate and specious plants, and 46 species of first class protected animals over China, and all of them are protected by the government's conservation policy. Recently, 73 natural conservation regions were projected and established. Animal conservation activities are also unfolding now, for example, Birds Conserving Week is held every year.

The environmental protection work in our country started at the beginning of the 1970s. The guidelines governing environmental protection work in our country are: overall planning, rational layout, comprehensive utilization, conversion of harm into good, reliance upon the masses with everybody taking part in the protection of the environment for the benefit of the people. These guidelines were put by the Chinese Delegation at the Stockholm Conference in 1972. The State Council convened the First National Environmental Protection Meeting in 1973. At the meeting, the above guidelines were officially approved, and some principles and methods of environmental protection were formulated. The Environmental Protection Leading Group of the State Council and its office were established in 1974. For many years, the central government and the people's government at all levels have established environmental management organizations in succession. They have worked out some rules and regulations, have carried out extensive investigations, have controlled and eliminated the pollution of the cities, waters, and industrial areas, and have achieved great results. But since the interference of the ten year turmoil and the "left" wrong thinking in the economic work, the environmental protection guidelines, policies and measures worked out by the state have not been completely implemented. In the winter of 1978, the Central Committee of the Communist Party of China (CPC) convened the Third Session of the Central Committee of the 11th National Congress of CPC with great historical significance. At the end of that year, the CPC Central Committee approved "Reporting Gists on Environmental Protection Work" which had been adopted at the meeting of the Environmental Protection Leading Group of the State Council, the Central Committee precisely pointed out that eliminating pollution and protecting the environment is an important part of economic construction and the realization of the four modernizations and is a major issue which must be grasped. The problems of environmental pollution should be well settled at the time of construction. This is the first stipulation of policy on environmental protection work made in the name of the CPC Central Committee, and it is of great importance to the environmental protection cause in our country. The Environmental Protection Law was issued in 1979. In April 1980, the Central Secretariat of CSC tendered four pieces of advice on the constructive policy of Beijing municipality. These pieces of advice are of guiding significance in the construction of cities and towns all over the country. In February 1981 the State Council made "the Decision on Strengthening the Environmental Protection Work during the Period of the National Economic Adjusting." The gist of the decision is that in the process of adjusting serious proportional dislocation of the national economy, environmental protection should be strengthened. In September 1981, leading comrades of the central authorities approved and transferred an investigation report on the municipal construction of the city of Suzhou. They pointed out that the construction of middle or small cities and towns should be combined with pollution control and environmental protection. At the fourth Session of the Standing Committee of the Fifth National People's Congress, Premier Zhao Ziyang, in his Government Working Report, stressed the issues of natural environmental protection and took the control and elimination of environmental pollution as the major guidelines for economic construction. The Ministry of Town and Country Construction and Environmental Protection of the People's Republic of China was officially established at the beginning of May 1982. The environmental management system of our country has been established. At present, the central authorities, local governments at all levels and important enterprises have all established environmental protection organizations. The improved state system has coordinated environmental protection with construction in the town and country. Through system reform, the environmental protection work of our country will enter a new stage.

The experience of the past ten years shows that the guidelines formulated by the Central Committee are correct. Under the direction of the guidelines, the central government and the local governments at all levels have successively formulated a series of concrete policies, decrees, measures, regulations, standards, and so on. On the basis of a lot of environmental protection work and environmental scientific research work, the above mentioned ten pieces of the environmental scientific and technical policy are being formed. In short, the environmental scientific and technical policy of our country is gradually developing.

However, it should be noted that the time for environmental work in our country is limited, actual experience is not much, and research work on environmental scientific and technical policy has not been systematically carried out. Consequently, there are a lot of problems which need to be gradually settled through further effort.

We are glad that more and more scientific and technical workers have thrown themselves into the scientific and technical cause of environmental protection.

The people of all strata of our country have increasingly paid great attention to environmental protection. By further perfecting the state system, unceasing accumulation of scientific knowledge and continuously thorough research on the environmental sociology, the research work of the environmental scientific and technical policy in our country will certainly make greater progress, so that it will increasingly play a greater role in the work of directing the settlement of actual environmental problems.

OUR VIEWS TO THE RESOLUTION OF CHINA'S RURAL ENERGY REQUIREMENTS

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Abstract

By analysing and estimating the energy requirement in China's rural area after taking four assumptions for the energy for living and consulting the nation's current supply for the energy for production, the article gives the total amount of energy needed in the whole rural area. A detailed analysis on China's rural energy resources was then put forth, and an amount capable of supplying was estimated. The supply-demand correlation in rural energy was studied on the above analyses and estimations, an energy flow chart for Chinese villages was drawn out, and the prospect of this correlation at various utilization ratios was demonstrated. Finally, related policies worth formulating and research directions worth undertaking were suggested, aiming at the amelioration of the supply-demand balance to attain the goal of self-sufficiency of rural energy.

CONTENTS

Some 80% of China's population is living in the villages. More than one-third of the country's total energy is consumed by these 800 million people for their living and production. On the other hand, the rural energy supply is insufficient, and the situation results in exceedingly unfavourable development of China's rural economy and an extreme inconvenience of the peasants' livelihood. Hence it is a matter of urgency to find ways to resolve the grave shortage in the current energy supply in accordance with the specific conditions in China's rural area.

What are the actual energy requirements both of living and production in the Chinese rural area? What is the amount capable of being supplied by the energy sources in the area itself? And how much is the balance between the two? How are the present and future correlations between supplies and demands of energy? And what are the feasible resolutions? All these are tasks which demand our study and answers.

1. General Situation in the Chinese Countryside

Located in the southeast portion of the Asian continent and facing the Pacific Ocean, China has a vast territory and a large population. China's territory covers some 9.6 million square kilometers and occupies 1/5 of the globe's land area. In China about 3/4 of the land is arable. Prairie covers 37.1% of China's land mass while forest 12.7%, leaving a mere 10.4% for farmland[1] and not much is reclaimable.

The natural conditions in China are complicated and diversified, and the degree of development in the agricultural economy in various areas is uneven. The differences in natural conditions mean that China may roughly be divided into the southeastern monsoon zone, the northwestern arid zone and Qinghai-Tibetan frigid zone. The monsoon zone covers some 46% of the country's territory, where nearly 95% of the agricultural population lives and 90% of the cropland is spread. This is the major farming area. The northwestern arid zone and the Qinghai-Tibetan frigid zone are sparsely populated and have dry weather, with all the deserts, rocky mountains, cold wilderness, frozen ground, glaciers and most of the country's prairies. Both zones are chiefly used for animal husbandry, while cultivated land is rare.

The distribution of precipitation decreases by degrees from the southeastern coast to the northwestern inland, and the annual isohyet runs more or less southwesterly from the northeast part. Along the southeastern coasts, the annual precipitation goes as high as 1,500-2,000 mm., while that in the northwestern inland remains under 100-200 mm.[1] Correspondingly, China's surface runoff gradually reduces southeast-northwesterly. Rich hydraulic power is in the southern provinces.

The peculiarity of the distribution of sun is that the southern and eastern parts of China have less sunshine than the northern and western parts. South China annually receives 1,800 hours of sun; 2,000-2,200 hours along the middle and lower reaches of the Yangtze River; 2,600 hours in north China; 2,600-2,800 hours in the northeastern plain; while in Inner Mongolia and in northwest China, the sun may reach 3,000 hours. However, as the intensity of solar radiation is different in various areas, the distribution of annual total solar radiation and the distribution of sunshine are not even, with an average variation of annual radiation between 85-200 $kcal/cm^2$, higher in the west and highlands and lower in the east and flatlands. On the Qinghai-Tibetan Plateau, the annual total radiation exceeds 160 $kcal/cm^2$, and in Inner Mongolia and Xinjiang Regions, the total amount mostly exceeds 140 $kcal/cm^2$. East China is generally lower than 120 $kcal/cm^2$, while in the Sichuan flatland and Guizhou mountain area, it is merely 80-100 $kcal/cm^2$(1).

Along with the great differentiation in natural conditions in various areas, distinct regional distribution presents in crop growing. Rice concentrates its growth in southern paddy fields, wheat, maize, and sorghum amass in northern dry land. In the vast area between the Great Wall and the Five Ridges, as well as in Gansu Province and Xinjiang Region, cotton concentrates its growing. And as for sugar and oil-bearing crops, the regional feature of their distribution is also obvious.

The spreading of forest is quite uneven. In the provinces of Heilongjiang, Fujian, Zhejiang, Taiwan, Jiangxi, Hunan and Guangdong, the forest coverage exceeds 30%. More than 20% of Jilin, Yunnan, Hubei, Liaoning and Shanxi provinces, and Guangxi Region as well, is covered with forest. While for Qinghai Province and Xinjiang and Ningxia Regions, the percentage of forest cover is less than 1%. China's forest resource disperses mainly in thickly forested mountains and remote border areas having limited transport facilities. The forest reserves along the Greater and Lesser Xinan Ridges and Changbai Mountains cover more than 30% of the country's total, another 20% is in the high mountains in the southwest.

China is presently divided into ten agricultural districts. The types and amounts of rural energy available in each district hinge on its natural conditions and its development of agriculture. The distribution of rural energy in the districts is roughly summarized in Table 1 (excluding No. 10 the Marine Culture District). The grades in the table are differentiated by per capita supply available. Small coal pit the other rural energy source is also listed.

Table 1. Distribution of Rural Energy in China's Agricultural Regions

Category of Energy Agricultural thermal	Straw & Stalks	Biomass Animal Wastes	Small coal Firewood	Mini-hydro pit	Power	Solar	Wind	Geo-
1. The North east	++++	++	++++	++++	++	++	+++	+++
2. Inner Mongolia, along Great Wall	++	++++	+	+++	++	+++	++++	+
3. Yellow & Huai Rivers	++	+	+	++++	+	+++	+++	+++
4. Loess Plateau	++	+	+	++++	++	+++	++	++
5. Mid + Low Reach of the Yangtze	+++	+	++	++	+++	++	+++	+++
6. The Southwest	+	++	+++	+++	++++	+	+	+++
7. South China	++	+	+++	+	+++	+++	+++	+++
8. Gansu-Xinjiang	+++	++++	+	++	++++	++++	++++	+
9. Qinghai-Tibet	+	++++	+	+	++++	++++	+	++++

Notes to Table 1: (1) Present production is listed for biomass energy, while for other energies, they are subjected to resources averaging per capita;
(2) Richness of energies is graded in terms of:
Straw and stalks--four grades by weight as below 500 kg. 500-625 kg, 625-750 kg. and exceeds 500 kg.
Animal wastes--four grades by weight as below 200 kg, 200-300 kg, 300-500 kg and exceeds 500 kg
(Both counted by annual averaged amount per agricultural individual)
Firewood--estimated by forest coverage, distribution and wood production
Mini-hydro power--four grades counted by averaged resources every agricultural individual avails, as below 0.02 kW, 0.02-0.05 kW, 0.05-0.1 kW and exceeds 0.1 kW
(3) The table merely shows energy available per capita, while different energy demands are beyond consideration. Sufficient supply is not definitely presented in areas with higher energy production. Tense situation in rural energy supply exists in the Northeast District owing to the high consumption requirement for house heating, despite its high rural energy production.

Currently, China's countryside depends mainly upon biomass energy, upon straw and stalks in paricular. These energy sources would play a major part in a considerable period in the future. Solar energy and wind energy have great potentials. These energies adapt themselves for exploitation and usage for single peasant families. Small coal pits, mini-hydro power and geothermal energy have strong localistics and could be exploited and adopted only by collective forces stronger than production team scale.

II. Estimation on Energy Requirement in China's Rural Area

The energy consumption in China's rural area has two peculiarities. One is that living consumption consumes most of the total, and the other is that energy for living is supplied chiefly by rural biomass, while that for production is satisfied mostly by commercial energy of coal, oil, and electricity. Great differences exist in the amount and sources between the two, and the situation is discussed below.

2.1 Energy for Living

Since great differences exist among various areas in kinds of food, habit of living and conditions of climate, it is hardly feasible to set up a unified criterion for the daily living energy need per capita of the rural population. Energy for living includes that for meals, hot water, lights, and heating in winter. From a primary survey, the average daily effective energy required for a family is 3,890 kcal[2]. To take each family having five persons, the daily per capita effective energy required for peasants' living is 778 kcal, which is a very low level. A considerable increase is expected following the gradual rise in the living standard from the development of the rural economy. Hereafter we take daily per capita effective heat requirement as (1) 700 kcal, (2) 900 kcal, (3) 1,100 kcal and (4) 1,300 kcal, with their results of estimation shown in Table 2.

Table 2. Estimation of Annual Effective Energy Consumption for Living in China's Rural Area*

Item	Daily per capita energy requirement (kcal)	Energy requirement for rural living in effective heat (kcal)	Tonne coal equivalent (million tonne)
(1)	700	2.124×10^{14}	30.3
(2)	900	2.731×10^{14}	39.0
(3)	1,100	3.338×10^{14}	47.7
(4)	1,300	3.945×10^{14}	56.4

*Take rural population of 8.313×10^8 in 1981, counting 365 days a year

The figures in column 4 in Table 2 are total effective energy consumption required for living of China's rural population. To divide them by energy utilization ratio N_e, the amount of primary energy practically required is calculated. Considering that the current N_e in the countryside is relatively low, we take N_e=12%, then the corresponding primary energy requirements are 2.525, 3.25, 3.975 and 4.70×10^8 TCE (tonne coal equivalent), which are equivalent to 519.8, 669.1, 814.4 and 967.6 million tonnes of straw and stalks. These figures are too large for the current straw and stalks themselves to satisfy by their current production alone.

2.2 Energy for Production

Rural energy for production involves the energy consumed for field work, irrigation and drainage, transportation, processing of products and by-products, as well as that consumed in commune or brigade-run enterprises. This amount of rural energy consumption can be estimated by the energy supplied by both the nation and the villages themselves, including:

Diesel oil & gasoline for farming: 8.9 million tons[3]=13.99 mTCE
Electricity for agricultural production: 336 million kWh[2][4]=13.76 mTCE
Coal for rural production: 37.4 million tons[2]=26.71 mTCE
Subtotal of commercial energy for agricultural production: 54.46 million TCE
Fodder for draught animals: 0.1328 billion tons[5][6]=64.5 mTCE
Total rural energy consumption for production:119 million TCE

The figure 119 million TCE is that of energy currently available for rural production, which is smaller than the figure actually required. For example, diesel oil presently required to run farm machineries is around 1/3 short[7]. (When disregarding cattle fodder, energy required for agricultural production is 54.46 million TCE.) Subsequent upon the development of agricultural production in our country, energy for production is bound to increase. Taking 119 million TCE as the basis for calculation, and different multiplications between 1.2-2.0 as the rate of increase in satisfying both present factual and future requirements of energy for production, various potential requirements are calculated in Table 3.

Table 3. Estimation of Energy Requirements for Rural Production (in million TCE)

	Multiplication	1.0	1.2	1.4	1.6	1.8	2.0
Energy needs	Commercial energy consumed	54.46	65.35	76.42	87.14	98.03	108.9
	Total energy consumption including fodder for draught animals	119.0	142.8	166.6	190.4	214.2	238.0
	NOTES	(1)	(2)			(3)	

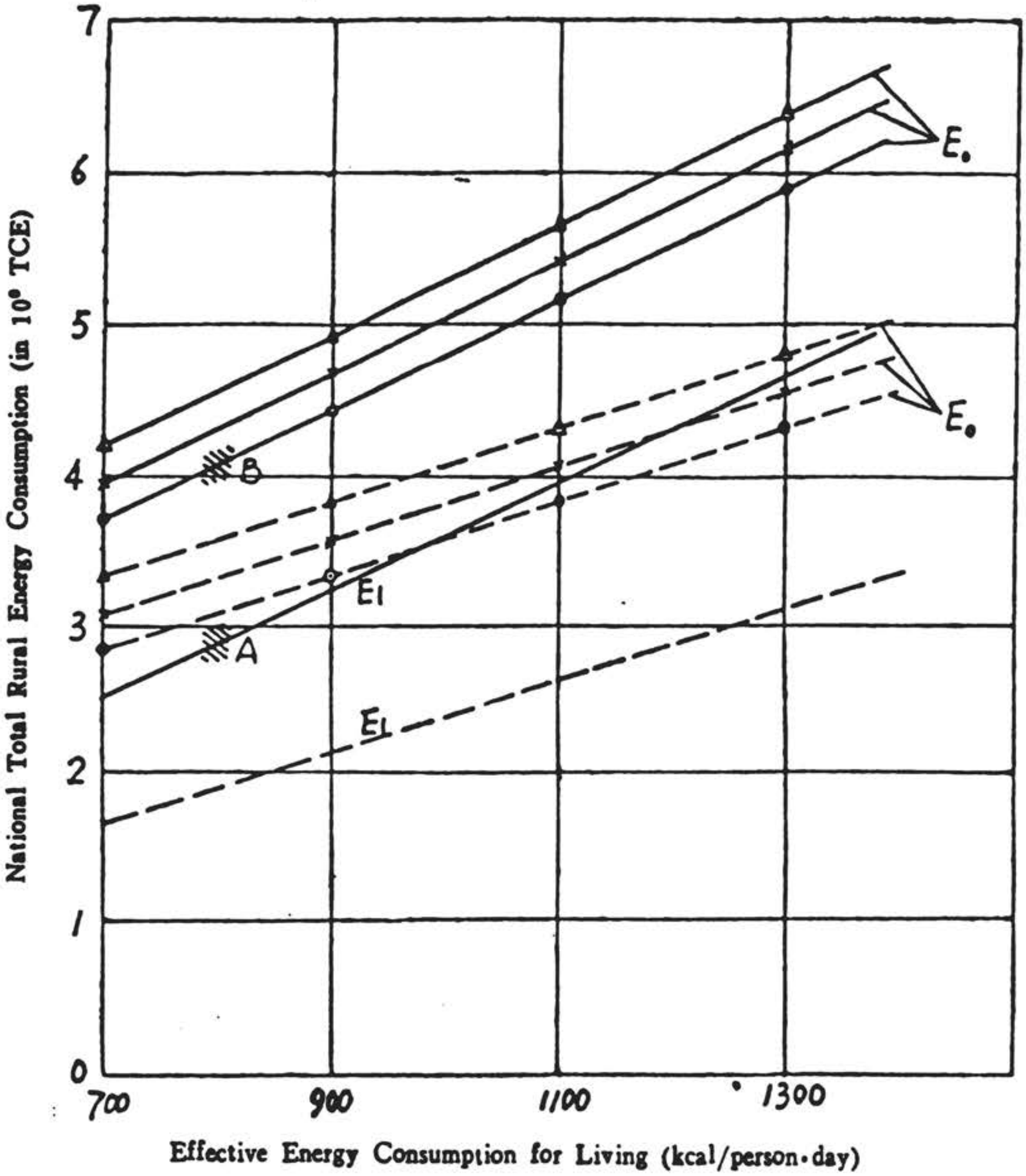
Notes: (1) Estimated by the allocated amount of the nation in 1981;
(2) Estimated by factual energy requirement for rural production in 1981;
(3) Estimating future rural energy requirement for production

Table 4A. Estimation of Total Rural Energy Requirement (η, = 12%, in million TCE)

Assumption / Energy consumption	Daily per capita effective energy requirement for living (kcal/person·day)											
	700			900			1,100			1,300		
For living E_1	252.5			325			397.5			470		
For production	1.0	1.2	1.4	1.0	1.2	1.4	1.0	1.2	1.4	1.0	1.2	1.4
E_2	119	142.8	166.6	119	142.8	166.6	119	142.8	166.6	119	142.8	166.6
Total $E_0 = E_1 + E_2$	371.5	395.3	419.1	444	467.8	491.6	516.6	540.3	564.1	589	612.8	636.6

Table 4B. Estimation of Total Rural Energy Requirement (η, = 18%, in million TCE)

Assumption / Energy consumption	Daily per capita effective energy requirement for living (kcal/person·day)											
	700			900			1,100			1,300		
For living E_1	168.3			216.7			265			313.3		
For production	1.0	1.2	1.4	1.0	1.2	1.4	1.0	1.2	1.4	1.0	1.2	1.4
E_2	119	142.8	166.6	119	142.8	166.6	119	142.8	166.6	119	142.8	166.6
Total $E_2 = E_1 + E_2$	287.3	311.1	334.9	335.7	359.5	383.3	384	407.8	431.6	432.3	456.1	479.9



Legend:

- (solid line) Living energy consumption taking conversion rate $\eta_0 = 12\%$
- (dashed line) Living energy consumption taking converson rate $\eta_0 = 18\%$
- (triangle markers) Total energy consumption E_0 by 1.4-fold current production
- (cross markers) Total energy consumption E_0 by 1.2-fold current production
- (circle markers) Total energy consumption E_0 by current production
- A: Present rural energy consumption for living (estimated)
- B: Present rural total energy consumption (estimated)

Fig. 1 Estimation on Total Energy Consumption in China's Rural Area

2.3 Estimation on Total Amount of Rural Energy Requirement

Summing up the outcome of analyses on rural energy consumption for both living and production, the estimated total figure of rural energy requirement is obtained and is listed in Tables 4A and 4B. The amounts of energy for living in both tables are estimated by taking comprehensive averaged energy conversion efficiency ratios N_e as 12% and 18%[8] respectively.

The bottom leftmost figure 371.5 million TCE in Table 4A is the estimated value for lower conversion efficiency and lower consumption, which is much closer to factual energy usage at present.

The results of estimation in Tables 4A and 4B are drawn in Figure 1, within it points A and B are the estimated value of factual current rural energy consumption.

III. Energy Resources and Energy Supplies in China's Rural Area

Indeed, China has abundant reserves of fossil fuels like coal, oil, and natural gas, yet their current does not satisfy the nation's requirement, and their supply to rural consumption is even more limited. The commercial energies supplying rural uses are presently: (1) Diesel oil and gasoline to run vehicles and farm machinery; (2) kerosene for lighting; (3) coal for living and production uses, and (4) electricity using in production and livelihood. All these energy supplies are far from sufficient in satisfying the rural requirements in the whole country. To meet the requirements, for living in particular, local resources in the villages themselves are relied on, including: biomass (straw and stalks, firewood, animal wastes), small coal pits, mini-hydro power, solar, wind and geothermal energies, which are discussed respectively of their supply or production, and the potentiality in utilizing them.

3.1 Biomass Energy

Biomass is the major energy supply in China's countryside, comprising crop stalks, firewood, and human/animal manure. On the overall productivity of China's rural biomass, different evaluations are stated in various literatures. Here we take the data of agricultural products in 1981, published by the State Bureau of Statistics[6], as a basis, and the productivity is estimated as follows:

3.1.1 Straw and stalks

The production of China's principal crop stalks is estimated in Table 5. In the total 442.7 million tonnes, some 40% is used for cattle fodder or for industry, with only the remainder 265.6 million tonnes or 129×10^6 TCE used as rural fuel.

3.1.2 Firewood

As a prerequisite avoiding deforestration, 90 million tons of wood is supplied for fuel per annum (2), i.e., 0.5786×10^8 TCE. However, the actual cut amounts to some 1.8×10^8 tonnes or $1,157\times10^8$ TCE, was a result of illegal denudation, which sabotaged forest resources, caused soil erosion and violated ecology equilibrium. In the rational cut of 0.5786×10^8 TCE, mostly serves as fuel for daily use. Put 80% or 0.4629×10^8 TCE for this fuel, then the other 0.1157×10^8 TCE is for agricultural production.

Table 5. Estimation on the Production of Crop Stalks in China

Item	Variety	Production (tonne)	Grain/stalk ratio of wt.*	Production of stalks	Remark
1	Grain	3.2502×10^8	1/1.3	4.224×10^8	(1)
2	Sugarcane	29.668×10^6	1/0.15	4.45×10^6	
3	Oil crop	10.205×10^6	1/0.59	6.021×10^6	(2)
4	Sugarbeet	6.36×10^6	1/0.4	2.544×10^6	
5	Cotton	2.968×10^6	1/2	5.936×10^6	
6	Hemp	1.26×10^6	1/1	1.260×10^6	
			TOTAL	4.427×10^8	(3)

Remarks: (1) rice, wheat and barley, other grain, legmina
(2) peanut, rapeseed, sesame
(3) 2.15×10^8 TCE

*references (5) & (9)

3.1.3 Human and animal manure

Human and animal manure is another major biomass for rural energy. In many areas, pastoral areas in particular, dry cattle manure has long been used as fuel. Table 6 shows the estimation on collected amount of human/animal manure in China's countryside.(5)(9)(10).

Table 6. Estimation on Production of Human/Animal Manure in China's Countryside

Variety	Number	Daily production (kg/head.d)	Collection rate	Fresh (t/yr)	moisture (x=%)	Dry (t/yr)
Cow	71×10^6	20	0.3	1.555×10^8	87	0.202×10^8
Horse, donkey	26.6×10^6	14	0.3	0.408×10^8	79	0.0856×10^8
Hog	2.937×10^8	4	0.9	3.859×10^8	82	0.695×10^8
Sheep	1.877×10^8	1.0	0.3	0.206×10^8	75	0.0514×10^8
Human	8.313×10^8	0.6	1.0	1.821×10^8	87	0.237×10^8

The total excluding human excreta: 1.034×10^8 t/yr=0.547×10^8 TCE
including human excreta: 1.271×10^8 t/yr=0.6718×10^8 TCE

The calorific value of the dry manure listed in Table 6 was taken as 3,700 kcal/kg(11). Should the collected manure be all utilized, the energy from which would exceed that from firewood currently burnt, thus it is an energy worth emphasizing. This considerable amount of energy is mainly used for fertilizer in the villages, with merely a small portion, around 1/10 used for fuel. Since manure possesses a proper C/N ratio, it is an optimal feeding for biogas generation. Hence it is an effective measure to develop biogas for the supply of rural energy in China by the full utilization of its human/animal manure resources.

3.2 Small Coal Pits

China has extraordinarily abundant resources of coal. Other than large coal mines, smaller coal mine resources exist in many areas, which suit mining by communes and brigades for local application. Currently more than 16,000 small coal pits are spreading over 1,100 odd counties in 26 provinces, cities, and autonomous regions, with a total annual production of about 100 million tonnes, and some 83 million tonnes (59.3 million TCE) are supplying the livelihood and production in the villages(2)(12).

3.3 Mini-Hydro Power

There are numerous rivers in China, numbering more than 50,000, with their individual drainage area covering more than 100 square kilometers, bringing along with them a very rich hydro-electric potential. Within which, the "mini-hydro power" potential with an individual capacity under 12,000 kW totals some 70 million kW(7). The dispersal of mini-hydro potential is rather broad, more than 1,100 out of the 2,000 odd counties, mostly in southwest and central-south part of China, possess their potentialities of capacity over 10,000 kW. Up to date, nearly 9,000 small hydropower stations have been built in 1,500 counties, with a total installed capacity up to 6.93 million kW and an annual power generation of coal is needed to generate this amount of electricity. Still the explored is merely 10% of the total mini-hydro potentiality in China.

3.4 Solar, Wind, Geothermal and Others

"New" energy sources like solar, wind, geothermal and others have begun their acceptance of attention. In northwest China and the Qinghai-Tibetan plateau where solar resources are relatively rich, the annual radiation reaches 140-160 kcal/cm^2. These areas are favourable in utilizing solar energy. Presently in the northwestern region, a peasant family can save 0.5 TCE of fuel in a year by using one simple solar cooker.(13) Put the case that half of the 1.2 million families in the area were using solar cookers all year round, then some 3 million TCE of fuel is saved per annum, which is rather a considerable figure. Solar water heaters have also begun their utilization in rural areas. Solar energy has quite a potential in China's countryside as a supplementary source of energy; and even as a major energy supply in some specific areas.

The averaged intensity of wind energy is not high in China, the maximum annual average is merely $200W/m^2$. However, the total wind resource if still quite sizable as her territory is vast enough. The areas with the richest mean wind energy distribution are northeastern, and northwestern China, as well as in the coastal areas. And for the rest, there are local or seasonal wind resources to be utilized. Although large scale wind power generation is not readily available owing to the limitation of average wind energy intensity, the energy source, however, suits decentralized small scale utilization in China's villages.

Geothermal resources spread almost all over China. There discovered some 2,500 outcrops of underground hot water, including natural outcrops and those prevailed by artificial drilling. Two main geothermal zones exist in China, i.e., the Pacific Oceanshore Geothermal Zone (involving Taiwan, Fujian and Guangdong provinces, and East Liaoning and Shandong peninsulas) and the Tibet-Yunnan Geothermal Zone. Other than the Tibet-Yunnan region and the island of Taiwan where some of the hydro/vapour-dominating resources exceed 100 C in temperature, the rest on China's mainland have only low or medium-temperature hot water resources under 100 C, and thus they suit direct utilization as heating, drying, greenhouse uses and warm water fish breeding.

3.5 Estimation on Energy Resources and the Amount of Supply in China's Countryside

From the above analyses, we may see that:

(1) Biomass resource is rather ascertained, and its available quantity is relatively large. This resource is the major source currently supplying rural energy and suits the exploration and utilization by individual peasant families and production teams.

(2) The resources and present supplies of small coal pits and mini-hydro power are also quite certain. They are the rural energy sources just next to biomass and are suitable to collective exploration and management.

(3) Despite the tremendous reserves of solar and wind energies, the present exploration on them is still low. Their availability is affected greatly by regional and seasonal limitations on the one hand, and by technical and economical feasibilities on the other. Yet their potentialities, however, are quite great, as their distribution is widespread, their supply is costless and their suitability for individual and/or collective exploration is favourable. In some areas, they may even become major sources of energy supply.

Summarizing the above-mentioned analyses and estimations on the demands and supplies of various rural energies, an "Energy Flow Chart in China's Countryside" (Fig. 2) and an "Energy Flow Chart of Supply for Living Energy Consumption in China's Countryside" (Fig. 3A and 3B) are illustrated. Figure 2 reflects the factual status quo of energy consumption in China's rural area, with dotted lines and brackets indicating the possible situation when increased energy conversion efficiencies are attained from the popularization of biogas technology. Figure 3A shows the possible condition after the modification of stoves increases the utilization rate of fuels. And Figure 3B demonstrates the resulted state achieved from the simultaneous adaptation of both.

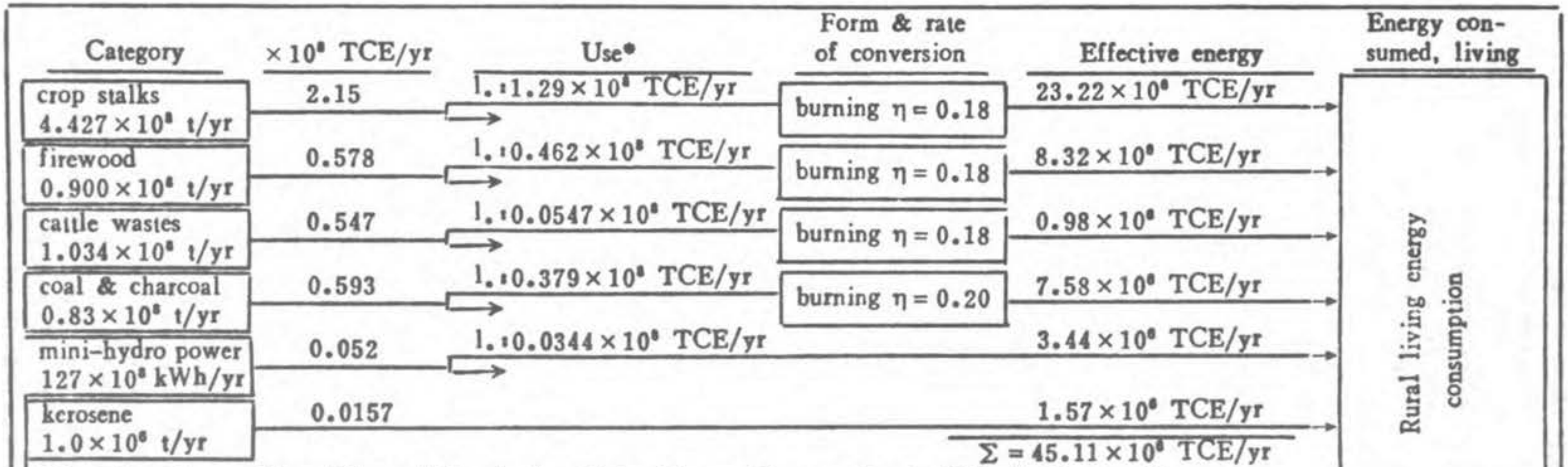


Fig. 3A. Energy Flow Chart of Supply for Living Energy Consumption in China's Countryside
(High burning efficiency Programme)

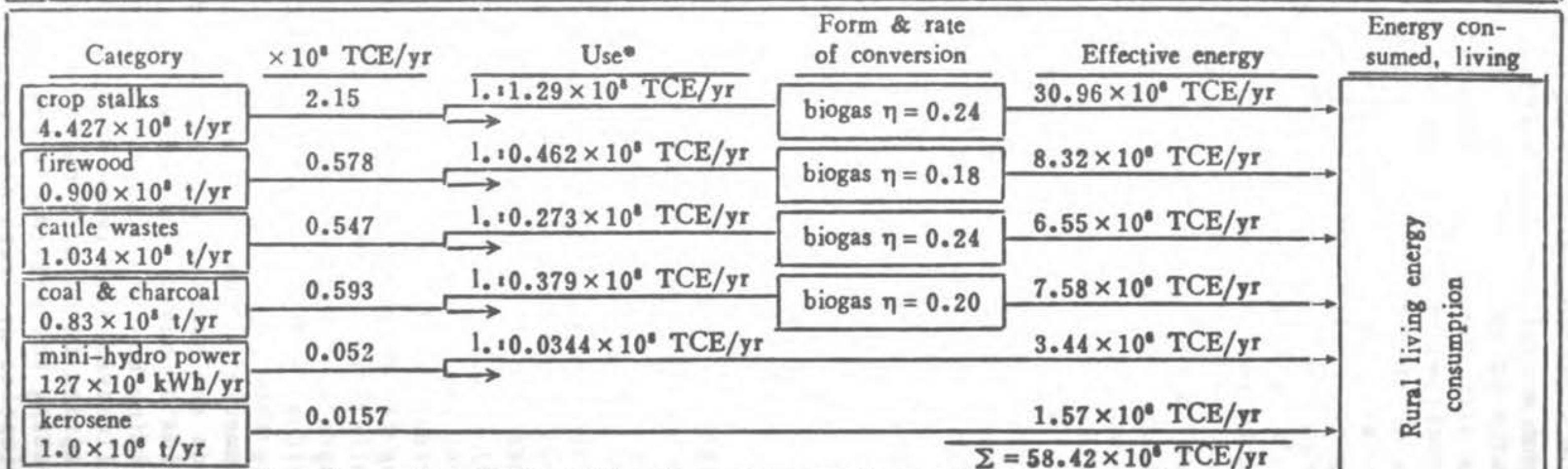


Fig. 3B. Energy Flow Chart of Supply for Living Energy Consumption in China's Countryside
(High burning efficiency + Biogas Programme)

*: l. stands for living

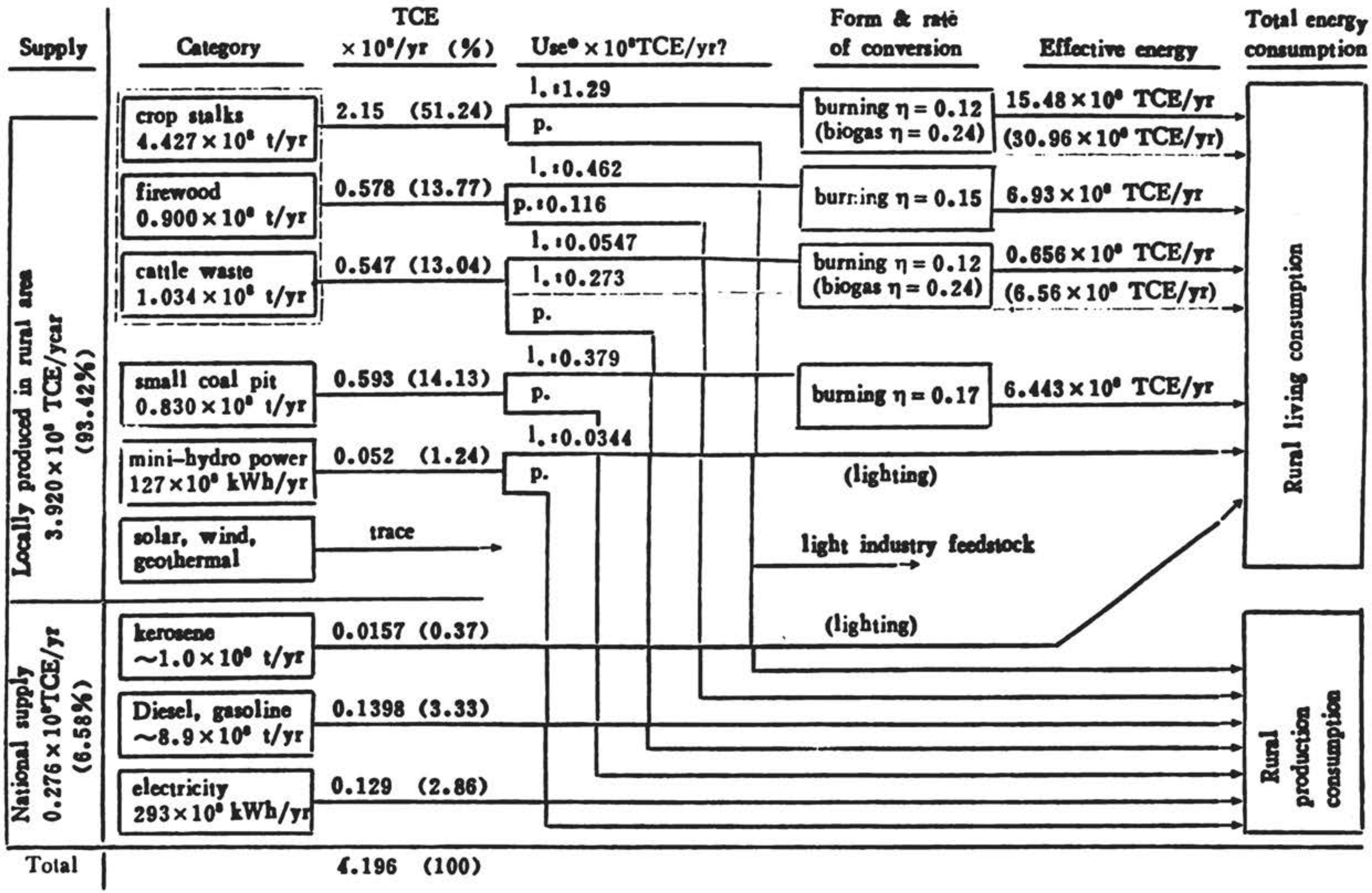


Fig. 2. Energy Flow Chart in China's Countryside

*: l. stands for living; p. stands for production

Referring to "TCE" figures the third column in Fig. 2, we may sum up the quantity of energy currently supplied by China's rural area itself, which is shown in Table 7. Seen from the Table, biomass and small coal pits are supplying 84% and 15% respectively of the total energy consumed for living in the countryside. This proves that biomass is actually the major source of energy.

Table 7. Estimation on Annual Quantity of Energy Supplied by China's Villages

Category of Energy	Quantity in million TCE (%)	
1. Biomass (1) stalks	215 (54.85)	
(2) firewood	57.8 (14.74)	
(3) cattle waste	54.7 (13.95)	
Subtotal		327.5 (83.54)
2. Small coal pit		59.3 (15.13)
3. Mini-hydro power		5.2 (1.33)
4. Solar, wind, geothermal		trace
TOTAL		392 (100)

3.6 Discussion on Supply-Demand of Energy in China's Rural Area

(1) Energy Used for Rural Living

Current supply of energy for living in China's rural area is chiefly in the form of direct burning. From the column of Effective energy in Figure 2, they are:

Crop stalks	15.48×10^6 TCE/year
Firewood	6.93×10^6 TCE/year
Dry cattle waste	0.656×10^6 TCE/year
Small coal pit	6.443×10^6 TCE/year
Mini-hydro power	3.44×10^6 TCE/year
Kerosene	1.57×10^6 TCE/year
TOTAL	34.52×10^6 TCE/year

The 0.345×10^8 TCE/year rural total energy supply for living is a figure smaller than the demanded 0.370×10^8 TCE/year requirement counted by 850 kcal/person _ day figure, thus it is a reflection of a tense situation of insufficient supply. In some areas lack of fuel, all burnable biomass, e.g., crop stalks, firewood, weed and even bark and root and anything, is peeled off or dug out for fuel. Fertility in farmland reduces year after year, due to insufficient organic substances returning. Forest coverage is reducing owing to denudation, resulting in soil erosion, climate deterioration and ecology equilibrium destruction. The situation is going from bad to worse. Hence the resolution of rural energy supply is an urgent task in the construction of modernization in China's agriculture.

Could the problem be resolved? The answer is yes, and the measure is "broadening sources while reducing waste." Cultivating fuel forest is an effective measure in increasing rural energy. Eight percent of China's territory is occupied by barren hills suiting afforestation, still there are odd pieces of uncultivated land and wasteland available. On the other hand, squandering is serious in rural living on energy as the utilization rate is rather low, consequently the potentiality of energy conservation is tremendous. In case all of crop stalks are used to supply rural living by biogas produced from microbial fermentation of crop stalks and animal wastes rather than by direct burning, then the energy provided by the stalks would be twofold, and that by the animal manure would be a tenfold increase as available manure increases greatly. From the column of effective energy in Figure 2, the effective energy provided after the popularizatiion of biogas technology could be estimated as:

Crop stalks	30.96×10^6 TCE/year
Firewood	6.93×10^6 TCE/year
Dry animal wastes	6.56×10^6 TCE/year
Small coal pits	6.443×10^6 TCE/year
Mini-hydro power	3.44×10^6 TCE/year
Kerosene	1.57×10^6 TCE/year
TOTAL	55.90×10^6 TCE/year

This total supply of 0.559×10^8 TCE/year is a figure larger than the annual requirement of 0.477×10^8 TCE/year effective energy counted by 1,100 kcal/person _ day for the whole countryside. From the above calculations, the effective energy supply rural living would increase by 60% when utilizing crop stalks and animal wastes through the adoption of biogas. By then the supply-demand correlation of rural energy would be greatly ameliorated. A completely different result would be obtained on the same composition and the same quantity of primary energy supply, when the form and efficiency of conversion is differentiating. On the form of conversion, the biogas approach is far better than direct burning, as it keeps the organic fertility of biomass, besides its merit of high conversion efficiency.

It is only natural that the above analysis is merely a theoretic possibility. Such a large scale popularization of biogas technology is hardly practical in a short period. Therefore, increasing the efficiency of direct burning and developing firewood/charcoal-conserving stoves are also essential measures in releasing the tense situation of rural energy supply.

The above discussion, however, is in a way considering the whole countryside as an entirety. It is a general ledger, while separate itemized accounts are needed to apply in individual areas or villages. Owing to the uneven distribution of rural energy resources and the inconvenience in transportation, great differences exist among various areas in their energy situations. To an individual village in a certain area, the supply may be either insufficient or excessive.

(2) Energy Used for Rural Production

Other than fodder for draught animals, the energy used for rural production in our country depends basically upon nation-provided commercial energy as coal, oil, and electricity. Since our rural labour is abundant while the level of farm mechanization is low, current energy used for rural production is not the crucial factor hindering the development of China's agriculture. Following further development of energy production, some but not much increase is expected in supplying the countryside with commercial energy. In several years to come, the supply could only be maintained at the present level. In view of this, China's agriculture has to take the path of energy-conserving type organic agriculture. Instead of copying the model of high energy consuming agriculture taken in developed countries, China's modernization of agriculture should adopt the approach of combining biological, mechanical, and other technical measures, with the former. We can only accomplish a selective mechanization and employ the limited energy to the aspects achieving maximum economic results. We have to make the most of manpower, livestock labour, solar energy and wind power. In recent years, China attained uninterrupted growth in agricultural production under the condition of basically not increasing energy consumption. The fact proves that developing agriculture along the path of energy-conservation is acceptable.

Views to the Resolution of China's Rural Energy Problem

In order to ease the tense condition in the rural energy supply, a policy was successively formed in recent years as "suiting measures to local conditions, mutual complementation among various energy sources, comprehensive utilization, and stressing practical results."

4.1 Suit Measures to Local Conditions with Overall Planning

Within the vast territory of China, energy resources as well as energy demands are different from each other among villages. This resulted the differences in the energy sources utilized and the measures adopted. Thus overall planning must be worked out suiting measures to local conditions, so to attain the goal of lessening expenditure while broadening profits.

In a considerable period to come, the energy sources for most of our villages would still rely on biomass, especially on straw and stalks. However, the materials are also serving as cattle fodder and industrial feedstock, besides those needed to be returned into the fields to increase organic matter in the soil. Therefore we have to fight for the reduction of crop stalks as fuel. In areas where condition favours, efforts should be made in cultivating fuel forests to produce firewood to substitute straw and stalks. While in areas rich in coal, e.g., in Shanxi and Guizhou provinces, small coal pits may be properly developed to increase rural coal supply and decrease fuelling stalks. Rich water resources exist in south China, where mini-hydro power is an effective approach supplying electricity to the villages. And rich solar resource falls in northwest China and Qinghai-Tibetan Plateau, there solar cookers and solar water heaters are worth popularizing, besides the abundant geothermal resources possessed in the latter which are also worth developing. Then in north and northwest China, and the coastal areas as well, rich wind energy resource would be recommended for popularization in driving windmills, junks, small-scale wind turbine and other wind power devices. For a country with complicated and diversified natural conditions like China, no immutable model could be applied to all places, and a policy "suiting measures to local conditions" must be implemented.

Investigations on energy resources and on energy consumption must be made thoroughly before formulating an energy program adapting the situation of a definite place. Such investigations need strengthening forcibly as they are far from accomplished. Planned and guided investigations must be explored with unified standards and approaches. Only on this basis could a rational program be formulated. And only by such formulation could reasonable planning be arranged in allocating funding, labour, and equipment by an overall programme.

Staged development of energy sources in accord with practical urgency is a substance in considering the program. Before every step of development is taken, detailed economic assessment must be conducted, so as to achieve the reality in the development and application.

4.2 Mutual Complementation Among Various Energy Sources and a Comprehensive Utilization

Owing to the divergent, seasonal and varied characters of rural energy sources, in most villages it could not be possible for a unitary source satisfying the local energy requirement in whole. The requirement for living and production can only be satisfied when various energy sources available are all effectively utilized. In this case, the policy of "mutual complementation among various energy sources and a comprehensive utilization" is doomed to practice.

Crop stalks and animal wastes are not only fine fuels but also fertile organic manure, thus they are suitable for being first fed into anaerobic digesters for biogas. When we get biogas, the fertility of the stalks and manure still remains in the digester. Such slurry and sludge are rich organic fertilizer and also adoptable for mushroom planting and earthworm breeding. This is an example of comprehensive utilization.

In some areas, the ambient temperature is too low for biogas digestion. Solar energy is then worth combining with biogas technology to increase the digester temperature to 35 C for mesophilic digestion for biogas, so to increase gas production and to extend the producing period in a year, even to winter season. This is an example of mutually complementing various energy sources.

In northwest China, it is applicable combining solar, wind and biomass energies. Solar cookers are for cooking, wind machines provide energy for pumping and lighting, while biomass is used as supplementary fuel or raw material for biogas production.

While in south China, we may combine biogas and solar energy with mini-hydro power. Biogas supplies fuel, solar energy provides domestic hot water, and mini-hydro generates electricity for lighting and power for communal enterprises.

To satisfy rural energy requirements, we have to broaden sources and reduce consumption. We must explore and exploit fuel forest, biogas, wood-conserving stoves, draught animals, small coal pit, mini-hydro power, solar energy, wind energy, geothermal energy and everything, with all-out efforts.

4.3 Rely Mainly upon Self-Support, with Proper Supply from the Nation

Since multi-phased, small-scale and scattered characters are in both resources and conumption of rural energy, the rural energy construction should rely mainly upon self-support, applying a policy that to those who built, he owns, he manages, and he benefits from. As to the projects need higher investment, like small coal pits or mini-hydro power, they may be managed jointly, rely mainly on the commune and/or brigade forces, and the nation supports with financial subsidies and provides with medium or long-term low interest loans. And to the energy development projects handled by peasant families or production teams, the government may accelerate their construction by means of subsidization. The amount and means of subsidizing may be determined in accordance with the difference of construction projects. For example, the suburb government of Guangzhou municipality supplies 100 years each to the peasant families building their domestic digesters(14).

While to commercial energy as coal, oil, and electricity neede for rural production, the nation would allocate properly in the overall national economy programme, so to guarantee the supply.

4.4 To Devote Major Efforts to the Strengthening of Rural Energy Research

The level of utilization and exploitation of China's rural energy is quite low while the squandering is rather high. To change the backward situation, research work must be strengthened energetically.

4.4.1 On the direction and projects of scientific research

Rural energy involves broad aspects of research, including basic research projects and massive applied research projects. Considering the current conditions that both economic and scientific research capabilities are rather weak in China, we must place our major efforts upon applied research, emphasizing those projects effecting in one or two years as focal points. On the other hand, optional supports should also be applied on the promising basic research projects. Listed hereafter are the major aspects we consider worth studying in a period to come.

(1) Studies on the conversion and utilization of biomass energy

As was stated, biomass is the major rural energy with rich and varied contents: studies on microbial anaerobic fermentation which involves the study in promoting its conversion rate (by use of medium temperature digestion and by adoption of high-rate bacteria) and the study in increasing the utilization rate of biogas (by the modification of various biogas apparatus and biogas internal combustion engines); studies in improving digester types, in limiting and eliminating gas leakage, and in improving feeding-discharging operations; adopting new materials, developing new digester types, lowering cost of building, and making maintenance and management easier; conducting studies on solid fermentation technology, etc. Moreover, the studies on pyrolysis of solid organics and producing liquid fuels from biomass are also prospective.

(2) Studies in increasing the utilization rate of fuels

Direct burning of various fuels would still be a chief way of energy consuming for quite a long period. Thus it is of immediate significance to modify various types of stoves and small boilers burning crop stalks, firewood and coal or charcoal, so to increase their thermal efficiencies. As to the materials not readily available for direct burning, the study of pretreatment technology as pressing them into suppressed materials and others are all important contents for research.

(3) Studies in breeding and cultivating fast-growing fuel forests

Breeding fast-growing species of trees adaptable to different climates and soil conditions and studying the related planting techniques.

(4) Studies on the utilization of solar and wind energies

As for near-term, studies could be applied in improving the performance and suppressing the cost of manufacturing of solar cookers, solar water heaters and solar driers, as well as in small-scale, high-efficiency and durable wind turbines. And as long-term projects, medium-temperature solar collectors, solar refrigerators, photovoltaic cells and solar energy storage technology are included.

(5) Studies and improvements on manpower and animal-powered farm machinery

(6) Comprehensive studies for "new energy village"

Study the ways of mutual complementation and comprised utilization of various energy sources in energy villages using biogas, fuel forest or other energy as major sources under different natural and economical conditions.

Within the aspects of research in the said projects, applied as well as basic research are involved, neither should be over-emphasized at the expense of the other. The applied projects would certainly effect faster. Nevertheless, basic projects such as non-crystallized solar cells, high-rate digesting bacteria, solid fermentation and breeding of fast-growing fuel forest would bring once new breakthroughs occur, the utilization of rural energy up to a new and higher level.

4.4.2 The dissemination of research results

Owing to the limitation of both financial and material capabilities and the low cultural and scientific knowledge levels of the peasants, the Chinese rural area has its peculiarity in disseminating the results obtained on rural energy research. On-site demonstration is a necessary form in disseminating results in rural area. In this respect, the projects developed by our institute, as biogas power station in Junqiao of Foshan, the new energy village in Xinbu Brigade, the 12 kW small biogas power plant, as well as solar silkworm cocoon dryer and solar water heater, had all played demonstrative roles in providing the peasants with personal experiences in the superiorities and with firsthand practice of the technique. The dissemination of the results are thus accelerated.

Conclusions

(1) Tense shortage situation exists in rural energy supply in China. The major resource for rural energy is straw and stalks, with firewood following, then are animal wastes and small coal pits, and finally comes the mini-hydro power.
(2) "Broadening sources while reducing wasting," massive forestation of fuel forests, popularizing biogas and firewood/coal-conserving stoves are current effective measures in easing the supply-demand correlation in rural energy.
(3) Policies should be formulated on the basis of sufficient investigations in "requirement" and "resources." The policies are overall planning suits measures to local conditions, and comprehensive utilization of various energy sources mutually complementing. The construction should be staged in accord with the urgency of requirement, emphasizing the projects effecting in the near future.
(IV) Strengthening scientific research is the crux in resolving the tense rural energy demand situation.

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ASSESSMENT OF ENERGY FROM BIOLOGICAL PROCESSES: A CASE STUDY

Thomas Bull

INTRODUCTION

Although technology assessment has been discussed previously in this session, it is useful to reiterate certain aspects of assessment which proved to be particularly important in the study of "Energy from Biological Processes," or simply bioenergy.

Technology assessment has many similarities to parts of the classical scientific process. Acceptance or rejection of a theory or hypothesis is determined by its conformity to accepted "laws" of science and its consistency with the available factual* information and data. Furthermore, a hypothesis should, in general, be predictive of things not yet tested. It should not be a self-fulfilling prophecy or a vaguely defined and all-encompassing generalization bordering on a tautology. It should not be a predication based on a lack of knowledge--"if we can't disprove it, it could be true." And it shoul not be an anthology of past experience with no invariants or insights into systems not yet tested.

At the outset of the assessment of bioenergy, public knowledge about the subject was based on a complex of theories and hypotheses that displayed varying mixtures of both the desirable and undesirable characteristics mentioned above. To a large extent, the assessment consisted of sorting through these various claims to determine which were technically and scientifically sound and if, possible, to develop predictive theories where none existed. Armed with the resulting

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* In this context, factual means objective and observable results of measurements. It excludes metaphysical "facts."

predictive descriptions or "models" of bioenergy systems, we were able to estimate the potential for biomass energy and its probable impacts under various future circumstances. This, then, led to the technical conclusions and policy analysis presented in the report. It also enabled us to analyze various specific issues that were of potential interest to Congress.

In the following, I will give a brief history of the events leading to the bioenergy assessment, discuss the assessment process in more detail, and describe the various ways we used to convey our results to Congress. However, because the potential bioenergy is very different from one country to another, I will not attempt to present any detailed results of OTA's assessment.

HISTORY

Soon after its formation, the OTA Energy Program identified bioenergy as a potentially significant source of energy for the United States and a subject worthy of further study in the interest of evaluating U.S. energy and other resources. Awareness of the significant potential of biomass as an energy source was accompanied by a realization that a major effort to that end could have important implications for competing uses including food, fiber, chemicals, recreation, and soil and water conservation. In 1977 a menorandum was prepared for internal evaluation
by OTA management that outlined various sources of bioenergy, together with literature estimates of the potential quantities of energy that could be supplied by each. The memo provided a basis for OTA's professional staff to discuss the subject with staff of Congressional committees.

At about the same time, the National Ocean Policy Study (NOPS) of the Senate Committee on Commerce, Science and Transportation was developing an interest in energy from the oceans, including OTEC (ocean thermal energy conversion) and ocean-based kelp farms. OTA indicated to NOPS that kelp farms might best be covered as part of a larger study of energy from biological processes. The members of NOPS agreed, and in January 1978 Senator Warren G. Magnusen, then Chairman of the Committee on Commerce, Science and Transportation and Chairman of NOPS and Senator Ernest F. Hollings, then Vice Chairman of NOPS, sent a formal request to the Technology Assessment Board (TAB) asking that OTA perform the assessment. Shortly thereafter Senator Birch Bayh, whose interests included ethanol from corn, sent a letter supporting the original request and asking that he be considered a co-sponsor of the study.

In response to these requests, Dr. Audrey Buyrn, then of the Energy Program, prepared a detailed project proposal, outlining the scope and estimated budget for the study. Following the usual review process, the proposal was submitted to TAB and approved. The assessment then officially began in late Spring of 1978.

THE ASSESSMENT

Defining the Problem

The first step of the assessment was to determine in detail what specific subjects would be studied. Bioenergy potentially includes a bewildering array of options; and it would clearly be beyond OTA's resources to study each one in detail. Dr. Buyrn (a nuclear physicist by training) and I (a physical chemist) therefore set up various criteria that would guide us in narrowing the study to manageable proportions but still allow us to produce a useful report. To satisfy these dual needs, it was essential that we quickly develop a sense of the major issues of bioenergy in the United States.

As the first step we proposed to include bioenergy technologies that had the potential of supplying large amounts of energy or that were (or might become) of particular interest to the Congress. For example, wood was included because of its apparently large energy potential. Ocean kelp farms were of special interest to the requesting Committee. And the production of ethanol from grain--particularly its net energy balance--was clearly emerging as a major issue.

Second, because there are numerous bioenergy options with near-term potential--bioenergy currently supplies over 2% of U.S. energy needs--we proposed to concentrate on technologies with a reasonable U.S. market potential in the 1980s. This enabled us to exclude various technologies for a variety of reasons. For example, biophotolysis was still at the basic research stage. Integrated food/material/energy systems such as those propsosed for the production of single cell protein did not seem to be the type of bioenergy system that would expand first in the U.S. economy. And labor intensive systems or those requiring a change in life style, such as the use of grass clippings and human excrement to produce methane for home cooking, likewise seemed inappropriate, given the social environment in the United States.

Finally, we left out municipal solid waste (MSW) because it was the subject of another OTA assessment that already was in progress.

We then examined various ways of subdividing the greatly reduced, but still large, list of bioenergy options into manageable tasks, or subunits. In the end, we chose the obvious division--individual resource bases, conversion technologies, and end uses--partly because this division seemed logical but more because this organization mirrored the way academic and industrial specialties are divided and thus would facilitate finding competent contractors (see below) for each task. We were aware that this would put the burden of integrating the results and analyzing interdisciplinary issues primarily on OTA staff, but it appeared to be the only way to obtain the detailed information we needed.

Using the organization that had been developed, we prepared a series of Task Statements, or detailed descriptions of the exact information and analysis we required, about each subunit of our bioenergy study. We initially defined 15 tasks, but the list would later grow to 28.

The final step in defining the problem was review and critique of our problem definition by the Advisory Panel selected specifically for this assessment. (See attached list.) At the first meeting of the full Panel and later meetings of "working groups" composed of 3 to 5 Panel members, the Panel basically confirmed our organization, sharpened the focus of the task statements, warned us of potential difficulties that we should work to avoid, and suggested contractors who might be able to provide us with the information requested in the task statements.

Assessing the Technology

There are a variety of ways to obtain the information needed for the analyses, and the methods used will vary considerably, depending upon the subject, maturity of the technology, availability of good information in the public literature, and OTA's in-house capabilities. Our general approach is the classical heuristic one--namely, to try any reasonable approach that can work and to keep trying new methods until one succeeds.

As indicated above, the public literature on bioenergy was of uneven quality and contained virtually none of the interdisciplinary analyses needed by OTA. Where biomass systems had been studied extensively (as in agriculture or forestry), energy was rarely a primary consideration, and the information in these areas needed extensive interpretation to be useful. Consequently, it was clear that considerable original analysis would be needed for the assessment.

To provide the bases for these analyses, the task statements called for a variety of information. In most cases, descriptions of the technology and its state of development as well as economic and environmental analyses were required. In one case (thermochemical conversion) a separate task was devised to examine the purely scientific and theoretical aspects of the subject. Many of the tasks called for critical reviews of the existing literature on the subjects, analysis, and critique of government data, and the derivation of new resource estimates designed to correct previous estimation errors or biases. One task provided a history of bioenergy use in the United States, and another examined the parameters limiting photosynthetic efficiency.

To supply us with this information, we relied heavily on faculty members of universities and research scientists. We attempted to find individuals who were critical of prevailing "common knowledge" or policies but who seemed to have sound analyses to back up their criticisms. More conventional views would come out in the review process, and for our purposes it was important to understand the reasons for their criticisms, whether or not we eventually were to endorse these criticisms.

A principal vehicle for obtaining the information and analyses called for in the task statements was to contract with an individual or group to write a report on each task. The basic idea is to obtain reports that are similar to good review articles often found in the scientific literature. The process consists of identifying potential contractors, having them submit proposals, and, where the proposals are adequate, issuing contracts containing the task statements. In some cases, a single contractor could do more than one task, while in others the task had to be further subdivided. In all cases, the contractors were carefully monitored while producing the report via frequent interactions between OTA analysts and the individual contractors to help insure that the results would be useful.

On the whole, this process was reasonably successful, and 11 of the 17 contractor reports were eventually published by OTA in an appendix to the report. Another contractor report on ocean kelp farms was published by the Senate Committee that requested the study. The others were not published because the information contained in them was either incomplete, erroneous, or simply not useful.

Another technique used was to bring (usually 1 to 6) experts on a subject (a working group) to Washington for several days to answer and discuss specific questions related to their discipline. This technique is particularly useful when one has a small number of questions which require interdisciplinary treatment. Generally, preliminary analyses are prepared, and the working group serves to refine, correct, and occasionally to extend the analyses. A successful example of this was the working group on limits to photosynthetic efficiency and plant growth, composed of five nationally respected scientists from the areas of biochemistry, agronomy, plant physiology and genetics, and plant growth in arid lands.

A final way to obtain information was simply to telephone advisory panel members and outside scientists, engineers, sociologists, etc., to discuss the issues and get leads to useful reports and articles. Where contractor reports and working groups failed to produce satisfactory results, this method was used and the information needed for our analysis was either acquired or we concluded it was not available. Virtually the entire body of background information used in our analyses of ethanol from cellulosic feedstocks, chemicals from biomass, and food/fuel competition was obtained in this way.

The assessment process, however, is not so much one of gathering information as it is of evaluating, judging, and analyzing this information to obtain an objective, scientifically and technologically valid, and predictive description of the technology. To aid this evaluation, all material used and produced by OTA is subject to extensive review by the Advisory Panel and outside reviewers chosen for their expertise in the subjects covered. This introduces new ideas, uncovers errors, and sharpens the analysis. This type of review was and continues to be an integral and indispensible part of the assessment process.

Nevertheless, reviews are often incomplete, contradictory and/or erroneous. Furthermore, the scope of several interdisciplinary analyses of bioenergy systems exceeded the expertise of any single specialist; and the diverse subjects, viewpoints, and interpretations had to be integrated into a coherent whole. For example, the subject of alcohol-gasoline mixtures covered subjects from animal nutrition to petroleum refining and from agronomy to automobile engineering. At the time of OTA's assessment, there simply was no authoritative and integrated body of knowledge or expertise covering the subject.

In the end, the final judgement on the quality of review comments, the types of analyses needed, and the content of OTA reports rests with the OTA staff. They must develop a description of the system that incorporates or explains all of the major viewpoints in the public debate; or the OTA staff may decide that the experimental information and its interpretation are inadequate to reach a conclusion. It is the OTA staff's creativity, (bolstered by many interactions with peers and critics from various institutions) and sense of scientific and experimental proof, physics versus metaphysics, and principle versus anecdote that determine the outcome. Although I do not understand this process in detail, the ability to make sound technical judgements surely has much to do with the individual analyst's scientific education and teachers, open-mindedness, interest in productive criticism, exposure to diverse viewpoints, and creative and critical abilities developed through experience, challenge, and familiarity with the analysis of apparent contradictions.

PRESENTING THE RESULTS

Because of the diversity of Congressional interests, expertise, and emphases, no single way of presenting the results of an assessment would be adequate for all of the Congressional needs. Consequently, the results of the bioenergy assessment like the results of most assessments, were presented to the Congress in a variety of ways.

Responding to Short-Term Congressional Needs during the Assessment

As work progressed on the bioenergy study, several issues related to the subject came under Congressional scrutiny. Through a technical memorandum, briefings, testimony, and a critique of proposed legislation, we were able to assist the Congress in some of the areas of interest before the full assessment was completed.

For example, little over a year after the start of the bioenergy study, ethanol-gasoline blends (gasohol) were clearly becoming a major issue before the Congress. We had received and reviewed most of the contractor reports relevant to the subject, but some of the reports were deficient, and the overall integration and analysis was far from complete.

Nevertheless, through two months' concentrated effort, we essentially completed a comprehensive analysis on gasohol--from production of corn to end use in automobiles--and presented the results in the first of what became known as "technical Memoranda." This was basically a mini-assessment on a specific technical topic of timely interest to the Congress.

The Gasohol Technical Memorandum (TM) was well received, and we later briefed--or gave short seminars to--Congressional staff members on the report's contents. (The TM made it clear that the energy implications of gasohol were complex, but marginal. Whether gasohol would increase or decrease U.S. consumption of premium fuels depended upon many details of how the alcohol was produced and used.) The TM also led to a general awareness of OTA's bioenergy study; and I subsequently testified at Congressional Subcommittee hearings on proposed bioenergy research and development legislation and wood energy in the State of New Hampshire. The bioenergy staff also prepared a critique of parts of what later became the "Energy Security Act," which established the Synthetic Fuels Corporation and created a variety of incentives to promote the use of bioenergy.

Other routes of communication during the assessment included talks at scientific conferences and interviews for a television documentary on gasohol and a television news report on President Carter's proposal to produce ethanol out of the grain embargoed from export to the Soviet Union.

Assessment Report

The OTA Assessment Report, a carefully prepared Summary, and a Publication Brief are the major vehicles for communicating the results of an assessment. The Report provides a permanent record of OTA's findings, and preparing and reviewing drafts of the report are integral parts of the assessment process, as mentioned above.

Organizing the bioenergy report presented some interesting challenges; and the process was aided immensely by the advice of the Advisory Panel. The report, like all OTA reports, needed to be written in clear layman's language easily accessible to non-technical people in the Congress, but it had to be seen by the scientific and engineering communities as presenting valid conclusions based on sound technical analyses. At the same time, the large number, diversity, and complexity of subjects covered seemed to defy a simple presentation.

In the end, the staff, with the help of the Advisory Panel, decided to present the results in two separate volumes. The first volume, aimed primarily at Congress, contained an executive summary and other sections concentrating on policy, issues, and four major bioenergy fuel cycles. It was not intended to contain a comprehensive analysis but rather to focus attention on the most important subjects for Congressional consideration.

The policy section in the first volume presented various options that the Congress might wish to consider to promote the use of bioenergy or avoid adverse side effects. In the issue section, each of a series of questions or issues that had arisen in the public debate over bioenergy were answered briefly and directly in a space of 0.5 to 4 pages, depending on the issue. The bioenergy fuel cycle section presented the technical and economic analyses and the environmental and social impacts of wood energy, alcohol fuels, energy from grasses and crop residues, and fuel gas from animal manure. In each case, the entire fuel cycle, from resource production through conversion technologies to end uses, was covered.

The second volume presented the comprehensive analyses on which the first volume was based as well as various bioenergy subjects that were assessed but excluded from the first volume. It was organized more according to scientific disciplines--i.e., wood resource base, conventional agricultural crops, processing wastes, thermochemical conversion, fermentation, etc.,--and provided the scientific rationale for the conclusions we reached.

This solution to the organization seems to have worked well. Most Congressional and general interest inquiries are answered in Volume I, while special interest and more technical inquiries are dealt with in Volume II. The reports also appear to have been well received. In addition to OTA's publication of the report, Volume I has been published by a commercial publishing company, while Volume II has been published by two separate companies.

Follow up

Following delivery of the report to the Senate Committee on Commerce, Science and Transportation, which had requested the study, summaries, publication briefs, or full reports, as appropriate, were sent to each Member of Congress and several other Committees in the Congress. Copies of the report or summary were also sent to individuals outside of the Congress, including academics, businessmen, and people in the various levels of government both within and outside the U.S. (including Chen Ruchen, Head of the Biomass Division, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences).

In addition to sending reports to various interested parties, the follow-up of the assessment has included numerous other contacts with the Congress and others. In all, OTA has presented testimony for Congressional hearings three times as a direct result of the bioenergy study, and the results of the study have contributed to testimony on at least three other occasions. In early 1981 a wood energy caucus was formed in the Congress, and the background information that accompanied the solicitation of membership in the caucus drew heavily from OTA's report. The bioenergy staff subsequently presented a briefing on wood energy to the caucus. In addition, numerous Congressional staff members have been briefed on various aspects of bioenergy, and we have been able to respond to countless telephone calls and other informal inquiries on the subject.

Outside of Congress, I participated in a National Academy of Sciences U.S. Agency for International Development (U.S. AID) sponsored consultation on renewable energy in Costa Rica, was the U.S. delegate to the U.S. Food and Agriculture Organization's expert consultation on food-fuel competition, and headed a team evaluating U.S. AID's Bioenergy Systems and Technology Program. Various bioenergy staff members have also given invited presentations on bioenergy at numerous conferences; and the summary booklet was the major piece of background material sent to participants in a recent Aspen Conference on "Increasing Use of Biomass for Energy and Chemicals."

Other types of follow-up activities, such as reviewing other people's report drafts and magazine articles, also occurred, but the examples given above serve to illustrate the diversity of ways the information is used. The important thing is that the follow-up, like the assessment process itself, must be prepared to be responsive to a variety of needs and interests.

CONCLUSIONS

Once the scope of assessment was reduced to a manageable size, the study proceeded using a variety of techniques. No formula was or can be given for success. But, in retrospect, it appears that the essential ingredients were a flexible and creative staff; cooperative and knowledgeable advisors, reviewers and contractors; and the willingness of OTA's leadership to allow the project budget and delivery date to be shaped and extended to the extent necessary to do the research thoroughly.

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TECHNOLOGY ASSESSMENT: CONNECTIONS WITH THE OUTSIDE

J. Thomas Ratchford

Technology Assessment has been around for a long time. It grows from a fundamental human desire to assign blame for past mistakes and get a better handle on how events will transpire in the future. I am sure Kublai Khan's failed invasion of Japan was subject to a 13th century version of a technologyy assessment. The conclusion that dragons were the cause may or may not have been correct.

There are no doubt cases where technology assessments should have been performed but were not. The magnetic needle described in the Sung-shu, a 5th century Chinese historical work, had evidently been used for hundreds of years to orient temples under construction. Other ancient Chinese sources tell us that it was used as a compass much earlier, during the reign of Emperor Chen Wang, over 100 years before the birth of Christ. It is a shame the Emperor did not have an Office of Technology Assessment to evaluate the primary, secondary, and tertiary effects--good and bad--of the widespread utilization of this new technology. If he had done so, and it were done well, the course of world history may well have been dramatically changed.

In the United States we have been involved in the assessment of technology since the early days of our republic. Well before the Civil War in the early 1800's, the Federal Government became concerned with explosions of boilers on steam ships. A concerned citizenry produced political pressure which resulted in the House of Representatives contracting with the Franklin Institute of Philadelphia to embark upon a technology assessment which would, hopefully, explain the puzzling rupturing of these boilers and the consequent toll of human life. Although the final report was not written with the care and precision of a contemporary OTA document and there is no record of an advisory panel like the ones we have today, the problem was eventually solved.

About 140 years later the Office of Technology Assessment was formally established by the Congress of the United States. Dr. Gibbons in the first paper of this trilogy has described the underlying philosophy and operating principles of the organization. Dr. Bull has described the process of the assessment on Energy from Biological Processes. I should like to add only one further comment on the origins of OTA. The members of Congress who voted for the enabling legislation were not of one mind as to the desired structure of the office or the role which it should play. Even those who had thought seriously about technology assessment had strikingly different concepts of what OTA should evolve into. But there was one common denominator shared by the founding Congressional fathers of OTA, namely a realization that Congress needed a source of information about technological issues which it could trust. I think we have that today.

The purists in the technology assessment community emphasize the need for carefully structured assessment of long-term problems, whether or not these problems are viewed as important by the general public and its elected representatives. This is laudable. But if done to the exclusion of assessments that are directly relatable to issues before the decision makers, the impact of the technology assessment process on public policy would be no more effective than most academic analyses.

One reason for this state of affairs is the unforgiving and in some ways unique temporal constraints one finds placed on decision-making in the Congress. Congress cannot wait for new knowledge before taking action on budget resolutions or appropriations bills. Furthermore, since the Congressional decision-making process operates in real time, the relevant information often must be co-located with an individual at a particular time and place, at a committee mark-up or on the floor of the House or Senate. It has to be reduced to one piece of paper or be in the mind of a member who has an opportunity to speak. If it is not there, or at least in the hands of a staff aide at the elbow of the member, the information just does not exist as far as the decision-making process is concerned.

The excrutiatingly temporal aspect of the information problem faced in the Congress emphasizes the need for timely assessments. What Congress desperately needs are assessments that are related to short-run decisions to be taken on long-range problems. Here we have what one might describe as a highly leveraged public policy opportunity.

Let me now address specifically the technology assessment of energy from biological processes and how that assessment connected with experts and opinion leaders from outside the Office of Technology Assessment. I shall address in particular the role of the Advisory Panel to the study, since I had the pleasure to serve as chairman of that body. My opportunity to observe at close range the actions and interaction of this Advisory Panel was supplemented by more distant observations of other connections of the study to the outside.

It was earlier noted that technology assessments at OTA are performed in a political environment. Their results are used in that same political environment. The biomass study was no exception. Before the requests for the study were even transmitted to OTA, existing battle lines were drawn between environmentalists and industrial interests. Many in the Corn Belt of this country viewed subsidies for ethanol production from corn as a way around mounting surpluses which continued to threaten an adequate market price for their product.

Just as the biomass issue is complex politically, it is also complex technologically. A myriad of scientific and engineering disciplines and specialties impinge on the problem. These include the agricultural sciences, various conversion technologies, marine science, transportation, environmental effects and trade-offs, and above all, economics.

The politics of biomass are complicated because of the numerous parties at interest. There are as well several mind-sets as to technical approaches resulting from differing disciplinary perspectives. It was the responsbility of the Advisory Panel to bring these differing views to bear on the problem at hand to assure a competent and complete assessment, one with a form and substance useful in the legislative process. This means that a panel was required whose members would work together in a constructive way in spite of strongly differing perceptions of the problem or its solution. For a panel such as this to work one must, in spite of differing perspectives, cultivate a feeling of collegiality. This implies a need to suppress grandstanding--statements of position without expectation on the part of the speaker that they will lead to a meaningful discussion and possible consensus. This also implies that the members must be logical whether their roots are in science, engineering or other disciplines.

The role of the Chairman of the panel is not to bring answers for confirmation by his peers. Rather it is to draw answers from the members of the panel and indirectly from those who relate to panel members. This implies a need for an underlying respect for his or her objectivity--neutrality if you like--and certain qualities of leadership which are often needed to produce a consensual document.

Perhaps the first problem in a technology assessment is that of defining the scope of the study. The Advisory Panel by its mere existence does this to a first approximation. The scope is established by the parties at interest which are represented on the panel and the scientific and engineering expertise of its members. To a second order the panel establishes the dimensions of the problem being assessed through discussions among itself and with OTA staff. The usual and desirable way to reach these decisions is through consensus, derived in part from a developing "pride in its product" on the part of panel members. As they see their contributions incorporated into the planning and implementation, panel members often submerge their special interests in order to derive an end-product which makes sense.

Let me give a few specifics. As noted earlier, the biomass panel worked long and hard on helping define the boundaries of the study and its approaches. The results were described by Tom Bull. The important point I would like to make, however, is that the Advisory Panel was able to come to agreement on almost all significant issues related to the structure of the study before the OTA staff sought additional outside assistance through contractual and consulting agreement. This was due in no small part to the competence, knowledge, and constructive spirit of all the members. They comprised an exceptionally gifted resource and met all the criteria cited above.

The full biomass panel met formally four times. These meetings occurred at critical points during the planning, execution, and review of the study and its results. In addition, there were numerous meetings or conversations between OTA staff and individual panel members during the entire period of study. Although the panel meetings were not highly structured, detailed agendas and a plan of action were worked out ahead of time by the Chairman and OTA staff. The major substantive contributions of the panel had to do with (1) definition and structure of the study; (2) provision of expert advice; (3) resolution of policy and technological disagreements, at least to the extent of defining and quantifying the range within which knowledgeable experts might differ; (4) structuring the report as to format, emphasis, technical complexity of the language to be used; and finally (5) review and comments on the final document.

My experience in chairing this and one other Advisory Panel for the Office of Technology Assessment leads me to conclude that the model developed by OTA for performing its assessment is sound. The role of the Advisory Panel is central. It provides an effective way of assuring the parties at interest are represented in the assessment process and that the spectrum of scientific and technological expertise required is in fact available.

One might ask if this model is transferable to other countries and societies. There is a great interest in technology assessment in many countries around the world including the socialist, planned-economy countries of Eastern Europe; the parliamentary democracies of Western Europe and Japan; and many developing countries.

Although one cannot be sure, I suspect this model can be transferred with only major changes. There are several reasons. Technology assessments performed for use in the Congressional decision-making process are structured, as we have seen above, through a process which contributes to the definition of the boundary conditions for the study itself. The Advisory Panel is an integral part of those boundary conditions, and its members are active participants in setting the scope, content, emphasis and form of the study end report. Although the model may not apply directly to other countries, including the People's Republic of China, elements are worthy of further analysis and discussion by the participants in this symposium.

THE POLICY ADOPTED FOR THE TOTAL SYNTHESIS OF INSULIN AND YEAST ALANINE tRNA AND THE MANNER IN WHICH THE WORK WAS ORGANIZED

Hu Yongchang, Jiang Chengcheng, Chen Changqing
Luo Deng, and Huang Aizhu

Introduction

In 1958 our scientists embarked on a project for the total synthesis of insulin, and in less than seven years successfully completed for the first time in human history the synthesis of bovine insulin (September). Some time later, in 1968, another group of scientists was organized for the total synthesis of yeast alanine tRNA. This second project took as long as 13 years, eventually succeeding in 1981. Figures 1 and 2 give respectively the chemical structure of bovine insulin as elucidated by F. Sanger in England in 1955 and yeast alanine tRNA as determined by R. W. Holley in the United States in 1965.

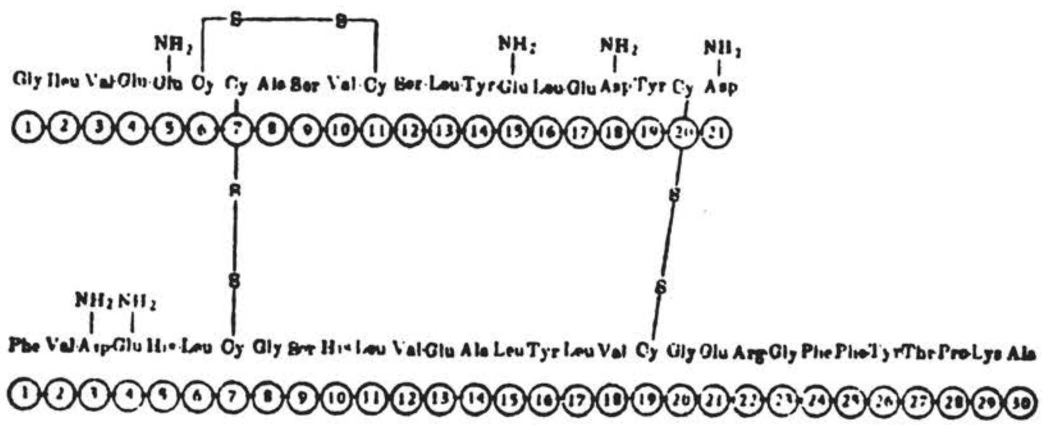
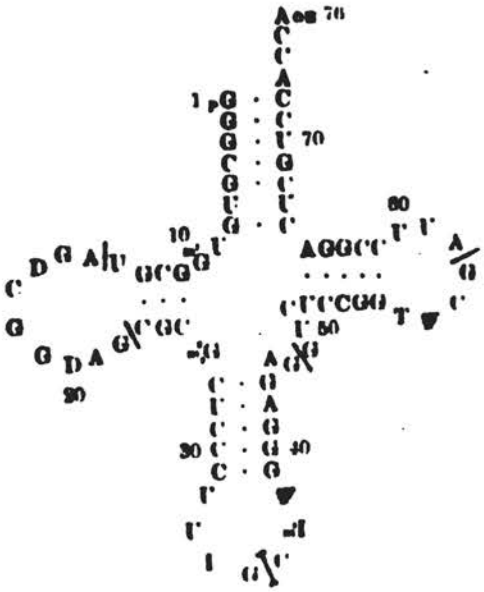


Fig. 1. The structure of insulin



The successful realization of these two projects is an indication that the synthesis of biological macromolecules forms an area in which our scientists have caught up to the world level. The work has been commented upon favourably by scientists both in China and from all over the world.

In this article, an attempt will be made to analyse the policies under which these research projects were formulated and the organization processes that were invoked to coordinate the work involved, in a country like China where science was still underdeveloped and research in science not yet placed on a firm foundation.

The Choice of Problem and Historical Background

In 1956 as a sequel to a specially convened session of established workers from every field of science and technology an "outline for the development of science and technology for the period from 1956 to 1967" was drafted and later ratified, which served as the guideline for development of science in general. The "outline" fully reflected the urgent wishes of our scientists to alter in the shortest possible time the backward status of science and technology in China and thus served to inspire confidence and resolution to go all out for the creation of a strong nation equipped with modern science. Under the subject: the study of certain basic theoretical problems of modern science, were listed the item: "the structure of proteins, their functions and synthesis and the study of nucleic acids," as one of twelve central problems to be considered.

Protein is one basic substance of life, it is closely related to a number of life phenomena such as growth, maturity, biological catalysis, respiration movement and immune reactions. That was a time, when much had already been done on the structure and function of proteins. In our country, however, one had to start from a low level of development. During the early years after liberation biochemistry in China was chiefly devoted to nutritional studies of foodstuffs, isolation and characterization of some enzymes and certain aspects of metabolism. It was later widened to include studies on respiratory chain enzymes, isolation of proteins and studies of their physical and chemical properties, amino acid composition as well as structure with some work on the synthesis of small peptides. Though progress was by no means slow on the whole, there was a rather big gap in the training and quality of the research workers, equipment and other facilities, when compared with the same in the advanced countries. In order to change this backward state one must organize a force to attack problems along the frontiers of the modern life sciences, and gradually catch up with the advanced world level in certain areas. The solution of such research problems which are highly significant but fairly difficult would be profitable for the training of our research personnel, to raise our confidence in scaling the mounts of science and to influence and promote development on all fronts.

In 1958 after two years of discussion, investigation and preparation, our scientific workers decided to embark on the synthesis of insulin. Our reasons were: first, this protein was of vital importance in life activities, and its total synthesis would be highly significant both in theory and scholarship; insulin was, by that time, the only protein which had ever been sequenced, and had an important role in life as a hormone. Second, the study of a biologically active substance usually has to go through the procedures of isolation, purification, crystallization, chemical structural analysis, synthesis and structural modification, aiming at certain practical applications or for studying the relationships between structure and function. From the above line of reasoning the synthesis of proteins must form one of the chief trends in the development of biochemistry and organic chemistry. Third, it is in the field of protein synthesis that we were almost on a par with our foreign colleagues. At the time the largest synthetic polypeptide was the tridecapeptide a-MSH, and we had already synthesized the nonapeptide oxytocin. Furthermore, we were fairly well equipped for chemical synthetic work. When we chose insulin as the object of synthesis, when we could direct all our efforts toward that target, we would be able, through our striving, not only to catch up with our colleagues abroad in the field of protein synthesis, but also stimulate work in isolation, purification, crystallization, structural analysis and the study of protein function. The history of what had happened in the period extending over 20 years since 1958 has justified our selection of subject and estimation of possible outcome.

The thesis of tRNA synthesis was put forward just after the completion of the total synthesis of insulin. During the two years from 1966 to 1968, our scientists had talked over many times on what was best to be done and how best to do it, after the successful synthesis of insulin. We all agreed that nucleic acid, besides protein, was another substance essential to life, playing a key role in such important life processes as growth, reproduction, heredity, and variation. From the trend already shown in foreign lands in the study of biological macromolecules, nucleic acid research had already become an active area alongside intensive studies on proteins. We suggested that, besides further explorations into the relationship between structure and function of proteins and practical application of methods of protein and polypeptide synthesis, a group for nucleic acid synthesis should be organized.

Nucleic acid research in our country was much behind protein work, with a weaker foundation when compared with the conditions that pertain when we took up insulin synthesis. In the fifties, we had only done some work on nucleic acid metabolisms in connection with tumours and on a few enzymes related to nucleic acids. We had made some progress in the sixties in the isolation, purification, characterization, and fundamental structural analysis of nucleic acids. We had also done some work on protein biosynthesis and on structure and function relationships of tRNA. All these, however, were far behind the advances made in other parts of the world. In order to speed up nucleic acid research, it would not only be possible, considering the circumstances then prevailing, to break through, as in protein synthesis, but also to benefit from such an endeavour in all out development in the nucleic acid area, provided we made full use of our previous experience and exploit our advantages. Having thoroughly weighted all possible advantages and disadvantages, our scientists selected from among six nucleic acids of known sequence yeast alanine tRNA as our target of synthesis. Looking back on the late sixties and early seventies, we could not but be impressed by the marked progress abroad in the chemical and enzymatic synthesis of DNA, especially during the period after the breakthrough in DNA sequencing and the rise of genetic engineering. DNA synthesis in its own right had drawn ever more attention. People began to wonder if it would be profitable to shift to DNA synthesis. The scientists who took part in the work held, however, that though DNA and gene synthesis were just as important, and though RNA synthesis would be comparably more difficult because of its additional functional group on the ribose moiety, RNA synthesis had its own particular significance. All experiences gained in RNA synthesis and the techniques developed would, after the completion of the work, certainly apply to DNA synthesis. Obviously, it would contribute to the development of both pure and applied research in the field of nucleic acids in China. Thus we decided to persist in continuing this piece of research to completion.

Evolvement of the Scheme and Assignment of the Work

1. A standard for evaluating the synthetic products:

Both bovine insulin and yeast alanine tRNA are biological macromolecules with specific biological function. By what would we judge a synthesis successful? Here arose the problem of setting a standard for evaluation. We held that the standard for evaluating the synthesis of a biological macromolecule should be identity of the synthetic product in chemical structure and biological function with natural substances.

Keeping in mind this principle, we always insisted that the product must possess the complete structure when we set the scheme for insulin synthesis and rejected the idea of synthesizing insulin analogs (for example, big circular insulin analogs) instead. In the course of synthesizing yeast alanine tRNA, we set out to synthesize a product exactly the same as that which occurred naturally. We did not replace the nine rare nucleotides (seven types) by common nucleotides. As for the chemical identification and activity assays of the final synthetic products, we put forth the most stringent norms.

Our synthetic crystalline bovine insulin and the total and the semisynthetic yeast alanine tRNA had been sufficiently verified by various chemical analysis and biological activity assays. They were apparently identical with the natural products.

2. The scheme for synthesis

The synthetic scheme was the first problem which must be solved for both insulin and yeast alanine tRNA syntheses.

(1) For insulin, we could select either chemical or enzymatic methods. Even if we had decided to proceed by the chemical method, we had still to choose from a) synthesizing A and B chains separately, and form the whole molecule through the binding of three -S-S- bonds and b) synthesizing two polypeptide blocks of "I" shape and then joining one to the other. Which was the more rational route? Only experimentation could provide the answer to this question. We arrived at the correct solution by adopting the following procedure: separating natural insulin at the three -S-S- bonds in A and B chains which were biologically inactive, and then, under the proper reaction conditions, reform the whole insulin molecule. If active insulin could be obtained by this method, it was clear that we could proceed by synthesizing the A and B chain separately and, by proper treatment, form the insulin molecule with biological activity. Acting according to this principle, we began our experimentation, after having summarized all experience in this area of research. In several months time we had done over 600 experiments, finally resulting in the successful recombination of A-chain and B-chain into a whole, active insulin molecule. This work laid the foundation for future work.

Meanwhile, attempts at enzymatic synthesis encountered much difficulty and had made little progress in a year. We therefore, abandoned the enzymatic approach in 1960, and focused attention on the syntheses of A and B chains, to be followed by combination of the two chains into whole insulin. After a hard struggle lasting for several years, we obtained at last chemical by synthesized A and B chains, which were shown to be correct to recombining with natural B and A chains respectively to form active insulin. The complete synthetic crystalline bovine insulin was finally obtained by combining the synthetic A and B chains.

(2) The scheme of synthesis for yeast alanine tRNA. By 1968 only triribonucleotides with specific sequences and a hexamer of uridylic acid had been reported for RNA synthesis; for enzymatic synthesis only triribonucleotides had been synthesized by the use of RNase. All these were very far from the requirements for the synthesis of a tRNA of 76 nucleotides. What was to be done? Our scientists, inspired by our success in insulin synthesis, attempted mild treatment of natural yeast alanine tRNA with RNase T_1, isolated the 3'- and 5'- half molecules, and studied the methods and reaction conditions for ligating these two half molecules into a complete one. On the other hand we laid stress on the method of chemical synthesis of oligonucleotides, at the same time doing experiments on enzymatic synthesis. Later, the discovery of RNA ligase greatly promoted RNA synthesis. Through this new discovery abroad and our own experiences in practice, we arrived at a reasonable scheme for total synthesis, that is: first, to synthesize small fragments by chemical methods or a combination of chemical and enzymatic methods, then to ligate them by RNA ligase into larger fragments, and finally into half molecules and whole molecules.

3. Assaying for activity

As mentioned before, biological activity assays form the key by which the synthesis of both insulin and tRNA were evaluated. For insulin synthesis we had carried out the mouseconvulstion test as well as the rabbit hypoglycemia test. As for alanine tRNA, it was necessary not only to test for its activity in accepting alanine, but also, somewhat more importantly, to determine its activity in incorporating alanine into protein. Due to the small amounts of the synthetic products, the conventional assay was not possible. In order to obtain a complete series of data of biological activity, we formed in time a special group aimed at the exploitation of a sensitive trace-quantity method of activity assay. After three years of work, a new activity assay, suitable for synthetic tRNA, was established, with a sensitivity reaching down to 5 pmoles. This sensitive test greatly reduced the amount of fragments and enzymes necessary for the synthesis, shortened the time required and made possible the accumulation of all necessary biological data for both total synthetic and semi-synthetic products.

4. Emphasis on the supply of amino acids and other reagents

An old saying in China has it: Food and fodder go before troops and horses. Amino acids and nucleotides were as food and fodder in the synthesis of insulin and tRNA. These materials, together with enzymes and chemical reagents were at that time not produced in China, whereas on the international market these were often very expensive. To import these from abroad, we had to spend much in foreign currency. Besides, it was also impossible to buy so many kinds in such quantities. The only way was to rely on our own efforts, i.e. to produce these materials ourselves. As a matter of fact, both of the two research projects began with the preparation of raw materials. With the cooperation of a few related factories, our homemade materials met the demand of these two projects. Today, with the completion of the above two theses, we are in possession of a factory which produces over 500 biochemical reagents including various amino acids and polypeptides, nucleotides and nucleic acids, and other reagents and enzymes. This serves as a comparatively good basis for carrying out studies on proteins, polypeptides and nucleic acids. Under the conditions in which we worked, the spirit of relying on one's own efforts was of great value.

Organizations and Administration

One of the essential reasons that made possible the completion of two huge and difficult pieces of research in a country which had been weak in scientific manpower and facilities and unable even to produce the necessary materials lies in the fact that we were able to organize scientists from different institutes and of different disciplines into the great cooperation.

1. How was cooperative research organized?

(1) Should work be integrated into one institute or should it be scattered among several institutes with proper assignments for each?

In pushing ahead the two projects mentioned above we adopted the policy of trying out various methods and various routes simultaneously so as to find out in the shortest time the best synthetic scheme, and the policy of relying on our own efforts in the supply of materials, reagents and equipment. Plenty of manpower was required. Where would these men come from? The solution was to organize several institutes into the cooperation. The reasons were: first, it was not possible to integrate these research workers into one institute as all these institutes had much work of their own to do, and it was not permissible to direct all personnel on to a few projects. On the contrary, several institutes in cooperation could easily share manpower. Then, both the two projects were interdisciplinary.

Cooperation would give each institute free reins to make use of their advantage to the fullest. Moreover, communication among different institutes and various disciplines was insufficient. When institutes of different disciplines join in a cooperative effort, one could compensate for such insufficiency and stimulate the development of these disciplines. For insulin synthesis, we organized the Shanghai Institute of Biochemistry, Shanghai Institute of Organic Chemistry, and the Department of Chemistry of Beijing University for intimate cooperation; and for the synthesis of tRNA the partners were the Shanghai Institute of Biochemistry, Shanghai Institute of Cell Biology, Shanghai Institute of Organic Chemistry, Institute of Biophysics. Department of Biology of Beijing University, and Shanghai No. 2 Reagent Factory.

(2) Why must a capable leader group be formed to direct the cooperative efforts?

A powerful leader group was necessary to ensure that research would be carried out systematically among several institutes in a long-term cooperation. In the syntheses of both insulin and tRNA, the leader groups were mainly composed of scientists and a few administrators. The tasks of these groups were: firstly, to organize discussions and direct the drafting of plans for the projects, to evaluate strategic schemes, to study carefully the work plans and assignments for the research workers; secondly, to inspect and supervise the execution of the plans, to communicate information concerning work in each institute involved in cooperation, to modify the plans and assignments, and to organize in time research groups for the solution of key problems whenever necessary.

2. The mass line

When we decided to embark on the synthesis of bovine insulin and of yeast alanine tRNA, work in the two areas was just beginning to emerge in other countries. Most of us who took part in the work did not have much experience, and some of the young people were even short of basic training in scientific research and had to start from the very beginning. In order to build up a team for protein and nucleic acid research, it was profitable to advocate the mass line, as it was so called in China, i.e. in the course of formulation of research project, assignment of schemes for synthesis, and the choice of methods, everyone involved in the work was exhorted to express his or her opinion without restraint, after which a discussion would usually be organized. On the basis of ideas and proposals collected from all participants, the leader group would start to make thorough analysis of the studies and weigh the ideas and proposals by evaluating their advantages and disadvantages, and finally arrive at a decision. As for such questions as might affect the whole situation or were hard to solve, higher authorities were approached for decision. With respect to the many diverse academic problems, hasty judgements were never made.. Instead, a set of experiments would be carried out to decide what was correct and what was wrong.

The facts that evolved tended to show that this method overcame the insufficiency of experience and made clear to everybody the significance of his part of the work and what was required of him. Everyone plunged into work conscientiously and with initiative. This was essential for maturation of the research workers. Owing to the democratic atmosphere prevailing in discussions over academic affairs, unity among the institutes and research workers in the cooperation was reinforced, and the cooperative effort was maintained and continued to the completion of the project.

3. When should integration division in carrying out research be fostered?

Much work had to be done in the execution of any one of these projects. The various aspects of the work mutually affected one another. We should therefore always pay attention to the proper balancing of integration and division. Our principle was: most of the work was assigned to the institutes by a directive from the leader group according to a unified plan. The synthesis of the A and B chains of insulin and the synthesis of small fragments of tRNA were all assigned to a certain institute according to a master plan. Certain urgent problems of vital importance were solved by the formation of a joint group, the members of which were drawn from every or from some institutes so as to form one single unit. The number of members in the unit varied with the requirements. In the last period covering the semi-synthesis and total synthesis of insulin, we adopted this form of organization; in the synthesis of tRNA, we formed joint research groups for ligation of the hexedecanucleotide, the preparation of enzymes, the ligation of large fragments, activity assays and also for the final assembly.

From the experiences of the joint research groups, we realized that an effective method of attack is to break through at key points with an overwhelming force, which usually enabled us to push the entire work ahead. For example, joint research on the ligation of the hexadecanucleotide had obviously influenced the design of the scheme and the successful development of future work. In another case, during the later period of tRNA synthesis, two joint research groups were set up for the synthesis of half and whole molecular tRNA and for the activity assays. After two years of hard work, both groups successfully achieved the goals first laid out. Here these joint research groups assumed the integration form. If we had carried out this part of research separately in several institutes, much delay would have occurred, even though the problem might eventually be solved.

Regarding the problem of integration and division, there were two points worth noticing, division of the work into several categories and consideration of the strong points of each institute.

4. The responsibility of the leaders:

The responsibilities of the leaders, when summed up, were: a) to promote confidence in the research workers so that they may persist in carrying the work through to the end, and to be able to, when difficulties arise, effect a cool analysis of the situation and to come to a correct decision and b) during the course of work, to effectively organize manpower in time at critical turning points, to coordinate the work among cooperative units, and to set up strict requirements for the research workers.

In studying insulin and tRNA syntheses, we underwent a crooked course consisting of exploration, failure, further exploration, more failures and to keep on exploring until eventual success. During the course of work many problems arose, not only of technology but also of ideology. When we had made some progress, certain of our participating workers were apt to become conceited. They would begin to relax, and as a result, research was affected. With disappointment following on failures, a few might lose heart and confidence and began to think of abandonment. Furthermore, since it was a long-term cooperation among many research workers from different institutes, it was only human that contradictions would arise from time to time. The members of the leader group should always keep in mind these possible interfering factors and strive to solve them in time to ensure rapid progress of the project.

When the cooperation was just being organized, it was important to have all research workers agree in theoretical outlook and in technical viewpoint. As the work proceeded, emphasis was laid on development of the collective spirit, the free exchange of information and mutual help. Meanwhile, the leader group saw to it that the democratic atmosphere was maintained in discussions on academic and technical subjects such that full play would be given to each individual to express his opinions and foresight for the good of the whole project.

All of these were very complex and painstaking.

The leadership had played an active role in the two research projects which had come to eventual success after having gone through long-term cooperation.

Conclusion

The foregoing is a detailed account of the events culminating in the successful syntheses of insulin and yeast alanine tRNA. The reason why these two pieces of research could be satisfactorily accomplished was, in the last analysis, that they fit in with actual conditions in our country and that our socialist system with its interest merits had provided the proper environment. When the work started, science in China did not have a solid foundation, but as it progressed, our shortcomings were overcome or compensated for through proper organization.

However, research in science has its own specific requirements. Whether a piece of work should take the form of some cooperative effort among several units depends very much upon the nature and substance of the problem. Only upon careful analysis should a decision be made. As for the two above-mentioned projects the eventual outcome certainly is a justification of the policy we have adopted. The chief reasons that prompted the leader group to adopt a cooperative policy were: a) the objects of attack were known chemical structures and thus the ultimate aim was perfectly clear to all concerned and b) the successful outcome of the endeavour was expected. In this sense, both projects bear much resemblance to an engineering project. For purely explorative undertakings, further discussion is required to decide which form of organization is more profitable.

When our research forces were being integrated for a sizable project, other lines of research should have to suffer from a lack or shortage of manpower. In our country which was weak in scientific manpower, how to make good use of our limited resources was a problem warranting careful consideration. The problem was and still is a complicated one, requiring careful weighting of pros and cons. From the first, one should correctly estimate from all aspects the importance of the project and any influence that its successful realizatioin would exert upon related areas. In other words, one should ask if success along one line would bring benefit to a broad area, and promote further work on a higher level. Science being a composite, of an integrated and interlocking system, a breakthrough at one point would surely bear influence on the development of a whole area. The correct handling of all such related factors is of prime importance in science policymaking and therefore remains a subject for further consideration and discussion.

BIOTECHNOLOGY AND THE OFFICE OF TECHNOLOGY ASSESSMENT: PAST, PRESENT AND FUTURE

Gretchen S. Kolsrud

This paper uses technology assessments undertaken in the field of biotechnology by the Office of Technology Assessment (OTA) to illustrate:

- o how a new field of science and technology emerges as an area of Congressional concern;
- o how the public can be involved in the assessment process; and,
- o how science policy follows an evolutionary, step-by-step development in the United States.

As introduction, it is important to understand what is meant by the term "biotechnology." "Biotechnology" is often defined broadly; for example, as the use of biological processes to produce useful substances, to act on the environment to increase the quality of life (as in pollution control), or to improve the characteristics of economically important plants and animals. Defined in this way, biotechnology has been practised for thousands of years. As primitive people moved from a hunter-gathering existence to farming, they selected seeds from plants which grew faster or produced larger fruit, and they bred animals for desired characteristics. Later, fermentation processes were discovered. The Sumerians used yeast to make beer before 6000 B.C., and the Egyptians learned that yeast could leaven bread in about 4000 B.C.

However, the above definition is too broad and does not adequately emphasize the new techniques of molecular biology which are the primary reason for current interest in biotechnology. Therefore, "biotechnology" as used by OTA means the use of <u>novel</u> biological processes such as recombinant DNA, cell fusion, and immobolized cells or emzymes for agricultural, industrial, and other purposes. Thus, classic beer, wine, bread, and fermented foods are not included unless they are modified by the new techniques. For example, while wine production per se is not included, production of wine with a higher alcohol content through genetic engineering would be included.

Biotechnology is not synonymous with genetic engineering. Genetic engineering refers to the directed manipulation of genetic material and is one tool used in biotechnology. Biotechnology also differs from genetic engineering in that it is directed at achieving a commercial objective.

Biotechnology is a term which has become broadly used only in the last two or three years -- as public interest moved from laboratory research in genetic engineering to its commercial applications. When OTA began its work in this field, genetic engineering, recombinant DNA technology, or similar terms were used. Thus, the first section of this paper uses primarily these terms rather than biotechnology.

Biotechnology Emerges as an Area of Congressional Concern

Citizen concern with the safety of recombinant DNA research was very high in the United States in the mid 1970s. Not surprisingly, this concern was reflected in actions taken by some of their elected public representatives. In 1976 thirty members of the U.S. House of Representatives requested the OTA undertake an assessment of the safety of recombinant DNA technology. However, many other groups were studying this issue at the time, and the study was not initiated at OTA.

In 1977 OTA conducted a major survey involving thousands of experts in many fields to identify areas needing technology assessment and to establish priorities among them. Genetic engineering ranked high on the list of priority areas, and the possibility of an assessment was discussed with several Senate and House committees. Considerable interest was found for a study which would include more issues than safety and which would interpret applied genetics more broadly than recombinant DNA.

Letters of support for such a study were received from the Senate Committee on Human Resources and the House Committee on Interstate and Foreign Commerce, Subcommittee on Health and the Environment.

A proposal was submitted to the Technology Assessment Board which called for sequential assessments in three areas of application: agriculture, industrial/commercial, and human. However, the Board felt that study of human applications should be deferred. Accordingly, a study limited to nonhuman applications was approved in October 1978. As is the case with most major OTA studies, this one required well over a year. It was completed in December 1980.

The project began with a workshop to assist the staff in planning the assessment. The workshop was attended by twelve people who represented academia, government, industry, and public interest groups and who had expertise in a broad range of relevant fields, from molecular genetics to ethics, from law to the environment.

Again, typical of major OTA assessments, an Advisory Panel was formed. While conduct of the actual study is always the responsibility of the OTA staff, advisory panels serve a number of important functions including: making suggestions for potential contractors and consultants who can supplement staff work by completing well-defined pieces of the study; reviewing and critiquing contractor and staff products; and, most important, ensuring that the results of the assessment fairly represent all points of view.

The panel was chaired by the Dean of the School of Agriculture and Life Sciences at North Carolina State University. The twelve additional panelists represented the concerns of both large and small firms and of management and workers. Expertise in the law, economics, science-society relationships, and genetic engineering as it applied to plants, animals and microorganisms were represented on the panel.

The panel met six times during the assessment. It provided the staff with useful information and many comments and constructive suggestions for improvement as the report was developed.

Two workshops were held to deal with particular aspects of the assessment. The first was to investigate public perception of the important issues in genetics. Twenty-three citizens who were not experts in genetics spent one day with the OTA staff. They ranged from those with almost no formal education to those with advanced degrees. They worked in a variety of occupations, come from different socioeconomic levels, and spanned about four decades in age. The workshop was very useful in gaining an understanding of public knowledge, opinions, and concerns on various aspects of genetics.

A two-day workshop on genetic applications to animals was also held. Thirty-five major scientists, applications experts, and government representatives prepared and presented papers on the state of the art in animal reproductive sciences, artificial insemination, embryo transfer, and similar areas as well as on economic implications and impacts of advances in animal reproductive biology. This workshop was felt by its attendees to have made a substantial contribution by fostering interdisciplinary communication among groups which had been working in relative isolation from each other. Of particular value to the assessment, the workshop developed a consensus on the time frame for the development and wide application of the more esoteric technologies which was of critical importance to the part of the study dealing with applications of genetics to animals. The papers presented at the workshop became the basis for a book edited by the contractors who managed the workshop for OTA. This book was published by a commercial publisher (Academic Press) under the title <u>New Technologies in Animal Breeding</u>.

Many people were involved in assessment. Besides the ten member OTA staff, there were seven major contractors and twenty-eight minor contractors and other contributors. Another 104 people were acknowledged in the final report for their assistance.

To assure that the work of the Office is complete, as up to date as possible, and accurate and unbiased, extensive use is made of outside reviewers. These individuals critique both contractor reports and the final report of the assessment which is prepared by the OTA staff using the contractor reports, the literature, personal knowledge, and information obtained from subject matter experts with whom they are in personal contact. For example, one contractor report was on applications of genetics to the pharmaceutical industry. It was reviewed by 22 people. Several contractors reviewed each others' findings. The draft report on the entire assessment prepared by the OTA staff was reviewed by sixty outside reviewers, ten reviewers within OTA but external to the project, and the 13 advisory panel members. External reviewers were drawn from academia, industry, the law, and the major Executive Branch agencies concerned with biotechnology.

This assessment, then, resulted in a report on the application of genetic technologies to nonhuman life forms. It covered classical and molecular genetics, and its objectives were to establish the state of the art research and development in these fields and to assess probable economic, social and environmental impacts. To accomplish these objectives the assessment looked at applications to microorganisms to produce substances in three major industrial sectors: pharmaceuticals, chemicals, and food. Three potential applications which could involve release of genetically altered organisms to the environment were studied, namely, mineral leaching and recovery, enhanced oil recovery, and pollution control. Applications to higher plants and animals were also included. Additional parts of the report addressed the problem of assessing the risk of genetic engineering, its regulation, patenting of life forms, and science society issues raised by the new genetic techniques. As with all OTA reports, policy options were developed, and the pros, cons and consequences associated with them were described for Congressional consideration.

As the study points out, new genetic technologies developed in the past ten years will have a major commercial impact on the pharmaceutical, chemical, and food industries, probably in that order. In the pharmaceutical industry, biological production in the absence of recombinant DNA is already used to produce about 20% of prescription drugs. The new genetic techniques will enable biological production to replace chemical synthesis or extraction from animal or plant tissues for many products. Human genes have already been transferred to bacteria for the production of insulin, growth hormone, interferon, thymosin-alpha-1, and somatostatin, and the new technologies open up new possibilities for developing vaccines for such intractable diseases as hepatitis and malaria. Other pharmaceutical products likely to be affected in the next 10 to 20 years include most antibiotics, enzymes, antibodies, and many hormones.

The chemical industry is one of the largest and most important industries in the world. The target for biotechnological applications is organic chemicals. These represent one third of the industry. The size of the market is shown by the fact that the 1979 U.S. market for synthetic organic chemicals was about $[illegible] billion.

Ninety percent of the substrate used for synthesis of these chemicals today in the U.S. is petroleum. Biotechnology represents an attractive alternative to chemical synthesis for several reasons including: 1) it enables use of renewable resources such as biomass rather than petroleum; 2) the reactions occur at temperatures and pressures compatible with life which may result in further energy savings; and 3) the pollutants and side products are often less noxious than those associated with chemical production.

The report estimated that $22 million of bulk organic chemicals could be commercially produced by genetic engineering in ten years and that the value would rise to $7.1 billion in 20 years. The combined potential of both the chemical and pharamaceutical markets deriving from the genetic techniques was projected at $14.6 billion which would require 30,000 to 75,000 workers.

Potential applications in the food industry are of two types. First, genetic techniques may be used to transform inedible biomass into food for humans and animals. Second, the food processing industry may directly benefit through development of new kinds of organisms to process food.

Application of the new genetic techniques to plants has been hindered by the fact that plants are genetically very complex, and current knowledge of plants at the molecular level is extremely limited. Success in tissue culture and regeneration of economically significant plants (e.g., grains) has also been limited. Finally, few vectors have been developed for the transmission of desired genetic traits into plants.

Thus, applications of biotechnology to traits in plants that are determined by the interaction of many genes, such as increased photosynthetic efficiency, nitrogen fixation by nonleguminous species, and increased yield, are long-term prospects. A commercially available product in these areas is unlikely in the next ten years. However, some significant characteristics of plants appear to be much simpler genetically, and plants genetically engineered for improvements in these characteristics may be developed sooner. Examples are resistance to diseases, saline and alkaline stress, drought, herbicides, and pesticides.

Animals are also genetically very complex, and the new techniques will probably not be used to directly affect animal production in the next ten years. However, use of genetic engineering to produce animal vaccines and hormones will be an important area of application in that same time frame.

At the time the report was prepared, there had not yet been significant work on the application of genetically engineered microorganisms in three areas involving their release to the environment: mineral leaching, oil recovery, and pollution control. Major obstacles were technical constraints and concern about potential effects of such released organisms to human health and the environment.

The report noted that while there was no evidence that any unexpectedly harmful genetically engineered organisms had been created, this does not prove that such an event could not occur. Nevertheless, as a result of the knowledge gained in the use of these techniques, the Guidelines for Recombinant DNA Research promulgated by the National Institutes of Health have been progressively relaxed.

The movement from the laboratory to commercialization has given rise to new concerns over the health and safety of production workers and consumers. However, in most cases, current Federal laws, such as those which regulate foods, drugs, and cosmetics, seem adequate to deal with the risks. Less clear is the adequacy of regulations to govern production methods of applications involving intentional release of genetically engineered organisms to the environment.

In the course of the assessment, the issue of the patentability of genetically engineered microorganisms was heard by the U.S. Supreme Court. In a 5-4 vote the Court ruled in the affirmative. Implications of the decision for the patentability of more complex organisms were not clear. In any case, the report concluded that the decision was not crucial to the development of the industry because there are alternative approaches to protecting commercial interests such as trade secrets or the patenting of nonliving components of organisms such a plasmids.

Finally, the study developed a number of policy options which Congress might choose to follow to further the development of the industry. These covered a range of topics, from ensuring an adequate supply of critical skills to patentability. For example, the Supreme Court specifically invited the Congress to overrule its decisions on patentability if Congress disagreed with it. Congressional options on this issue thus ranged from taking no action with regard to the decision, overruling it, or developing a comprehensive statutory approach to patenting of living things. The implications of these options were described in the report.

The report was used to brief staff members of Congressional committees in the House and Senate with responsiblity for science and technology and for agriculture. Knowledge gained as a result of the study enabled the OTA staff to be of assistance to the Subcommittee on Investigations and Oversight of the House Committee on Science and Technology in preparing for hearings on the commercial development of biotechnology and on potential problems in university-industry relationships associated with such commercialization.

The report was also of use to others besides the U.S. Congress. Many newspapers and magazine articles were based on it thus providing the general public with further information on the potential of applied genetics. Because OTA work is in the public domain, commercial publishers, if they feel there is a market for a report prepared by the Office, may obtain copies of it at no charge and publish and sell the report to the general public. This occurred in the case of the assessment, and the report was published commercially by Westview Press. The commercial version was a Library of Science Book Club selection further bringing the work of the Office to the attention and benefit of the public.

As examples of use to other countries, the report was translated into Japanese. Its findings were also summarized and distributed to a conference on biotechnological applications of interest to less developed countries which was held in India.

Biotechnology Becomes A Continuing Area of Congressional Concern

In 1981 the Senate Committee on Commerce, Science and Transportation and the House Committee on Science and Technology requested that the Office of Technology Assessment undertake a second study. The new study, which was approved by the Technology Assessment Board and initiated in October 1981, follows naturally from the first. Its objective is to compare the development of biotechnology in the United States with that in other countries, describe the factors facilitating and constraining commercialization, and estimate the probable competitive position of U.S. in biotechnology in the years ahead.

There are several reasons for continuing Congressional interest in biotechnology. One is that biotechnology has been increasingly recognized as a major area of innovation, as significant as the splitting of the atom or the invention of semiconductors. Response to the potential of biotechnology has been both rapid and large as illustrated by figures presented at the conference on genetic engineering held in April 1981. The cash value of corporate investment in genetic technology rose from about $92 million in 1979 to $339 million in April of 1981. Excluding drug firms, the value of industrial research and development (R&D) rose in the same period from $80 million to between $500 million and $700 million. Shares in firms specializing in this new technology were not available to the public in 1979, but by April of 1981, the value of public offerings reach $1.1 billion. In fact, the genetic engineering firms have at least two firsts on Wall Street. One was Genetech's public offering -- Genetch went public as a small firm with negligible profit for the year and without one product on the market; yet its per share price went from $35 to $89 in 20 minutes after trading opened. The second was when Cetus went public. The price rise of Genetech was not repeated for Cetus, but Cetus was the largest initial public offering in U.S. corporate history. At a time when Congress is concerned with the ailing U.S. economy and declining U.S. productivity, biotechnology is seen as a possible solution to these problems, provided the U.S. establishes a competitive position in the field.

Another reason for Congressional interest is that problems associated with the commercialization of biotechnology are emerging which concern members of Congress. One of these is the problem of university scientists who found new companies in order to capitalize on their research in biotechnology while they continue to hold positions in the university. A variety of issues associated with such arrangements are of Congressional concern, for example, potential distortion of basic university research to applied ends and ensuring an adequate return to the public from public funds awarded by the government to support university research. Do small firms begun by university scientist/entrepreneurs represent capitalizing upon the fruits of publicly funded research for private gain?

The commercial development of biotechnology also raises issues of regulation and patenting, some aspects of which have been mentioned earlier in this paper. Both of these are areas of Congressional interest and juridiction.

A final reason for a second study was that, like all studies conducted in the fast moving technological areas, the first study was out of date at the time it was published. For example, it contains almost no treatment of the hybridomas and the monoclonal antibodies which these make possible because their commercial implications were just being realized at the time the first study was completed. Yet the Food and Drug Administration, from queries of 190 specialists, found that the medical technology predicted as most important in the next ten years was hybridomas. Two years ago there were no U.S. firms capitalizing on this technology. Now there are over 40. Clearly the first study not only could be extended but also needed to be brought up to date.

The second assessment has been underway for ten months and is scheduled for completion in July 1983. Reflecting the breadth of the study, a relatively large Advisory Panel has been formed. It has nineteen members which represent large and small firms in the industry, academia, venture capital interests, the sociology of science, interests of labor and management, and states within the U.S. which are interested in establishing centers of biotechnology. Panelists have subject matter expertise in such fields as molecular genetics, economics, technology transfer, and political science. Some have knowledge of particular countries such as Japan. The advisory panel has met three times since the initiation of the assessment. Panel meetings are also attended by the liaison representatives from a number of Executive Branch agencies concerned with biotechnology and its commercial development, staff members of interested Congressional committees, and staff from other Congressional agencies such as the Congressional Research Service of the Library of Congress.

There are several methodological problems associated with this assessment. First, it was necessary to establish a definition for biotechnology because the term is used very differently both within this country and in other countries. The definition being used by OTA was presented in the beginning of this paper.

Second, it was necesary to establish that the term "biotechnology industry" is a shorthand way of referring to a rather diverse set of firms in the United States. One the one hand, the industry includes new firms established specifically to develop and/or market products using genetic technology, especially recombinant DNA and cell fusion. Most of these firms are less than three years old. The industry also includes established firms considering using biotechnology as an alternative to presently used chemical synthesis or extraction from tissues or to prepare new products which may fall into any one of a number of industrial sectors such as pharmaceuticals, chemicals, mining or pollution control. In this sense there is no biotechnology industry per se but a set of techniques which may be used by many industries. Nevertheless, such established firms are classified in this study as part of the biotechnology industry.

The final group of firms included within the "biotechnology industry" consists of those which are not applying the novel biological processs themselves but which support firms that are. Forms of support include the preparation and sale of reagents specifically used in genetic engineering such as restriction enzymes; the production of apparatus uch as fermentors or DNA synthesizers; and the supplying of information, such as on DNA sequences.

Finally, since the assessment is concerned with the relative competitive position of various countries in biotechnology, it was necessary to consider whether to actually measure competitiveness and if so, how.

To this end, it was noted that competitiveness means the relative ability of a country (and more particularly, the firms within that country) to succeed in the international marketplace with biotechnology products.

Yet quantitative measures of competitiveness in the biotechnology industry are not likely to be meaningful. For example, one accepted measure of competitiveness is market share. This measure cannot be applied because so few products of biotechnology have reached the market. One approach to the problem would be to use market shares of existing products which could be produced by biotechnology. However this approach would not be very informative because: 1) the cost and timing of the replacement of many of the current processes in existing markets are largely a matter of speculation, and 2) there will be substantial new markets of unpredictable size (e.g., interferon).

Therefore, it was decided that the best approach would be to identify factors that will facilitate or retard the development of a competitive position both in this and in other countries. Essentially these are the factors which will affect the efficiency of translation of research into application. The importance of the factors in different countries will vary with the cultural and sociopolitical milieu and can be compared in terms of their influence upon competiveness with each country (e.g., labor costs do not appear to be as important to competitiveness in biotechnology as the patent environment). Factors can also be easily compared among countries. For example, the structure of the industry varies among countries; the particular structure in Japan favors commercialization, whereas the U.S. structure tends to favor intervention. Finally, with judgments as to the importance of the factor and its relative state in various countries, policies can be suggested with some certainty of their probable effect on competitiveness.

The study is being conducted with a staff of eight and a number of outside contractors. To date, ten contracts have been let. Four of them deal with various aspects of the state of the art of the technology, specifically, with hybridomas; plant agriculture; animal agriculture; and the applications technology, fermentation (or biochemical engineering). Four other contracts are for case studies of the development of biotechnology in selected countries; specifically, Brazil, France, Germany, Japan, Switzerland, and the U.K. The ninth contract is for a study of industry-academic relationships at three California universities. The tenth is concerned with U.S. and foreign intellectual property law relating to biotechnology. Additional contracts are anticipated on such topics as health, safety and environmental regulation in other countries, and antitrust issues.

Given that the study is less than half complete, results cannot be provided. Instead, brief discussion of a few of the issues follows to illustrate the approach being taken.

First, it is clear that competitive position will depend upon a firm, or a country, either having, or obtaining access to, the state of the art in relevant fundamental genetic research. However, research does not guarantee competitiveness. Equally important is capability in such bioengineering processes as fermentation and enzyme technology. Thus, both of these aspects are being assessed in this study, both in the U.S. and in other countries.

Many other factors will influence industry health in this and other countries. One example is financial health. Changes in the U.S. tax laws vastly increased the supply of venture capital in the late 70's, and thi, coupled with the glamour of the biotechnology industry, led to the capitalization of a number of new firms through public offerings. The number of public offerings in biotechnology with 1 in 1979, 4 in 1980, 16 in 1981, and 2 so far in 1982. In two years the public has invested a third of a billion dollars in bioengineering firms.

The vast majority of the new firms are privately held, and thus information on such characteristics as annual revenues and net incomes is often not available. From what information is available, it can be said that annual revenues are often less than $1 million and rarely over $5 million. Net income is often negative.

Both the public and the venture capitalists are becoming more sophisticated, and funds for biotechnology are less available today. An understanding that revenue from biotechnology products will take longer to realize than originally anticipated undoubtedly has contributed to the poor market performance of the publicly held biotechnology companies over the last year and to the increasing scarcity of venture capital. Second and third round financing will not be available for all the new startups, and many will disappear. One estimate is that about 50 of the new companies will go bankrupt. Others will be acquired by large firms.

Some shakeout is undoubtedly healthy for the industry. The question is how much shakeout will occur and what is impact will be on the innovative capability of the industry.

Another major influence on the development of biotechnology will be government policy. It will shape the industry in the U.S. and in the countries which are its major competitors. Of importance is whether the country has an explicit policy or comprehensive plan for facilitating the commercial development of the technology and whether it allocates funds for that purpose. The U.S. does not have an explicit policy with regard to biotechnology. However, there has been a steady increase in Federal spending for basic molecular biology research. In 1978 NIH invested about $30 million in recombinant studies; in 1979, about $60 million; and in 1980 total government expenditure on more than a thousand separate projects was estimated at $120 million (with NIH funding nearly $100 million; NSF, $18 million, and the Department of Agriculture, $3 million). The number of published research papers grew from 400 in 1979 to 800 in 1980.

In the U.K. several position papers on British biotechnology have been prepared since 1980; notably the "Spinks" report, the Government's White paper, and a report from a working group of academics and industrialists. To date, the Thatcher government has taken the position that biotechnology should be developed by private industry. If this occurs, it is likely to be done by large firms since the climate of venture capital combined with the entrepreneurial interests of highly skilled professors which has been seen in the U.S. does not seem to be occuring in Britain. Despite the lack of direct support at the highest levels of British government, it appears that the British civil service feels that biotechnology should be encouraged. Thus, certain steps recommended in the Spinks report have been taken including the coordination of U.K. biotechnology activity by public organizations and the allocation of available funds to applied research. Further, a combined private-public organization, Celltech, has been set up to facilitate the translation of publicly funded basic research to practical application.

Interestingly, a report from a working group of academics and industrialists does not see a manpower shortfall with the exception of a few academic posts. The problem of increasing the interaction between departments of biology and chemical engineering so as to be better prepared to apply this new technology receives little treatment.

As for the U.K.'s interests in areas of application, these appear to be broad, but pharmaceuticals and agriculture are receiving particular attention.

In France the lack of a clear distinction between public and private sectors means that government interest is especially important if biotechnology is to flourish in that country. The French government appears to be strongly supporting biotechnology. A biotechnology mission has been set up in the Ministry of Science and Technology to coordinate activities. It is also preparing a biotechnology "plan" for the next 5, 10, and 20 years and budget proposals for 1983, 1984, and 1985. Attempts are being made to collect data on funding and manpower. Lack of such data makes estimates of the adequacy of these two factors impossible at present. However, there is a high probability that manpower will be a problem because biology has only recently been recognized as a subject of importance to France. Traditionally, mathematics and physical sciences have been considered far more valuable.

Japan is a major competitor in biotechnology and thus of special interest. Unlike the U.S, the Japanese government has made an explicit decision to emphasize biotechnology as a key "macrotechnology" of the next twenty years. The Ministry of International Trade and Industry (MITI) has included biotechnology as a major research theme in the New Basic Industrial Research Plan. A technical association for the development of biotechnology was established in August 1981. Fourteen leading chemical, pharmaceutical, and food firms are participating in this research association which will spend $26 billion yen ($110 million) on biotechnology in the next 10 years. Five other government agencies have projects underway in biotechnology.

Many firms are involved including some of the largest such as Mitsubishi and Mitsui. Mitsubishi Chemicals is ranked first in Japan for basic genetic engineering research.

Japan lags behind the U.S. in recombinant DNA technology but is rapidly increasing its capability. And many feel that Japan leads in fermentation. Its conventional fermentation industry is very large, accounting for 5% of Japan's gross national product. Some of the manpower deficiences found in the U.S., for example, in microbial physiologist and fermentation engineers, do not appear to be mirrored in Japan.

Besides the tools of funding and policy, governments can shape the development of biotechnology by changing the legal and regulatory environment, by changing laws or guidelines governing research and consumer and worker health and safety, and by tax laws, antitrust laws, and patent policy. For illustrative purposes, brief consideration will only be given to the last.

There are differences in patent law between countries and the question is whether these may limit free exchange of information in this new field. Thus, in the U.S. a researcher has a one-year grace period in which to file a patent after disclosure of an invention. Japan has a 6 month grace period. Disclosure prior to filing invalidates a potential patent in many other countries.

A last example of a significant factor in determining U.S. competitiveness in biotechnology is university-industry relationships. The university contribution to U.S. competitiveness in biotechnology is particularly important in two areas: 1) provision of trained personnel; and 2) advances in basic research. Related to each of these is the fact that in the United States the universities have been the source of scientist-entrepreneurs who start new companies to commercialize their research. Such persons, when they retain their university connections, have stimulated re-examination of conflicts of interest and similar issues raised by the different goals and demands of the academic and commercial worlds. Inevitably, government becomes involved as yet a third party with its own goals directed at national objectives.

It must first be noted that the goals of universities and industry differ. The goals of the university are education and unhampered pursuit of knowledge while those of industry are profit-making and increasing a firm's market share. Universities and industry are mutually dependent, but each must recognize the safeguards necessary to preserve each other's autonomy. For example, universities emphasize basic research while industry engages in both basic and applied research targeted at the development of new processes, products, and services. The time frames of each differ: industry, always aware of competition, must move quickly; universities keep to academic calendars with scheduled examinations and time for the reflective development of theses. Finally, the university must maintain credibility and objectivity as an institution that serves as the repository and provider of knowledge and education.

It is also important to note that university-industry relations have changed over time in response to changing social needs. Science has been a force of change in university-industry relationships. Tension between science as an intellectual endeavor and as a factor in economic gain did not arise until the twentieth century. At that time, scientific research became so expensive that it was beyond the capability of universities to support. However, both industry and the university concurred that science should be done in the university rather than the industrial setting and developed mechanisms to enable its continued existence there with financial support from industry. However, in the 1920s and 1930s, patent and funding issues arose in the physical sciences and concern was expressed over the detrimental influence of industry. During and after World War II, public perception of the danger of industrial control of universities reached a peak. A major factor was the perceived role of the pursuit of pure knowledge in winning the war and the feeling that pure knowledge can only be pursued in a university setting. To ensure scientific preeminence through pursuit of knowledge without outside influence, government funding was substantially increased. Thus, government support in the U.S. has grown from zero (except in agriculture) in 1939 to the point where it greatly exceeds the contribution from industry today. Today the pendulum is swinging again as shown by concern with the increasing tendency of grants to reflect funding agency priorities and the heavy demand on the time of professionals to prepare applications or to demonstrate accountability. One sign that society has recognized the need once again for change is the change in tax law permitting industry an increased deduction for contributions to university R&D.

The conflict between goals have given rise to a number of issues that many groups are trying to resolve. Significant events are the Parajo Dunes conference, the guidelines that have been drafted by a committee representing the Agricultural Experiment Stations, and guidelines expected in October from the American Association of Universities, the Agricultural Division of the National Association of Agricultural Experiment Stations and Land Grant Universities, and the American Civil Liberties Union. Fundamental issues are as follows:

- conflict of interest. This is emerging as the major issue. An example is a faculty member with an equity position in industry. The fundamental question is disclosure, that is, whether faculty members must reveal their extra-university affiliations.
- conflict of commitment. Consulting facilitates technology transfer and supplements faculty income. At the same time extensive consulting with a particular firm could lead to conflict of commitment. Even within universities, departments vary in their disclosure requirements. What is excessive is difficult to define, and most departments are reluctant to police consulting too closely. Requiring detailed disclosure can be detrimental because some faculty could be damaged by attitudes of guilt by association.
- patents, including tangible research property and licensing. Of concern are the conditions under which exclusive licenses should be allowed, how cell lines and other tangible research property should be handled, and whether the investigator should relinquish any royalties he receives to his school.
- the use of the university name by industry, protection of university credibility and protection of the university from liability.
- the degree to which there should be peer review and consensus on relationships established between faculty members and industry.

- consistency in funding. Inconsistency has been a problem with government funding and is now becoming a concern with industry funding, e.g., through bankruptcy. Several university-industry agreements contain specific provisions for termination of funding.
- personnel. The degree to which this is a problem is questionable but there are clearly specific shortages, for example, plant molecular biologists. Whether there is a shortage of biooengineers is equivocal.
- comingling of funds. Accounting procedures now in place appear adequate, but a definitional problem may remain in the form of a de minimus provision of the new patent law.

The above descriptions briefly indicate some of the issues being studied in OTA's current assessment of technology. As should be apparent, while there is clearly a great deal of activity in biotechnology in the U.S., there are some areas of concern. Among these are:

- the possible adverse impact on the development of the field of bankruptcies among the new small firms;
- the adequacy of capital for scale-up;
- unresolved issues in patent and regulatory laws;
- possible shortages of critical skills in such areas as plant molecular biology; and,
- evolving relationships between universities and industry.

These and other issues will be studied further during the remaining year of the assessment.

Speculation On Future Congressional Concerns in Biotechnology

The promise of biotechnology and its potentially wide applicability to many industrial sectors coupled with the intense interest of other countries suggest continuing Congressional interest in assessments in this area. Given diminishing petroleum preserves and a desire to significantly reduce U.S. dependence on foreign oil, one area likely to be of interest for a detailed assessment is on biotechnology as a contributor to reducing petroleum needs. Such an assessment would describe the present state of the art and potential contribution of biotechnology to each of the following areas:

- production of nonfuel substances now produced from petroleum substrates;
- production of fuel substances (e.g., ethanol, methanol) from nongrain sources (lignin, cellulose) and from animal and human waste;
- increased efficiency of alcohol production from grains; and,
- use of genetically engineered microorganisms to release trapped oil and to improve oil drilling.

Another area of great significance in terms of the ethical, emotional, and moral issues that it raises is alteration of the genetic characteristics of humans. Societal issues raised by this possibility vary with the type of alteration. Thus, correction of genetic defects may be expected to be much less controversial than deliberate genetic engineering to produce particular characteristics. Though most human characteristics of interest, such as intelligence and athletic ability, are determined by many genes and are far from our ability to alter in a direct manner at the present time, the potential for such alteration lies in the future. Given the complexity of the issues, it may be that Congress will decide they should begin to be addressed now.

SOME PROBLEMS IN THE RESEARCH AND DEVELOPMENT OF ANTIBIOTICS AND TRADITIONAL CHINESE MEDICINE IN CHINA

Zhang Shugai and Hu Yongchang

Since the founding of New China, a large-scale economic construction has been launched in this country. In view of the important role which scientific research plays in the production and construction of the country, our government has paid great attention to the advancement of science and adopted a series of measures to organize scientists to work in various important fields of science and technology, so that they could serve the cause of socialist construction more effectively and our country would join the ranks of those scientifically advanced countries in the world as soon as possible.

Research and development of traditional Chinese medicine and antibiotics occupy a prominent position in drug research and in the domain of medicine and hygiene in this country. During the period of the first five-year plan, the research and production of antibiotics was listed among the most important items in the economic construction projects of our country. In the national programme for the advancement of science and technology drafted in 1956, research on antibiotics and traditional Chinese medicine was again included among the 57 important items of scientific research. With regard to traditional Chinese medicine, after liberation there was an erroneous trend that some people looked down upon and rejected the adoption of traditional Chinese medicine, but our government promptly rectified the deviation and established the policy to protect and develop traditional Chinese medicine. As a consequence of the attention paid and a series of proper policies and measures adopted by the government, we have since made rapid progress in these two fields, and this has contributed greatly to the cause of medicine and hygiene and to the development of science in our country.

In this article, only some facets of the research and development carried out in these two fields will be briefly discussed.

RESEARCH AND PRODUCTION OF ANTIBIOTICS OCCUPY A PROMINENT POSITION IN CHINA

Ever since the fourth decade when penicillin first appeared, many countries all over the world have made great efforts to carry out research on antibiotics. Not only have antibiotics shown to be highly effective against common bacterial infections and tuberculosis and thus greatly changed the status of medical treatment, but they have also shown some promise in the treatment of tumors and virus diseases. In recent years, some scientists assumed that these microorganism metabolites might be used to influence enzyme activity or immunological function within living organisms and thus might be effective in still some broader areas.

Owing to the virtues and significance which antibiotics possess as mentioned above, they have achieved very rapid progress. In the United States, the production of antibiotics has expanded at a rate of 10 to 20 per cent yearly and reached a total output of 10,000 tons in 1977. New antibiotics are now still being discovered in Japan and other countries and even more rapid progress is seen in the field of semi-synthetic antibiotics.

Even though China is such a big country, before liberation she did not have the ability to produce even one gram of antibiotic. After the founding of new China and having hardly revived from the wounds of war, we launched a socialist construction on an unprecedented scale. The demand for medicine and hygiene by the great masses of the people increased tremendously, and there was an especially urgent need for antibiotics. At that time, full-scale reconstruction was underway and a thousand things remained to be done. Nevertheless, our government took into consideration the importance of antibiotics and made research of antibiotics one of the major research projects of the country. More than 30 years have elapsed since that time and the production of antibiotics in this country has grown rapidly. In 1952, the production of penicillin in our country just reached the stage of pilot plant production. It increased to approximately 10 tons in 1956. In 1966, 30 kinds of antibiotics with a total output of 2,000 tons were produced. This expanded to 4,000 tons in 1971. The 1982 total output is expected to be less than 10,000 tons nowadays, there are factories producing antibiotics nearly in all the provinces and major cities in this country. Judging from annual output, China has become one of the largest antibiotic producing countries in the world. In the main, we can now meet the need for antibiotics of our people and also have the capacity to export some of the species even in large quantity.

The advancement of our antibiotic production is closely related with research work in this field. In view of the need for antibiotics by our country and people, the then newly established Chinese Academy of Sciences made research of antibiotics one of its 11 major research projects. In some of its institutes namely the Institute of Organic Chemistry, the Institute of Materia Medica, the Institute of Plant

Physiology and the Institute of Microorganisms, scientists of various disciplines carried out cooperative research on antibiotics from different angles. The aim of their research was to solve the problems in the production of antibiotics, in order to meet the health needs of the people.

With the aim of organizing scientists from both inside and outside of the academy to make a joint effort in the research of antibiotics and at the suggestion of the Chinese Academy of Sciences, a so-called Shanghai Committee for research work on Antibiotics was established in 1952 in Shanghai, which was one center of research work on antibiotics in this country. In 1955, it proceeded to form the National Committee for Research Work on Antibiotics. The mission of the committee was to guide the units concerned in mapping out their plans according to the demands of the country and the policy concerning the research and production of antibiotics put into effect by our country, to push forward and examine research work on antibiotics so that the manpower and facilities of the units concerned can be concentrated to solve the various problems in the research and production of antibiotics in a well-planned and orderly way. These measures make scientific research benefit production better.

The Shanghai Committee for Research Work on Antibiotics organized under its projects not only scientists from the Chinese Academy of Sciences but also from colleges and universities and the research institutes in industrial and medical spheres, and engineers and technicians from factories producing antibiotics. At that time, the total number of persons engaged in this work amounted to about 100.

Research work on antibiotics is comprehensive. It covers scientific investigations, industrial manufacturing and clinical practices and has something to do with such different branches of science such as microbiology, biochemistry, organic chemistry, chemical engineering, pharmacology, medicine, etc. It is, therefore, extremely necessary to organize everybody from the above mentioned fields to do research work cooperatively under unified leadership. The Committee effectively conducted a large amount of such cooperative works. It was composed of senior scientists and administrative leaders of the related units and thus possessed a certain degree of authority. It drafted a unified plan with unequivocal guiding policy and aims and made rational division of tasks among these units. Moreover, the Committee set up several working groups each with its own responsibilities. In this way, the Committee was able to exert its leadership concretely and thoroughly, while the leaders of the units were also able to fully exert their leadership within their own units. The Committee paid a lot of attention to the interchange of scientific ideas and experiences as well as the results of research work of all units. The Committee also helped the units to promote solidarity and mutual understanding and told them to respect each other.

In line with the status of development of antibiotics and the necessity of our country at that time, the Committee emphasized the arrangement on four important antibiotics namely pencillin, streptomycin, chloromycetin, and aureomycin. Since penicillin and chloromycetin had been put into trial-production in factories, the aim of the Committees was to coordinate with the factories to solve the key problems in the scientific and technical aspects of the production of these two antibiotics. As for streptomycin, the Committee urged the units to start laboratory work at once to elevate the units of this antibiotic in the culture medium, to study on physiology and metabolism of the strains producing the antibiotic and to isolate the metabolic products. It was requested that a process for the production of streptomycin be established and to provide the necessary data for projecting a pilot plant. In addition, the Chinese Academy of Sciences also launched a research project on new antibiotics. Under the organization and coordination of the Committee, scientists worked with extraordinary zeal. They not only gave full play to their own specialty, but also cooperated very well with each other and learned the strong points of others to offset their own weaknesses. Thus rapid progress was achieved, with the result that the trail-production and the production of the four antibiotics mentioned above also advanced by leaps and bounds.

To review the research work on antibiotics in this country, a national symposium on antibiotics was convened in 1955, under the sponsorship of the Chinese Academy of Sciences. All scientists engaged in research on antibiotics in this country flocked together, and some foreign scientists were also invited to attend the meeting. In the symposium, experiences of the researchers on antibiotics in our country were fully exchanged and the research work on antibiotics carried out after the founding of new China was thoroughly reviewed. The State Council and the ministries of government concerned all paid ample attention and gave strong support to the symposium. Scientists expressed their own views freely and put many valuable opinions and proposals, from the guiding principles and policies for the development along the line of antibiotics in our country to specific problems in scientific and technical aspects. On the basis of this symposium, the Committee made detailed dispositions on many problems such as the trial-production of some important antibiotics, research on new antibiotics, basic research on antibiotics and research on the application of antibiotics in medical, agricultural, and industrial uses. Through this symposium the research forces on antibiotics of our country were further organized to join in a common effort, this created a better condition for the development of the cause of antibiotics in our country.

There established a specific group on antibiotics under the National Committee of Sciences and Technologies in 1957. It led and organized the research work of antibiotics successively.

Along with the development of the cause of antibiotics, the research forces on antibiotics in our country also grew rapidly. The industrial enterprises have paid a lot of attention to the construction of some base units for the research and production of antibiotics and to the training of technical staff. In the long period in which our country was segregated from foreign countries, everybody displayed the spirit of self-reliance to surmount the difficulties one by one. Many kinds of antibiotics come out of factories one after another. In the meantime, a large number of qualified scientists and technicians grew up. This raised our level of research and production of antibiotics ceaselessly. For example, we have bred quite a lot of high yielding strains and in the 1960s the units of penicillin in the cultural medium approached the world level at one time. In the 1970s, the production of tetracyclines in our country achieved rather rapid development. Both units of antibiotics and total yield of production reached a rather high level until the tretracyclines were still being exported in large quantity and occupying an advantageous position in the world market. Our scientists have so far isolated about 20 antibiotic producing strains from the abundant microorganisms in our soil, some of which have already been delivered to factories to be put into production. This freed ourselves from the situation of depending on foreign countries to supply the antibiotic producing strains and created a condition for us to produce antibiotics on self reliance.

THE INTEGRATION OF TRADITIONAL CHINESE MEDICINE WITH WESTERN MEDICINE PROMOTED RESEARCH AND DEVELOPMENT OF MEDICAMENTS

The position of traditional Chinese medicine in the history of our country: According to legend, there appeared in ancient China about 2700 B.C. a founder of traditional Chinese medicine named Shen Nong. He had tried to take hundreds of herbs to find out many crude drugs and taught people how to treat diseases. In thousands of years elapsed, our ancestors have accumulated a rich and colorful wealth of literatures on medicaments, the total number of which amounted to about 400. In the 2nd century, there appeared the oldest book on medicaments which are still now existing with the title "Shen Nong Ben Cao Jing" which means "Shen Nong's Scripture on Medicinal Herbs." The book enlisted 365 different kinds of medicinal herbs. The potency of some of which such as Chang Shan (*Dichroa febrifuga*) for malaria, Ma Huang (*Ephedra Sinica*) for asthma and the analgesic Wu Tou (*Aconitum carmichaeli*) has already been verified by modern scientific research and their active in principles have been isolated by scientists. In the 6th century, the emperor of the Tang Dynasty ordered that a so-called "Xin Xiu Ben Cao" by compiled. The title of the book means "newly compiled Pharmacopoeia of herb medicines." This was the first pharmacopoeia ever appeared in the world and was more than 800 years ahead of the Nuremberg Pharmacopoeia which was published in Europe in 1542. 844 kinds of different herb medicines were listed in "Xin Xiu Ben Cao" which included both Chinese herb medicines and herb medicines imported from foreign countries. In the 16th century, the great pharmaceutical scientist of our country Li Shizhen summed up the rich experiences before the 16th century on medicine and medicaments of our country and spent all his lifetime personally investigating and collecting specimens. As a result of his tremendous efforts, he wrote the monumental work "Ben Cao Gang Mu" meaning "Classified Outline of Herb Medicines," which was composed of 52 volumes and included 1,892 different kinds of herb medicines. For each of the herb medicines listed, there was a detailed description of its name, species, places of production, morphology, cultivation, collection, processing, medicinal properties, taste, and uses. There were also the sketches of these medicinal herbs. This book is one of the most important literatures in pharmaceutical science of the world. It has already been translated into many foreign languages and has spread far and wide in the world with great influence.

The rich knowledge of traditional Chinese medicine and herbal medicines has not only been inherited by the later generations through this vast amount of literatures on medicine and medicaments, but also through the practitioners of traditional Chinese medicine and veteran workers of herbal medicines who passed their skill and artistry from generation to generation. Besides, China is a country of such a vast territory and rich natural resources, there is a vast reservoir of folk experiences which has been accumulated and produced ceaselessly by the people in their long struggle against diseases. In short, it has been verified through practice that traditional Chinese medicine and pharmacology are a great treasure house which has made great contribution to the prosperity of the Chinese nation and to the pharmaceutical science of the world and has occupied a prominent position in the realm of science. The workers of pharmaceutical science of new China should take on the responsibility to explore and systematize our ancient experiences and to carry out research on them and raise them to a higher level so that they could make still greater contribution to the benefit of mankind.

The integration of traditional Chinese medicine and western medicine is an important policy of our government and it has greatly promoted the research work on medical and pharmaceutical sciences of this country.

After the founding of New China, our government, on the basis of the special conditions of our country, decided to integrate traditional Chinese medicine with western medicine, to inherit and develop the legacy of medicine of our nation, to carry on research on traditional Chinese medicine and Chinese herbal medicines and to make them the most important of our country's policies on medicine and hygiene. The main contents of these policies may be outlined as follows: we should unite with and depend on doctors of taditional Chinese medicine and bring them to a higher level so that they might give full play to their professional knowledge. We should insist on the integration of traditional Chinese medicine and western medicine. Organize the doctors trained in western medicine to study and carry on research on traditional Chinese medicine. The sciences of traditional Chinese medicine and herbal medicines should accomplish its modernization step by step. The development of traditional Chinese medicine and cause of the integration of traditional Chinese medicine and western medicine should be proceeded in a planned way and we should create the material prerequisites for this development. Finally, we should protect and make use of our plentiful resources of herbal medicines and develop the cause of Chinese herbal medicines.

In the past 30 years or so, our country has done a lot of works to implement the policies mentioned above. About 280 thousand practitioners of traditional Chinese medicine and workers of Chinese herbal medicines have been recruited to work in the state operated medical establishments. In order to train and bring up qualified personnel in traditional Chinese medicine and Chinese pharmacy, more than 20 colleges of traditional Chinese medicine have been established and departments of Chinese parmacy have been set up in many of the colleges of traditional Chinese medicine. Several hundreds of hospital of traditional Chinese medicine have been founded and in some of the other hospitals there are sections of traditional Chinese medicine or dispensaries of Chinese herbal medicines. A large number of factories for the production and processing of Chinese herbal medicine have been established or extended. Besides, many batches of study class have been conducted to help the doctors trained in western medicine to learn traditional Chinese medicine. Now it is a common practice for our doctors to use western medicine and traditional Chinese medicine together in the treatment of their patients. A more significant measure was the establishment of many research institutes working in the area of traditional Chinese medicine. The research workers of these institutes have carried out a lot of research work in cooperation with their collaborators in clinical and industrial spheres.

In China, with the exception of some institutes specialized in antibiotics, most of the research institutes of pharmaceutical science engaged in research on Chinese herbal medicines. They carried out their research from different angles such as botany, pharmacognosy, introduction of fine species and their cultivation, isolation of active principles, the processing of medicinal herbs, the formulation of drugs, pharmacology, toxicology and clinical medicine. The cooperative research of these different angles have expanded medical and pharmaceutical sciences of our country, promoted the development of our cause of medicine and pharmaceutical industry and helped to form the distinguishing features of our drug research.

One of the important patterns of carrying out research on Chinese herb medicine by means of modern scientific methods is to isolate the active principles of the herb medicines by means of phytochemical methods, to elucidate their chemical structures and pharmacological actions and to carry out their clinical traits. From the drugs thus obtained, still better drugs might by produced by modification of chemical structure. These kinds of works have ample scope in this country and have been carried out in many pharmaceutical institutes and colleges. These works may be roughly divided into the following types:

1) The investigation of the active principles in traditional herbal medicines by means of modern scientific methods: The traditional herbal medicines commonly used in our country amount to more than 500, of which only a few have been investigated scientifically and whose active principles elucidated. After the founding of New China, the pharmaceutical scientists of this country have carried out a large amount of work and achieved some successes.

For example, Chinese medicine Yan-hu-suo (Corydalis ambigus Cham et Sch) is a famous traditional analgesic. There are many descriptions about this herb in ancient medicinal literature. Ben-cao-gang-mu taught us that, Yan-hu-suo has analgesic and diuretic actions. The late director of the Shanghai Institute of Materia Medica under the Chinese Academy of Sciences (SIMM-CAS), famous Chinese phytochemist Professor T.Q. Chao separated 13 alkaloids from this plant. Their pharmacological actions were studied by the pharmacologist in this institute. They found that one of them, Corydalis B has evident analgesic and sedative action both in animal and clinical. Corydalis B has been produced in factory, part of it has been exported to south-eastern Asia.

Due to the rather low content of Corydalis B in Yan-hu-suo, they isolated palmatin which can be converted to Corydalis B by hydrogenation. Later on they found l-terahydropalmatin the more active form of Corydalis B, from another plant. The total synthesis of Corydalis B has been performed in a pharmaceutical institute. Analgesic mechanism of Corydalis B has been studied in SIMM-CAS. It influences several neuro transmitters, especially depresses the action of dopamin receptor evidently. They will study its mechanism in a deeply going way, and some new discoveries are desired.

There are many such examples. Shi-jun-zi (Quisqualis indica Linn) is a traditional anthelmintic. Ben-cao-gang-mu described that it has anthelminthic action; it is an important drug for pediatrics. Chinese scientists separated an active principle from this plant. It is a new type of amino acid named Quisqualic acid. Its chemical structure has been determined; its total synthesis has been performed.

All such works laid the scientific inherence to Chinese traditional medicine and medicaments, and expanded Chinese traditional medicine significantly.

2) Folk medicine is another important resource for studying active principles:

Our country is abundant in folk medicine, especially in the vast rural areas. Peasants and village doctors always use local herbs for therapy. They accumulated many good experiences in their long practice, and hence effective herbs were discovered one by one.

For example, in north Jiangsu province, peasants use Qing-hao (Artemisia apiacea) for therapy of malaria. They collect a handful of such herbs before or after their houses and boil it in boiling water for a few minutes. Usually malaria may be stopped by drinking such kind of Qing-hao water. This valuable experience was discovered by scientists when they visited the village to investigate the folk medicine. After trying various devices they separated ultimately an active principle named Artemisinine. It has antimalarial action both in animal and clinical tests. Its chemical structure has been detected and proved to be a new type of sesquiterpene compound with peroxide bridge. This is a very significant invention. But it still has some insufficients, such as low solubility, relapse, etc. SIMM-CAS accepted this program. They synthesized several series of derivatives. Through detailed comparison in chemistry and pharmacology, they found a compound named Artemether, which can overcome the weak points of Artermisinine. It shows high curative effect low side effects and lower relapse, and it is easy to make ampules. Now it has been used in clinics.

Artemisinine and artemether are new antimalaria weapons. They aroused attention in other countries and are now being studied in cooperation with WHO. We will do our best to make it more perfect to make contributions to the world, especially to the Third World.

Here is another example: Tian-wha-feng (*Trichosanthes kirilowii* Max) with the other three herbs as a whole was used in Hubei province for abortion. After systematic study scientists found that Tian-wha-feng is the chief active one. They separated from it a protein having abortic action. The sequence of its amino acids and the mechanism of abortion are now being studied in several institutes of Chinese Academy of Sciences in an ongoing manner.

3) It is possible to discover some pharmacologically active materials, if you have noticed any particular or accidental phenomena among the folk. Some districts in the villages in Hubei and Hunan provinces of our country are inhabited by daughters of a family who can give birth to children but the daughters-in-law cannot. After a long period of exploration they found out that the use of coarse cotton seed oil in these districts may have some connection with this pheonmenon. Then the scientists began to separate and got one chemical constituent called gossypol from cotton seeds and put it on trial in animals. Gossypol caused the male rats to be sterile and then a male contraceptive was discovered. We have carried on a large-scale study on this drug in our country. Since male contraceptive is seldom, gossypol has drawn much attention and aroused international interest and now the study on gossypol has been developed also in America and some other countries.

4) Since the plant resources are abundant in our country, the screening methods are also used to search for new drugs. Although the work load is large but there is a chance to gain new discoveries. In case of *Agrimonia pilosa* Ledeb which is a famous haemostatic in China, we have separated a chemical constituents with an action against the protozoa of malaria, but its severe toxicity prevented the clinical use. Anyway, it gives us some information in further studying.

5) Besides the experience learned from our country we also learned the experience from foreign countries in making use of our own plant resources to search for new drugs, to enrich the substantial content of our research, and to develop a new way for drug production. For instance, alkaloids from Xi shu (*Cephalotaxus fortunei*) and San jian shan (*Camptotheca acuminata*) were reported in foreign literatures to have antitumor activity. These plants grow mainly in China in plenty. We learned the experiences from foreign countries and separated some antitumor constituents from them. We have done lots of work on chemistry, pharmacology, clinical trial and the technics in production. These works have been proceeded much ahead of those of foreign countries and these antitumor drugs were put into production in our country and drew much international interest again.

Another example is the steroid hormones which are a kind of drug of great significance. China has put on much effort to investigate the plant resources of steroid saponins in order to supply great quantities of raw material for hormone production. These resources not only meet the need of domestic necessity but also serve the supply to international market on a large scale.

All facts mentioned above are the successful examples to bring light into the development of our scientific research and pharmaceutical industry in drugs. We have studied not only the separation of the active principles from plants, but also the traditional medicines through different branches of learning or different routes of research. We explore, systematize and heighten Chinese medicine and pharmacology from various angles.

In Chinese clinics many doctors and physicians can utilize both Chinese traditional drugs and synthesized drugs (so-called western medicines) in combination to treat various diseases. Some of the physicians who have been trained in traditional style and method, can also apply the principle of "Diagnosis and treatment based on an overall analysis of the illness and the patient's condition" in dealing the treatment with the prescriptions of Chinese drugs. They have also observed and analysed the effect of these treatments. We use the Chinese and synthetics drugs in combination in the treatment of some acute abdominal illness, such as acute appendicitis type peritonitis etc. with a non-operation cure rate above 70%. It is proved in clinical trial that this way of treatment has good effects: releasing the pain of patients and lowering the death rate.

In the work of pharmaceutical industry, we make Chinese drugs in several dosage forms. such as ampoule, pellet, tablet, pill, drop, syrup, tincture, paste, ointment, etc., according to the experiences of Chinese physicians or applying the techniques and methods of western medicine in making the dosage form. Most of them have good therapeutic effects and are convenient to the patients and are widely accepted by both Chinese and western medicine; likewise, they develop and enrich the pharmaceutical industry in China.

Chinese physicians apply usually complex prescriptions in treatments according to the compatibility and property of drugs. From the substantial evidences obtained from the practice we acknowledge that complex prescriptions always give promising results. Much work has been done on ancient recipes according to the principles of traditional Chinese medicine. Eliminating the false and retaining the true, we make the recipes and dosage better than before to accord with the demands of being proven, convenient, and simplified.

How to apply modern scientific principles in studying or explaining the many rules, such as: "Invigorate the circulation of blood and reduce the deposit," "Prop up the right and strengthen the health," "Use aromatic material to straighten out the mind," in therapeutic practice by Chinese physicians is now another important problem to be solved by the medical and clinical researchers in our country.

Along these lines many pharmacologists and clinicians have attempted to settle the problem and have had a good beginning. Someone tried to use the theories of variation in blood circulation and/or biochemistry of blood to explain in scientific aspect, the utilization of Chinese drugs in vasculitis, thrombus, angina pectoris the theory "Invigorate the circulation of blood and reduce the deposit." Others assumed that the modulation of immunity may have some connection with "Prop up the right and stengthen the health."

In the investigation of the raw material resources of medicine and study on phytotaxonomy, we introduce the fine varieties of raw materials in scientific method, domesticate the plants; cultivate and breed the medicinal plants and find the substitutes for the rare materials. All the above courses are important fields of research in Chinese medicine and are now carried on by medical organizations, plant and drug research units and plant culturists.

Studies on ancient pharmacological literatures of our country pose other important problems. Four hundred volumes of ancient pharmacological literatures are the record of practical experiences of thousands of years. With a view to carry on and explore the pharmcaology of our mother country we must study these precious literatures.

DISCUSSION ON SOME PROBLEMS

China is a big country with her billion population, that is the basic situation which must be taken into account in whatever we do. With reference to the medicine research and development, as well as the pharmaceutical industry in our country, it is therefore most important to select proper ways, to formulate correct policy and to adopt efficient steps, so as to ensure the health of our billion people and to enhance their health quality. In order to change the backward face of the medicine and health condition in China, we relied mainly on our own scientists and technicians. On learning advanced experience from abroad, we investigated, developed, and produced a lot of western drugs, including antibiotics and synthetic drugs, and then made great effort to put them in use in vast countryside and cities. On the other hand, we have paid, and are paying great attention to explore, systemize, and heighten the legacy of traditional Chinese medicine. Neither the advanced foreign experience ought to be refused, nor our own tradition and valuable legacy ought to be neglected.

As usual, several science-technology regions with economical and scientific importance are to be selected as the main research items during a specific period by the government. The leading organization on science-technology have the responsibility to perform the selection. For the purpose of making such a correct selection, we must understand the trend of relevant science, learn the experience in the similar fields of other countries and analyze our own concrete condition.

Antibiotics show great validity soon after their discovery. They enriched the content of biology and chemistry, displayed an important role for improving health of mankind and were reasonably important to the socialist construction in our country. In spite of the extreme backwardness of antibiotic industry in the early years of new China, the government decided to select the R/D and production of antibiotics as one of the key items in our economical construction. This decision has shown to be correct without doubt.

A retrospect of the history of antibiotics development in new China would reveal that in order to develop a certain technology regimen, it is necessary for a developing country to take measures as follows. The research force in institutes should be well-organized and closely combined with those in the industry to form strengthful collaboration. The science-technology problem should be divided into different topics which belong to fundamental research, applied research and development research to be carried out by different collaborator teams. It seems necessary to draw up a general research program under which the collaborator teams aim at a common goal, share out the work and cooperate with each other. Each subteam would have its own concrete object timetable, and ask for the necessary cooperation from other subteams. An effective leadership is doubtlessly needed, by which the research and development progress would be checked and coordinated frequently, and also proper instruction would be proposed frequently.

In case that the above mentioned steps have been adopted, it would be quite possible for a developing country to resolve their problems by their own forces even if no external assistance had been provided. Of course, it never means that any external assistance is not necessary. Had the international interchange been possible the development would be more effective and accelerated by introducing the advanced foreign experience.

Another important experience worth mentioning is that the formulating of science-technology policy must conform to actual conditions of the country. Before liberation the reactionary governors discriminated against the traditional Chinese medicine. They trampled on the traditional medicine and even threatened "to abolish old medicine in order to wipe out the obstacles from the way of medicine and pharmacy" with the result that medicine affairs in China had been seriously wrecked. Even not long after the foundation of New China, there were still a few people who underestimated and gave little support to traditional medicine, some of them even adopted the extremely wrong rejection policy. At that time there prevailed in the pharmacy science circle an opinion that after the birth of sulfamides and penicillin, the synthetic drug had become the main current in the world trend and the research on plant disciplines had been going downhill. They held that it would be a retrogression if the research would mainly accent on plant disciplines. But all of the above mentioned opinions neglected the most important thing--what was the actual condition of China. In China, we have experiences on traditional medicine and drugs accumulated for thousands of years, we have abundant plant resources and the majority of our population, especially the massive rural inhabitants are still dependent on traditional medicine for curing sickness effectively. That there is a great treasure house of Chinese traditional medicine must be confirmed. Directed by this idea, our government promptly formulated the policy of integration of traditional Chinese and western medicine and the policy of exploring, systemizing, and heightening traditional Chinese medicine. We did develop synthetic drugs and antibiotics, but at the same time we devoted major efforts to promote the research, development, and production of traditional pharmaceutics. Such a policy exerts profound and lasting influence not only on the development of medicine of China, but also on that of the world, and as a fact the medicine and pharmacology science in China today has attracted worldwide tremendous interests and attention.

POSTSCRIPT

During the long years of development of world medicine, the medical science of our country is both ancient and young. It has accumulated plentiful experience and has constituted the most ancient part of world medicine. On the other hand, having absorbed the advanced portion of western medical science, it has got new vitality and shown bright and vigorous prospects. The practice experienced during the 33 years after the foundation of the People's Republic of China has proven that with the right policies formulated in accordance with the specific conditions in our own country and on the basis of the actual situation of different kinds of drugs in different developing stages, the development of medicine and pharmaceutics facilities in our country has been energetically promoted and accelerated. So long as we can follow such a principle to investigate and formulate relevant policies seasonably and rationally in the future, we can predict that the medical and pharmaceutical affairs in our country will advance more rapidly and will make more fruitful contribution to the "Four Modernizations" of China and also to the welfare of mankind.

THE UTILIZATION AND TRANSFORMATION OF THE NORTH CHINA PLAIN

Jiang Dehua

The North China Plain occupies an important position in the country. However, natural disasters of drought, flood, salinization-alkalization as well as wind-sand disaster frequently take place over a long period of time. Besides, there are more than 100 million mu of low-yield land, hence agricultural production is unstable and low, and the living standard of the local people is slow to rise. As long as what is beneficial is promoted and what is harmful is avoided and superiority is given full play, the great potential of production can be tapped. Therefore, it is possible to build the region gradually into an important base for commodity grain, cotton, oilbearing corporation, soybeans and fruits as well as an integrated agricultural region. Favorable conditions for decision-making are as follows: land resource, heat and temperature conditions as well as manpower in the region are sufficient, flourishing industry and developed urban areas and transportation are favorable for agricultural development; in a certain sense, it has a solid foundation for production due to the long history of agricultural development; and some achievements and experience have been obtained by the state on the development, utilization and management of the region. The symposium on the agricultural development of the North China Plain held in June 1982 marked the decision which has been basically shaped to develop and transform the North China Plain.

The strategic thinking on the management and transformation of the North China Plain should be: under unified leadership, draw up an overall plan to undertake integrated management; cope with more difficult points after the easy ones have been tackled; carry on work in units and areas in a combined way; persist in realizing the goal for a long time to come; and finally, stress practical results. In the respect of conquering natural disasters, problems should be solved in the order of flood drainage, salt control, drought resistance and fertility fosterage so as to improve the natural ecological environment step by step. Meanwhile, the agricultural production structure system should be established accordingly. In order to ensure fundamentally the realization of the objective on disaster elimination and production increase, from a long-term point of view, water transfer from south to north, the regulation of the three major rivers--the Huanghe, Huaihe and Haihe--as well as soil conservation in the upper reaches are all principal measures related to the development of agricultural production of the North China Plain.

To this end scientific research on both theoretical and practical problems of vital importance must be given special attention. In addition, multi-disciplinary research should be arranged to tackle key problems in coordinated efforts by relevant departments and institutions. Basic theory research, application research and development research should be integrated; and scientific theory, intermediate experiment should be combined with popularization and application so as to develop a whole set of scientific and technological policies suitable to the characteristics of this particular consultative, organizational, and management system.

Favorable Conditions for Comprehensive Development and Management of the North China Plain

The North China Plain, bounded by the Great Wall in the north, the Huaihe River in the south and the Taihang Mountains in the west, is located between 32 -40 N and 114 -121 Ea with an area of 300,000 sq. km. It has a population of 160 million among which the agricultural population amounts to 145 million. The arable land here is approximately 270 million mu* which occupies about 18 per cent of the total arable land of the country.

The North China Plain lies in the warm temperate semi-humid region, annual precipitation ranges 600-1,000 mm. Its gentle relief is covered with a thick soil layer. This region has a long history of agricultural development and sufficient manpower resources. It is also well developed in urban construction, industry, and transportation. Its agricultural production occupies an important position in the country. Grain output makes up 18.4 percent of the country's total; wheat output approaches one-third, maize, peanut and soybean occupies about one-fourth each, cotton amounts to two-fifths and sesame, nearly one half respectively. In addition, fruit outputs of apple, pear, persimmon and dates all exceed that in other agricultural regions of the country.

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* 15 mu = 1 hectare

The favorable conditions for agricultural development are as follows:

1. In terms of agricultural population, per capita acreage of cultivated land averages 1.84 mu, in the North China Plain, this figure is higher than the nation's average level. The widely distributed arable lands are easy to cultivate and favorable to develop comprehensive agriculture. The frost-free periods here range from 175 to 220 days and have an accumulated temperature of 3,600-4,600 C during the 10 C period which lasts 250-310 days. The mean temperature of the hottest months reaches 24-28 C. The annual average total solar radiation for plain areas is about 110-130 k cal/cm^2, of which photosynthetic effective radiation is 38-44 k cal/cm^2. If sufficient moisture and nutrients were available, crop diseases and injurious insects would disappear, and relatively rare unfavorable weather conditions (hazardous low temperatures in growing season, dry-warm wind, crop lodging due to high wind velocity, extreme low wind velocity, deficient supply of CO_2, and poor soil aeration caused by continuous rain, etc.) could be avoided, it is quite possible to increase per mu yield for potential productivity may ensure an average grain production of over 1,250 km/mu.

2. Population density of the region is 470 people per square kilometer, and the single labor force is responsible for cultivating 4.7 mu of farmland on average. Huge population can be an unfavorable factor but it is favorable if fully utilized. In addition to the two cities of Beijing and Tianjin, there are more than 20 cities inhabited by over 200,000 people, who can provide production materials such as fertilizer, pesticides, agricultural machinery, farm tools and so on to the countryside. Grain production in the suburban areas is generally higher and more stable. Besides, a farmer's income here is one to several times higher than that in the remote countryside. At present, machine power contributes to one single mu of arable land is 0.17 horse power on average, and tractor ploughing acreage exceeds 56 percent of the existing cultivated acreage. The level of these two items is higher than the country's average level. There are rich mineral resources including coal, iron, oil and others in the North China Plain and the neighbouring regions. Meanwhile, electricity, petroleum, chemical, iron and steel, textile and food industries are all well developed. Communication and transportation of highway, railway, civil aviation, and waterways are also very convenient.

3. Four or five thousand years of agricultural history provide the region with rich experience in production. Dry farming and seri culture here occupied the first place in the country during the more than one thousand years from the Western Zhou Dynasty to the Qing and the Han Dynasties (221 B.C. to 220 A.D.). From the unification of China in the Qin Dynasty to the end of the Han Dynasty, the North China Plain became an economic center for the whole country. China's

earliest (the Warring States, fifth to third centures B.C.) irrigation works also originated here. Although the country's economic center moved south of the Changjiang River following the Wei Kingdom, Jin Dynasty, Southern Dynasties and Northern Dynasties (22-590 A.D.), the North China Plain still held an important position. From the days just before liberation to the early stage of the founding of New China, this region was the largest cotton-producing base of the country.

In the last thirty years or so, numerous water conservancy agricultural surveys have been conducted. The Huaihe is the first river to be harnessed. As a result, downstream discharge capacity increased from 8,000 m^3/sec to 23,000 m^3/sec, and the flood control standard has also been raised significantly. Eighty percent of the areas liable to waterlogging have been improved, saline-alkali land acreage reduced by over one-fourth, and irrigated area increased from 10 million mu to 70 million mu. The available reservoir capacity of the Haihe River is 23.4 billion cubic meters. Total flood discharge capacity to sea has been increased from 4,600 m^3/sec to 23,000 m^3/sec. It now has the capability to prevent great flood with an occurrence probability of fifty years. Area liable to waterlogging is diminished by over 80 percent, and saline-alkali land is reduced by 60 percent against the 1960s. Irrigated area increased from 8.5 million mu to 84 million mu. The available reservoir capacity of the Huanghe River is 53.6 billion cubic meters and large scale dyke reinforcement (both in height and width) has been done three times. The dyke has never breached in the last 32 years. Peak flood discharge of 22,000 m^3/sec occurred in Hauyuankou in 1958, but brought about no dangerous situation. In the mid 1950s a soil survey for the North China Plain was conducted by a coordinated effort of the Chinese Academy of Sciences and the Ministry of Water Conservancy and Power and the soil map of the North China Plain was subsequently drawn. Among the six items in the National Programme for Agricultural Science concerning the tasks on agricultural development and transformation of the nature, two of them with the headings "saline-alkali land improvement" and "utilization of tilled flats along the coast and lake reaches" are directly related to the management of the region. The conference on drought resistance of the northern eight provinces held in 1963 listed the disasterous drought and flood control and prevention as a major task for the agricultural development of North China. The Ministry of Water Conservancy and Power then immediately began to prepare setting up northern Henan provincial experimental station of water conservancy and soil improvement, which later became a scientific research experimental station on integrated management of the North China Plain. A proposal on how to conduct research on the comprehensive control and prevention of drought, flood, and salinization-alkalization of the North China Plain was put forward in 1964 at a seminar on saline-alkali soil sponsored by the Chinese Academy of Sciences. Meanwhile, a plan for long-term management of the North China Plain by all parties concerned was drawn up and the means of drawing upon experience gained at key points to promote work in various areas and extend to the entire region was adopted. A field survey team, consisting of over one hundred scientific personnel who were engaged in several dozen disciplinary research projects from ten-odd scientific institutions including pedology, geology, hydrology, geography, botany, microbiology, zoology, genetics, etc. was organized accordingly. Experiments on diversified measures of well-irrigation and well-drainage, agriculture, and forestry were carried out to deal with the 100,000 mu of farmland in Fengqiu County, Henan Province. In 1966 the National Commission on Science and Technology organized a massive survey team to conduct scientific experiments on well-irrigation and well-drainage and comprehensive control of drought, flood and salinization for 140,000 mu of land in Yucheng County, Shandong Province. Experimental plots were also set up successively in Sheng County and Quzhou County in Hebei Province. Since 1978, Academia Sinica and the Ministry of Agriculture have chosen Luancheng County in Hebei Province and Tong County in Beijing respectively as the comprehensive experimental base for agricultural modernization. In 1982, 3 million mu of low-yield land transformation and comprehensive management was launched in the nine counties of Qihe, Yucheng, Lingxian, Shangqiu, Minquan, Ningling, Mengcheng, Woyang and Suixi in the three provinces of Shandong, Henan and Anhui, using the loan provided by the World Bank. Up to now there are more than forty experimental sites of various forms in the North China Plain centered around drought and flood control and alkalization improvement, and some achievements have gained correspondingly. Generally speaking, average grain yield per mu for the low-yield land can be increased by 200 to 300 catties (2 catties = 1 kg) and cotton by 30-100 catties after several years' management. Each catty of chemical fertilizer applied may result in an increase of 3 catties of grain. Every yuan invested for agricultural capital construction may result in an increase of 1.5-3 catties of grain or 0.5-1 catty of ginned cotton on an average level, the rate of profit of investment being 10-30 percent, and duration of recovery being 4 to 7 years. Through one year's work on well-irrigation and well-drainage to control drought, flood, and alkalization in the experimental plot of the Yucheng County, Shandong Province, grain yield per mu went up from 180 catties in 1966 to 640 catties in 1981, the average increase being 8.9 percent annually. Cotton yield per mu went up from 10 catties to 103 catties in the corresponding periods, the annual average increase being 16.8 percent. Of the 242 million mu of cultivated land in the Xuhuai district, Jiangsu Province which covers an area of 36,000 sq km, total grain output increased from 4.5 billion catties in the 1950's to 8.8 billion catties in the 1970's. It reached 15.1 billion catties in 1981. Since the 1970's, the output has increased at an average rate of 6.8 percent yearly. As a result the state of affairs has been changed: grain can be sent out from this district to other provinces rather than being sent in. In 1981 a total net weight of 2 billion catties of grain was turned over to the state. Taking the North China Plain as a whole, during the more than thirty years since the founding of New China, the state has made an investment of 25 billion yuan on irrigation works to the region. In 1981 total grain output was 1.02 times, ginned cotton 1,93 times and oil-bearing crops 1 time higher than that in 1952. The rate of increase of food grain, cotton, and oil-bearing crops exceeded that of the nation's average level. Under these circumstances, the Chinese Agronomical Society, the Forestry Society and the Hydraulic Society jointly convened the symposium on agricultural development of the North China Plain in June 1982. At the meeting, relevant questions were extensively discussed and proposals on transformation and management of the region were put forward. Now the topic on management and construction of the Plain has been listed in the long-term national economic development plan by the state, and organizational and technical measures will be adopted accordingly. This decision is bound to exert profound influence on the future management, transformation, and agricultural development in the North China Plain.

Major Problems and Scientific-Technical Line Related to Management

Although great achievement has been gained in the management and development of the North China Plain, still unfavorable factors of drought, flood, salinzation-alkalization and impoverished soils caused by physical or historical reasons exist, which restrict agricultural development.

The Huanghe, as a "hanging river" above the ground, is apt to flood. "Not a single meter is firm, thousands of square meters are inundated." It once migrated to Tianjin in the north and captured the Haihe River in the south for the past centuries. Wherever the muddy stream occurred, a whole area would become submerged. In more than two thousand years prior to liberation, the Huanghe burst its banks over 1,500 times and shifted its course 26 times. By and large, "it breached its dykes two years out of three and shifted its course once in a hundred years." Although it never breached its dykes after liberation, the riverbed has kept rising. The rise averages 5-10 cm above the surrounding land each year because of the deposition of large quantities of silt. Now it is 3-5 meters higher than both banks, some sections even exceeding 10 meters. Thus the threat has by no means ended but is becoming more and more serious. In addition, the area of the Huaihe and Haihe drainage system is often flooded. According to the estimation for the last five hundred years, the probability of flood occurrence of the entire area might reach 32-36%. In recent years, the whole North China Plain has been affected by flood and waterlogging disasters four times. Drought commonly occurred in less rainy seasons and disastrous drought occurrence probability was 25-40%. Spring drought is generally more severe than autumn drought. Salinized land area occupies one fourth of the total area. Organic matter content of the poor soil is normally less than 1% and total phosphorus concentration is about 0.1%. The available form phosphorus of the 80 percent of the arable land is less than 5 ppm. In part of the area sand is drifted by wind and some of the soils contain Shachiang soil (soil with calcium carbonit concretions in profile). Of the 100 million mu of low-yield land in the region, saline-alkali soil amounts to 40 million mu, sandy soil 25 million mu and Shachiang soil more than 30 million mu. Solar radiation in this region is more intense than various localities in southern China. Warm season, however, is comparatively short, winter wheat can still grow here but sometimes there is a drop in production due to the effect of dry-warm wind. Spring and summer sown crops also cannot avert the damage from autumn microtherm. Agricultural production in most parts of the region is still in a low and unstable condition. In accordance with average estimation of 1976-1978, average yield per mu of grain in three-fourths of the counties was below 400 catties and that of cotton 36.6 catties, being 22.8 catties lower than the mean value of the whole nation. The production level of the yield per unit area of chief crops within the region may differ 5 to 10 times.

In light of the existing problems in the Plain along with experiences and lessons, what should be done in regard to future management is, under the unified leadership, to draw an overall plan on comprehensive management; handle more difficult issues after the easy ones have been tackled; combine the work in units and areas, persist in realizing the goal for a long time to come, and finally, stress practical results. While concentrating efforts to conquer natural disasters, raise soil fertility and improve agricultural ecological environment, relevant rational agricultural production structure system should be developed, in addition to taking appropriate measures to ensure a high speed, sustained and steady development of agricultural production.

1. For the purpose of changing production conditions and conquering natural disasters, it is necessary to deal with problems in the order of flood drainage, saline-alkali soil amelioration, and drought resistance, fertility fosterage.

Flood drainage is the prerequisite of saline-alkali soil amelioration. So far as drainage is practised, it means that groundwater level should be dropped below critical depth. As to waterlogging prevention, it is designed to get rid of flood with probability occurrence of five to ten years. For a trunk project, it is necessary to prevent floods which have a probability occurrence of 25 to 30 years. Besides drainage by irrigation works, afforestation should also be actively undertaken so as to bring biological drainage into play.

On the basis of drainage, measures on saline-alkali soil amelioration include platform field and strip check construction, shaft well sinking, well irrigation and well drainage, salt surpression by turning up the soil, land levelling, proper cultivation as well as alkali-resistant plant and crop plantation. In a word, agricultural, biological and engineering measures must be combined properly in accordance with the actual conditions of different localities.

In areas where waterlogging and salinzation have basically been put to an end or controlled, irrigation should be taken into account. Besides the cases where well irrigation should be combined with well drainage, the following problems should be considered: (1) In certain irrigated areas water consumption has exceeded water requirements, this not only resulted in waste of water and loss of soluble nutrients which are favorable to crop production but also caused a rapid decline of groundwater level in well irrigated areas, and rise of phreatic water level above critical level in ditch irrigated areas. So measures should be adopted actively to save water. (2) In areas where the water source is sufficient but irrigation project is deficient, the major task is to develop irrigation, and in areas where it is impossible to develop irrigation due to water shortage, the cropping system should be changed to suit the water deficient circumstances. As to inter-basin water transfer, since many other issues will be involved, it is necessary to study it carefully before decisions are made.

In areas proper solutions have been found for the above mentioned problems, attention should be centered on how to deal with the limited factor of soil impoverishment. The specific steps that follow are to break plow pan or loosen compact soil column by means of plowing so as to allow the crop root system to penetrate one more meter deeper, increase moisture retaining power, aeration, and the extent of crop moisture absorbing capacity along with the increased application of nitrogen and phosphoric chemical fertilizers. In 1981 for each mu of sown acreage in the region was applied 7.9 catties of chemical fertilizer in average, being only one-seventh that in Japan and West Germany. The added fertilizer of nitrogen and phosphorus may cause a rapid development of root systems, branches and leaves as well as an increase of economic output. Most of the increased organic matter is directly or indirectly returned to the fields which is helpful to consolidate and enhance the soil physical properties that have been improved as a result of deep ploughing. At the same time, green manure should be planted as much as possible to compensate the deficiency of nitrogen fertilizer. Since total phosphorus content in soil is by no means low, every effort should be made to enable the crop to absorb phosphorus from soil by means of nodule bacteria cultivation via inoculation. These measures will enable the elimination of the unfavorable factor of soil impoverishment.

What is mentioned above is merely a general procedure for comprehensive prevention and control of drought, waterlogging and alkalization. Our previous work associated with North China Plain's improvement, however, had once taken a roundabout course for violating the sequence. For example, in the 1950's to the early 1960's, the Huanghe River was diverted to the extensive areas of north Henan, north Shandong, and Hebei provinces to develop plain irrigation, drainage was neglected and secondary salinization and alkalization was brought about in large areas. This resulted in an increase of saline-alkali soil in areas in the three provinces, i.e. from 28 million mu in the mid 1950's to 48 million mu in the early 1960's. Since the 1960's, in the course of harnessing the Haihe River, particular stress has been laid on drainage but the whole situation has not been taken into account. As a result, a serious water shortage occurred in the Heilunggang district and the Tianjin area of Hebei Province, water has to be "diverted from the Huanghe River to supply Tianjin" at great expense.

2. While the above mentioned measures are being adopted, or after they are adopted, in the process of eliminating what is harmful and promoting what is beneficial work must also be done on agricultural structure adjustment. In accordance with the characteristics of the North China Plain, a proper agriculture production structural system should be established, which takes farming practices as its principal part and exercise an overall development on agriculture, forestry, livestock breeding, side-occupations and fishery. In light of the principle of "suiting measures to local conditions, developing favorable points and avoiding unfavorable points, and giving full play of superiority," farming practices must adhere to the policy of "actively developing multipurpose economy while enhancing grain production." In the piedmont alluvial fan-plain areas where both grain production level and economic benefit is high, predominant place should be given to developing grain production; while in areas where grain production level is relatively low but economic benefit of cotton plantation is comparatively high, it is possible to properly adjust cropping pattern so as to "use grain to ensure cotton production and use cotton to promote grain production" according to actual conditions of soil, water, fertilizer, and manpower.

Plain area afforestation generally takes shelter-forest in predominance, combined with turning the ditch sides, road sides and "four sides" of village green, as well as making sandy and saline wasteland afforestated. Therefore, the system which is a combination of points, belts, networks and tracts can be gradually formed. On the basis of it, intercropping of Tung (Pawlownia) trees, twigs (twigs of red chaste tree, willow tree, false indigo) and dates, all for agricultural use, can be developed step by step. As for sandy land development, forestry should go ahead of other works; meanwhile, economic forest such as grape, pear, apple and so on should be developed properly. Every effort must be made to increase the percentage of forest cover of the entire region from present 3-5% to 10-15% by the end of this century.

Animal husbandry in plain areas should be energetically developed alongside large-scale development of agriculture and forestry. Sandy, saline-alkali land and coastal beaches as well as part of low-yield field can be utilized to grow grass. Grassland and cultivated land rotation can be practised. Efforts should be made to expand pig, cattle, sheep, and poultry raising. However, the scope of their development should fit into cultivation practices.

Of the 237 million mu of water area including rivers, lakes, reservoirs and ponds, and 3 million mu of coastal marshes in the North China Plain, only 7 percent have been utilized so far. So there is great potential to develop aquatic products. Concerning the existing water surface area, it is possible to make full use of it to develop fishing and fresh water agriculture and expand to a proper degree small fishponds for domestic fish-farming. Moreover, low-lying depressions and swamps can be made use of to develop aquatic plants such as reeds, cattail, lotus and lotus rhizome so as to open all avenues for people of talent for industry, sideline occupations and multipurpose enterprises. The development of industry, sideline occupations and multipurpose enterprises will in turn provide much more funds, materials and technical facilities for agriculture.

Major Measures for Comprehensive Management

In order to improve thoroughly the natural ecological environment of the region, and guarantee agriculture and national economic development, several major measures concerning utilization and transformation of nature deserve special attention.

1. Water transfer from south to north. According to estimation, the volume of water resources (stream runoff plus groundwater replenishment, excluding duplicated volume in the North China Plain) totals 133.1 billion m^3, and each mu of farmland can get an average of 260 m^3. Since its temporal and spatial distribution is quite uneven, there is a great gap between water consumption and water requirement. Water shortage is particularly acute in the Haihe-Luanhe River Basin located at the northern part of the Plain. Total water resource in the basin is 32.7 billion m^3, and the available volume is 29.1 billion m^3. According to current estimation, water requirement would be 45.5 billion m^3, and water deficiency is 16.4 billion m^3. In the last 10 years, serious drought occurred for over three years running. As a result, reservoirs dried up, rivers ran dry, and groundwater level continued to decline and numerous perennial depression funnels of large sizes have formed, making groundwater exploitation more and more difficult. Both industrial and agricultural production and domestic life were affected. Water transfer from south to north is therefore an avenue worthy to be considered. The preliminary project consists of two routes. One route, which is referred to as "Middle Route Scheme," aims at diverting water from Danjiangkou Reservoir located on the Hanshui

River, one of the chief tributaries of the Changjiang River, to Beijing. Water will be carried northward across the Huanghe River via northwest of the city of Zhengzhou, extending further northward along the eastern foot of the Taihang Mountains through to the terminal. The other, which is referred to as "East Route Scheme," is devised to divert water from Sanjiangying located downstream of the Changjiang River via Jiangdu Pumping Station. Then water will be carried northward approximately through the Beijing-Huangzhou Grand Canal through to Tianjin. Both schemes can lead to an increase of water +esource in the input area, but this in turn may cause many problems. As to water output areas, the principal resultant issue would be a reduction in water resources, acceleration of river sedimentation and sea water intrusion into estuary. As to water conveyance areas, the apparent impact would be the rise of groundwater level in areas along both water conveyance canals and peripheries of water storage bodies, causing soil salinization-alkalization. Consequently, lake body environment, water quality and aquatic products would be affected. And as to water input areas, secondary soil salinization-alkalization might take place. If the irrigation water averages 250 m^3/mu yearly, infiltration coefficient of groundwater is 0.1, and specific yield is 0.03 to 0.05, the accumulated value of groundwater after irrigation would be 0.75-1.25 m. If the critical depth for salt accumulation on soil surface is 2 m, extensive secondary soil salinization-alkalization in areas where groundwater lies below 3^m depth prior to water transfer would probably occur unless corresponding measures are adopted.*(insert footnote) In stormy and flood season, flood and waterlogging damage might be aggravated in irrigated areas due to possible blockade of water diversion engineering facilities. Furthermore, what might happen on climatic changes also needs to be studied.

In light of the varying degrees of difficulty in handling the engineering problems, the East Route scheme should be carried out first. Provided the water is diverted at a rate of 100 m^3/sec across the Huanghe, the impact on water discharge in the lower reaches of the Changjiang would not be great. The leading factor worthy to be noted is how to avoid secondary soil salinization-alkalization in either the conveyance area or the input area.

2. Regulation of the three major rivers (the Huanghe, Huaihe and Haihe). Before liberation the Huanghe "breached its dykes two years out of three." In the Huaihe drainage basin, "heavy rain would cause a severe disaster; small rain, a small disaster; and drought would occur if there was no rainfall." Similarly, in the Haihe drainage basin, drought waterlog happened nearly every year. Since the founding of New China, the government has regarded regulation and harnessing of the three rivers as a principal object, that has resulted in a stable state for the lower reaches of the Huanghe for the last 30 years. Flood prevention capacity of the Huaihe, Haihe and other rivers has been constantly improving, so that people's life,

production activities and safety transportation are fundamentally guaranteed. However, hazardous flood and waterlogging have not been completely controlled, greater hidden danger still exists expecially in the case of the Huanghe. Flood-threatened region, bounded on the south by floodplains south of the Zhengzhou and on the north by the northern Henan and western Shandong plains, covers an area of 100,000 sq km, and is inhabited by over 50 million people. Currently, the available disaster prevention or control measures are as follows: (1) continue to reinforce embarkment; (2) build large-sized silt-detention reservoir (e.g. reservoir site can be chosen in the valley area around Taohuayu); (3) undertake soil and water conservation work in the middle reaches; (4) select favorable sites for opening up proper flood-relief channels. No matter what is to be done the danger from the Huanghe must be eliminated, at least for over 10-15 years. Before these measures are adopted, no investment characterized by an increase of fixed assets should, in general, be made for areas threatened by the Huanghe. River harnessing for both the Huanghe and the other two rivers must be continued, otherwise, developing agricultural production in the North China Plain is just like building houses on shifting sand. Moreover, special attention should be paid to soil and water conservation work, particularly for the Huanghe. Only by grasping this key issue, can an overall consideration be made.

(1) the combination of control and prevention objectives on waterlogging, sedimentation, salinization-alkalization and pollution with that of drought;

(2) the combination of regulation work of upper reaches with lower ones, left bank with right bank, main stream with tributaries, and small watershed with large drainage basin;

(3) the combination of engineering practice, agricultural practice with afforestation and grass grow;

(4) the combination of temporary solution with fundamental solution of problems, and the combination of control with transformation.

In a word, systematic analysis, overall planning, diversified control and prevention, concert action, stress on practical results, promoting what is beneficial and abolishing what is harmful, and ensuring both safety and stable yield must be accomplished in the course of management.

3. Soil conservation in lower and middle reaches. Heaviest soil erosion in the middle reaches of the Huanghe is known to the world. Since more than 50 percent of the loess contains silt with a particle size of 0.05-0.005 mm but very few clay particles, it is quite easy for it to separate from soil mass under the effect of rain-drop splash. Soil granule is difficult to form becuase of low organic matter content. All the above mentioned, in addition to vegetation damage due to human activities, make the hydraulic soil erosion particularly intense. However, numerous favorable factors also exist for the control of the erosion: (1) the thick soil layer makes the ploughing easier, and the field-works practice more possible; (2)

permeability of loess is excellent except plough pan; (3) moisture-holding capacity is rather low; (4) salt-bearing base mineral is rich in the soil, and the chief component of clay mineral is hydrate mica which is beneficial to the formation of soil structure. The resultant structure, however, is relatively stable; (5) rainstorm in loess area is not so heavy. It is possible to carry on soil conservation if these favorable factors are appropriately utilized. To turn this possibility into practice, it is necessary to create to the minimum limit the following conditions: (1) to implement population control, and place the Loess Plateau as key area for birth control popularization; (2) to double efforts to make grain self-sufficient; (3) to realize a basic self-reliance in firewood, fodder, and manure, and increase some energy supplies in places where conditions are permitted; (4) to increase to a proper degree some more chemical fertilizer supply from the state, and necessary aid should be given in the beginning; and (5) from a long-term point of view, all cropland with an inclination angle larger than 20 should be abandoned. No efforts should be saved to plant trees, shrubs and grasses in the non-cultivated land so as to integrate biologic practice with engineering practice. In the respect of comprehensive control and management, small watershed should be taken as a unit and large drainage basins as a system. Only through prolonged arduous attempt, can the longterm goal be realized with regard to the simultaneous regulation and management of the three rivers--the Huanghe, Huaihe and Haihe, along with the mountainous areas in the lower reaches.

Major Scientific Research Themes and Scientific and Technological Policies

In light of the general demand set on the development and transformation of the North China Plain, scientific research themes for comprehensive management to be studied are recognized chiefly as follows: the formation and law of development of drought, flood and waterlogging, salinization-alkalization and sandstorm; the integrated survey and assessment of water resources and their rational utilization; the inter-basin water transfer project and its impact on the geographical environment; the investigation and comprehensive evaluation of land resources and land types and their rational utilization; water-salt dynamics and salt equilibrium of different soil types; soil improvement, soil productivity fosterage, rational planting, land utilization and soil fertility; variety improvement and proper breeding on crops, trees, domestic animals, and fish; rational agricultural production structure, rational agricultural production allocation and agricultural regionalization; the development and utilization of rural energy including solar energy and bio-gas; the production, supply and sale of farm products (grain, soybean, cotton, peanut, etc.) with the rational combination of agriculture, industry and commerce; finally the proper regional economic structure and regionalization.

These themes involve multi-disciplines like hydraulics, geology, pedology, meteorology, biology, agronomy, physical geography, economic geography, economy, management science and systematic engineering. The content treated consists of basic theory research, application research and development research.

Various research works should be engaged generally in the following order:

First, to advance problems according to demands set on the task and its principal target.

Second, to counter these problems, make investigations and experiments towards the set objective.

Third, to work out different alternative schemes; data obtained through investigation, observation and experiment should be classified and processed before system analysis, grouping and summarization.

Fourth, to choose the best scheme from among the alternative ones, and then submit it to the department concerned for examination and approval; in case any problems are found, additional investigations and revision should be reorganized for demonstration of the new alternative.

Fifth, to conduct tests at selected points of carry out intermediate experiments and simulations directed against the crux of the scheme.

Sixth, to carry out the approved and verified scheme, popularize and make use of the achievements until the objective is realized.

In order to promote the completion of the work on the development, utilization, and transformation of the North China Plain, a set of effective scientific technical policies and management measures must be implemented.

Firstly, guided by the modernized long-term objective, it is necessary to combine the development, utilization, and transformation of the North China Plain with the national plan. From the view of the national agricultural development, the measure of the increase of agricultural output is nothing more than the expansion of arable land and the raise of the yield per unit area. According to the situation more than thirty years, the reduced acreage of the arable land, to meet the needs of capital construction at all scales, nearly counteracts the increased wasteland reclamation acreage. The potential of future arable land expansion will become less and less. Agricultural development mainly depends on the increase of the yield per unit area, particularly in the low-yield areas. Most parts of the Plain are made up of the middle and low-yield lands. Quite a number of the counties and districts tend to go up rapidly in agricultural production, as the facts in recent two years indicate. Up to 1980 the grain yield per mu has reached 500 catties, cotton reached 83 catties, and oil bearing crops reach 123 catties. In the whole region the yield per mu of both grain and cotton has exceeded the nation's average level. The progress of cotton production is particularly obvious. Provided advantages are fully utilized, disadvantages are avoided and production conditions further improve, output will double within a short period of time. Therefore, the improvement of the North China Plain has been ranked as a key project to be tackled in China's agricultural development and scientific technology, and the plain's agricultural development and construction has been included in the national plan for long-term economic and construction development. For this reason, how to combine key problem tackling by means of scientific research, leading organ decisionmaking and national plan has become a crucial problem for the development, transformation and construction of the North China Plain.

Secondly, combine basic theory research, application research and development research under the presupposition of tackling key problems concerning various disciplines by relevant departments. For example, in the experimental research on the control and prevention of drought, waterlogging and alkalization in a comprehensive way in Yucheng experiment region, over a hundred staff from agriculture, forestry, and hydrology departments involving dozens of fields--hydrography, geology, pedology, meteorology, biology, agronomy, geography, and economics--worked in coordination. At that time, their common starting point was, by applying the basic theory of the relevant disciplines and through the close coordination of well irrigation and well drainage with ditch irrigation and ditch drainage and the close coordination of hydraulic measures with agricultural measures to control and pre-drought, waterlogging and alkalization in a comprehensive way, and to provide scientific data and technical means for the improvement of the extensive low-yield cropland in the North China Plain. Centered around saline-alkali soil amelioration and common objective of disaster prevention and production enhancement, application research and development research were carried out by various disciplines. For example, by applying basic theory on groundwater dynamic equilibrium, the hydrogeological workers, on the basis of the existing knowledge of groundwater storage, characteristics of buried depth and law of the movement, worked out a scheme on appropriate distribution of pumped wells. Coordinated with the pumped well scheme and through application of basic theory on water circulation, research workers in hydrography and hydraulics proposed a scheme on the distribution of irrigation and drainage systems based on the existing knowledge concerning the laws of precipitation, surface water and groundwater movements as well as their interchanges. By application of the basin theory on soil moisture and salt balance in coordination with water conservation measures, they worked out a scheme on soil improvement and fertility fosterage and rational land use and productivity maintenance, based on the knowledge concerning soil moisture-salt dynamic laws; by application of the basic theory on effect of forest on environment and in coordination with river harnessing, alkalinity control and fertility fosterage, they worked out the scheme concerning allocation of forest belts and forest networks; and by application of the basic theory on production allocation and agricultural regionalization, investigation on agricultural geography of relative communes and brigades, they worked out the agricultural development program of the experimental plots based on the research work done on different topics concerning water, soil, and forest. Finally, the comprehensive plan of control and prevention of the drought, flood, and alkalization in Yucheng experimental region was put forward by generalizing the findings of the special topics. Repeated tests within 15 years indicate that these schemes, tentative ideas and theories, which have improved steadily by means of summarizing experiences and drawing lessons essentially coincided with practice, and the achievements become more and more evident. The scientific technical policy implemented here is to use the basic theory to guide application research and development research, which in turn, after repeated practice, enriches the basic research. This process repeats in cycles and each cycle advances in spirals.

Thirdly, under the guidance of overall situation, models are selected to carry on intermediate experiments, so as to use the experience of selected units to promote the work in part of the area, then popularize it to the entire region, thus combine scientific theory, intermediate experiment with application and popularization, and unify organically the models, partial areas and the entire region. Still we will cite the example of comprehensive control and prevention of drought, flood and alkalization to illustrate the relationship among the several aspects. Although the basic theory guiding drought, flood and alkalization control has something in common, different areas have their respective characteristics. Different models represent different types. For instance, the Yucheng experimental plot is a representation of the type in gentle sloped depressions of the northwest Shandong plain where groundwater is abundant. By using the experience of this plot, work on comprehensive control and prevention of drought, flood and alkalization in the entire gentle slope depression of the northwest Shandong plain can be promoted. Quzhou experimental plot of Helunggang district, Hebei Province, is a sample of low-flat land with shallow brine groundwater. Experience of this plot can be utilized to promote the work on comprehensive control and prevention of drought, flood and alkalization in this particular district, and so on and so forth. So long as specific measures are adopted to suit local conditions, work is directed by areas, and control and prevention are exercised in groups, the problem on transformation of the entire North China Plain would be readily solved.

Fourthly, as regards the funds and investment for the control and prevention, we implement the policy of self-reliance in the first place and foreign aid the second. According to actual experience, it is quite necessary for disaster-ridden low-yield areas to get proper aid from the state in case production conditions begin to change. But from a long point of view, money should be raised by localities rather than given by government. Roughly speaking, the proportion of commune and brigade funds (including service investment), middle- and long-term, low-interest loan (general deadline 15-20 years, extended deadline 5 years, rate of interest 2-3%) provided by banks and interest-free investment made by the state account for one-third respectively. So the state can invest in the projects at and above the key level and those below the key level may be financed by commune and brigade funds. In this way it is beneficial to bring the initiative of the local masses into play so that the funds can be spent in an economic, rational, and effective way.

The World Bank made a loan in the North China Plain which is also one of the financial sources for the transformation and construction of the region.

When investment is made for construction, necessary investment should also be made in developing intelligence, e.g. to strengthen cultural, educational, and scientific and technological training.

Fifthly, in regard to scientific and technological method, measures should be adopted to combine the application of conventional technical facilities with that of new ones. So as to renew old installations for scientific and technical purposes step by step. In the course of the comprehensive management of the North China Plain, some traditional instruments for field observations, laboratory experiment and analysis in the hydrographical, meteorological and soil sciences will continue to be utilized because of China's present economic and technological conditions. In order to improve the accuracy of data, it is necessary to replace instruments, facilities, and installations according to plans. New technology should be adopted in some fields of research. For instance, water circulation observational experiments can be performed by utilizing tele-control systems; land-use survey, soil type classification, ancient channel and coastal zone investigation can be carried out by using remote sensing techniques and ground-truth spectral analysis; system analysis on agricultural ecology and agricultural structure, natural disaster for agricultural predication and agricultural production inventory can be carried on by using computer-set data bank.

Since the development, transformation, and construction of the North China Plain is an extremely complicated subject on regional development and regional study, and is characterized by its strategic, comprehensive, and practical significance, the state organizations of economic construction, scientific research as well as relevant production should organize a unified, coordinated organ of management and scientific consultation in order to mobilize various forces and accelerate the completion of the vital break-through on science and technology and the reconstruction task.

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TRAINING AND UTILIZATION OF SCIENTISTS AND ENGINEERS IN THE UNITED STATES

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The United States is a large industrialized economy with a continuing need for high-quality skilled labor and well-trained scientists and engineers. This paper provides a description of the general characteristics of the U.S. system through which the training and employment of scientific, engineering and technical personnel takes place. Beginning with a description of precollege education, the paper goes on to describe the system of higher education, graduate training and the training and utilization of technicians. The utilization of scientists and engineers in the various employment sectors is next described, followed by a brief section showing various estimates of the future supply of scientists and engineers. In the concluding section, some current issues regarding the training and utilization of scientists and engineers in the United States are discussed, and some of the mechanisms by which such problems are being addressed are described.

A. Precollege Education

Figure 1 depicts the general structure of education in the United States. Formalized education begins at the age of 5-6, with higher education, at the baccalaureate level, completed by the age of 21-22. The system is based on the concept of compulsory elementary and secondary education to ages 15-16.

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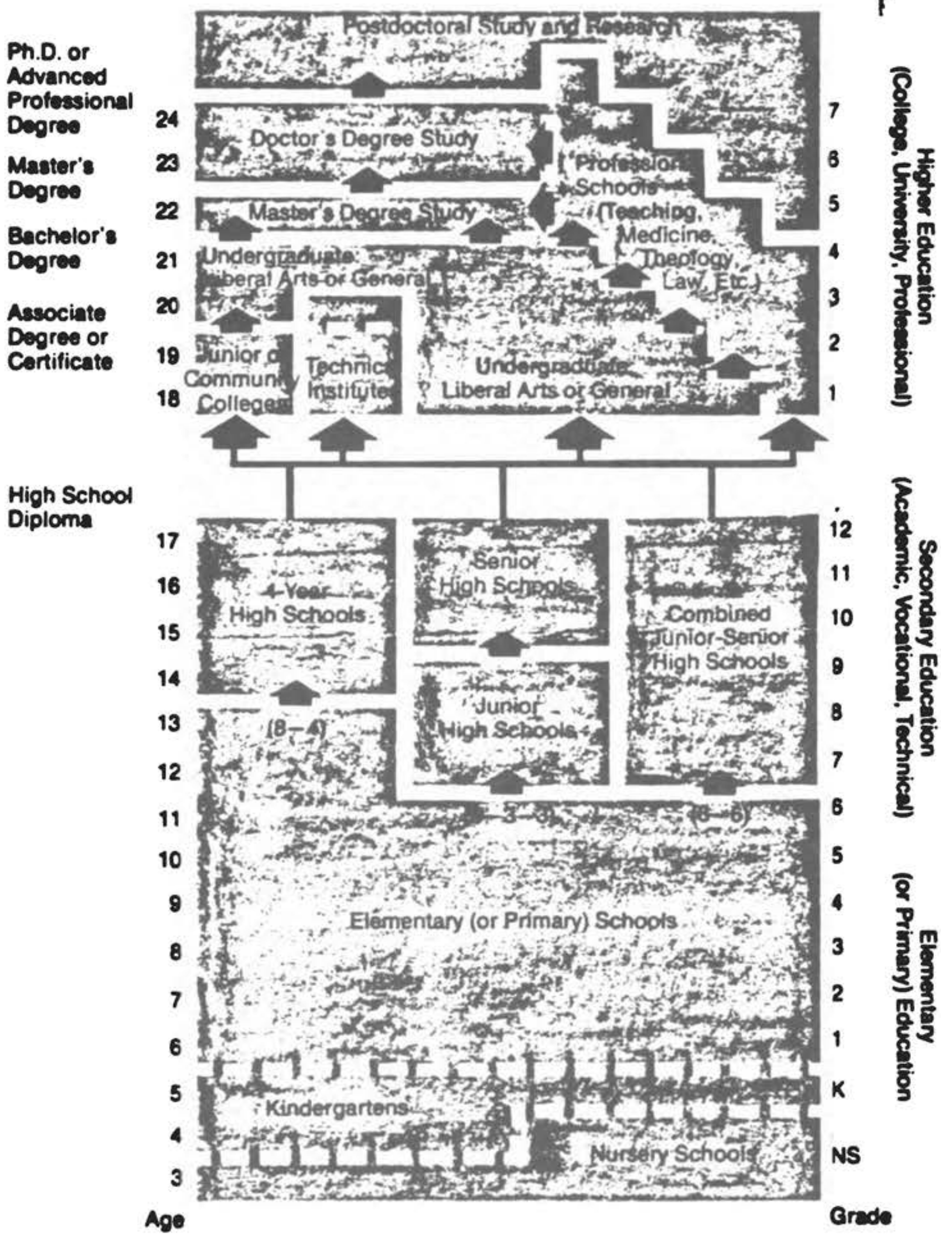
[1]Much of this paper is based on an earlier work by the authors, The Science Race: Training and Utilization of Scientists and Engineers, US and USSR (New York: Crane and Russak), 1982.

Figure 1.—The structure of education in the United States



NOTE.—Adult education programs, while not separately delineated above, may provide instruction at the elementary, secondary, or higher education level.

Source: National Center for Education, Digest of Education Statistics 1980, p. 4.

Table 1

U.S. EDUCATIONAL ATTAINMENT OF THE POPULATION:[1] 1960-1980

	1959-60	1970	1975	1976	1977	1978	1979	1980
	Percent							
College, 4 Years or More	7.7	11.0	13.9	14.7	15.4	15.7	16.4	17.0
High School, 4 Years or More	33.4	44.2	48.6	49.4	49.5	50.2	51.3	51.6
Fifth Grade, or More	50.6	39.5	33.3	32.0	31.4	30.5	28.7	28.0
Less Than 5 Years of School	8.3	5.3	4.2	3.9	3.7	3.6	3.5	3.4
	Number of Years							
Median Level	10.6	12.2	12.3	12.4	12.4	12.4	12.5	12.5

1 Data for persons 25 years of age or older.

Sources: U.S. Department of Commerce, Statistical Abstract of the United States, Washington, D.C., Government Printing Office, 1978, p. 143; 1979, p. 144; 1980, p. 148; 1981, p. 141.

There is a high degree of participation in the educational process in the United States. As indicated in Table 1, the level of educational attainment of the population, measured by number of years of training completed, is now 12.5, up from 10.6 in 1960. About 17 percent of the population has now completed four or more years of college, more than double the percentage in 1960.

U.S. education is organized on the basis of a decentralized system, in which each state retains control over education within that state. However, because the 50 separate state school systems are derived from a common tradition, they are essentially similar to one another organizationally and differ only in minor respects. For the purpose of administering elementary and secondary education, states are usually divided geographically into local school districts, controlled by directors or board members who are usually elected by the people of that community.

The financial support of public primary and secondary education in the United States is essentially local, with the portion that is raised and distributed by state agencies used primarily in the interests of equalization of educational opportunities between wealthier and less wealthy local districts. Support from Federal sources is used primarily as a supplement to state and local resources.

It is customary to divide the elementary/secondary educational program into three categories: preprimary education, which includes both nursery school and kindergarten; elementary or primary education, which traditionally begins at the age of six and includes the span of grades from the first through the sixth; and secondary, which includes the span of grades above elementary up through the twelfth grade, at the completion of which the student is awarded a diploma. The secondary educational program is frequently organized into two separate schools, each administered as a separate unit and offering instruction of a different type. A common pattern is a three-year junior high school, consisting of grades 7, 8 and 9, and a three-year high school consisting of grades 10, 11 and 12, although other patterns are also utilized.

Preprimary education refers to formal education for children during the year or years preceding the primary level. It includes prekindergarten or nursey school and kindergarten. While generally not included as an integral part of the elementary school program, preprimary education is being considered more and more important as a preparation for the early elementary grades.

Elementary education essentially attempts to transmit to the child general information regarding his historical and cultural heritage and to guide him in the development of basic skills. During the first three grades, the child is helped to develop the fundamentals of such skills as reading, writing and arithmetic; he is exposed to significant cultural and historical events; and he is aided in understanding and making intelligent use of his environment. In grades four, five and six, learning is frequently specialized into such areas as reading and language arts, elementary mathematics, social studies, natural science and physical education.

The average number of instructional hours per week devoted to mathematics, science, and social studies in U.S. elementary school programs[1] is shown below:

Subject	Grade Range	
	Kindergarten-Third (hours per week)	Fourth-Sixth (hours per week)
Mathematics	3.2	3.7
Science	1.6	2.9
Social Studies	1.8	3.3

There is growing concern among educators, as well as employers and government officials, that the current number of instructional hours devoted at these levels to science, and particularly mathematics, is well below what should be provided in preparing students for an increasingly scientifically and technologically oriented world. International comparisons suggest that total hours devoted to these subjects in the United States are considerably below the average for these same grades in other countries.

As noted above, secondary education is frequently divided into two components--junior high school and high school. Typically, the junior high school is an organized unit consisting of grades seven, eight and nine, with an educational program designed to meet the unique needs of the 12-to-15 year-old child. The basic program of the junior high school is general education. The more specialized programs and courses that are specifically designed to prepare a child for his future vocation or profession are generally not included in the junior high school curriculum, but postponed until high school.

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[1]National Science Foundation, "The Status of Pre-College Science, Mathematics and Social Studies Educational Practices in U.S. Schools," NSF-SR-78-71.

Under a general education program, seventh and eighth graders are commonly required to take courses, meeting five times weekly, in the following subjects: English, mathematics, general science, social studies and health and physical education. Ninth graders are commonly required to take courses in English, history or social studies, biology or general science, and health or physical education. The student then chooses from among various elective courses in areas such as mathematics, foreign languages, or general business. The most common science courses offered in grades 7-9 in descending order are: general science, earth science, life science, physical science, and biology. General science is the only science course offered by more than 50 percent of all the schools with grades 7-9.

Except for some of the larger school districts where specialized high schools (vocational, college preparatory, performing arts, etc.) are found, most high schools attempt to offer a comprehensive set of course offerings, which will meet the diverse needs of the entire high school population of a given community or school district. The typical high school curriculum therefore provides for both general and specialized education.

Most high schools have certain minimum requirements in general education that must be fulfilled by all students. A typical distribution of required courses in general education is 3-4 units of English, 2-3 of social studies, one of mathematics, one of science and one or two of health and physical education. To this minimum, the student then adds other general or special education courses which contribute to the higher educational or career opportunities available to him. The most frequently offered science courses in grades 10 through 12 are biology, chemistry and advanced biology.

In addition to the concern noted above about the level of emphasis on science and mathematics at the elementary level, there has also been a significant amount of concern expressed about the declining enrollment in science and mathematics courses among U.S. secondary school students. Findings from a sample survey in the United States show that over 56 percent of the school systems require no mathematics course or only one for graduation from the secondary school program. Changing patterns for courses in secondary schools in the United States do seem to reveal, however, an increase in better mathematics training for some students, especially advanced college-bound students; these students generally complete a calculus course and perhaps a course in probability and statistics. For most students, the general level of education in the United States seems to provide at least some training in general mathematics, geometry, and algebra (basic and advanced). A recent study of science education found, however, "that one-half of all high school graduates take no mathematics or science beyond the 10th grade and only one-half of the students entering college have had any significant exposure to physical science or advanced mathematics beyond the 10th grade."[1]

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[1]National Science Foundation and Department of Education, Science and Engineering Education for the 1980s and Beyond, October 1980.

Those students who do not successfully complete their secondary education (through grade 12) generally enter the labor force. Some, however, may enter vocational training schools to acquire skills related to particular occupations. Others who fail to earn a high school diploma sometimes complete their education at adult night schools. The student with a diploma either enters the work force or goes on to higher education to earn either an associate degree or a bachelor's degree.

B. Higher Education

In the United States, the various higher educational institutions can be distinguished with respect to the content and extent of their academic offerings as universities, other four-year colleges, or two-year colleges (often called junior or community colleges). They can also be distinguished with respect to their control and support as either public or private.

Except for a handful of institutions, chiefly the military academies or postgraduate schools associated with the military services, which are federally controlled, U.S. college-level public institutions either are part of the higher educational systems of the states or are under the control of municipalities or local school districts. More than half of the colleges and universities, however, are privately endowed and controlled.

The U.S. two-year colleges are widely distributed throughout the states. They are generally local or community institutions that provide an opportunity for students to obtain two years of college training while residing at or near home and to defer seeking admission to a four-year college until ready for the third (junior) college year. The two-year schools grant Associate of Arts (A.A.) or Associate of Science (A.S.) degrees. The completed curriculum is the equivalent of the first two years at a four-year college or university. The two-year colleges also provide some opportunities for vocational training and grant Associate of Applied Science (A.A.S.) degrees for technicians or mid-management type jobs. In addition, they often offer programs for adult continuing education at the collegiate level. Enrollment in the two-year colleges represents about one-third of total enrollment in all U.S. colleges and universities.

U.S. four-year colleges provide a full academic program leading to a baccalaureate degree, either a Bachelor of Arts (B.A.) degree or a Bachelor of Science (B.S.) degree. Although many of these colleges grant master's degrees, few offer doctorates. Universities provide a wide range of training, offering all levels of undergraduate and advanced degrees, and often include affiliated professional schools such as for law and medicine.

In the United States, any person who desires to obtain a college education can apply for admission to the college or colleges he chooses to attend. Several factors are usually involved in a student's choice of a college: the type of program he desires to pursue, the location, size, enrollment, student/faculty ratio and tuition charges and other expenses of the college or university, greater familiarity with certain institutions because of parents or other relatives having attended them in the past, etc. As the decision as to whether or not to admit any particular applicant is left to the discretion of the individual institution, another factor which generally plays a significant role in a student's choice of colleges is his estimation of the likelihood of his being granted admission, given his academic credentials and the admissions criteria of the institution. Because admissions to colleges are generally competitive, a student is not assured of being granted admission to any specific college of his choice. To ensure that he is admitted to at least one institution, a student often applies to several, at least one of which he feels will find him an acceptable candidate.

Within the constraints imposed by faculty and space limitations, U.S. colleges generally attempt to admit those students who will most profit from their educational programs and facilities and be able to meet the established academic standards of the school. As a result, the criteria for admissions vary markedly from one college to another. Many colleges have selective, highly competitive admissions standards, sometimes accepting as few as one of every 10 applicants. Some four-year colleges and many two-year colleges have open admissions policies, requiring only that a student have graduated from an accredited high school or attained a high school equivalency certificate.[1] Some state systems of higher education, such as the California system, include several types of institutions with different admissions requirements.

Most U.S. colleges and universities evaluate several criteria in deciding which applicants are likely to have the ability to do creditable work and eventually earn a degree from their institution. Significant among these are the high school record or transcript showing courses completed and the grade earned in each course, the applicant's rank in his graduating class, and recommendations from teachers, department chairmen, guidance counselors and school principals. Because of wide variations in the academic standards of different secondary schools, a large number of colleges emphasize scores on standardized national entrance examinations, such as the Scholastic Aptitude Test and the American College Testing Program's assessment tests, as well as the high school record in evaluating an applicant for admission. In addition to factors demonstrating an applicant's academic ability, colleges and universities frequently take into consideration a number of nonacademic factors, such as leadership potential, athletic activities, or impressions made at personal interviews.

In the United States, analysis of undergraduate curricula and graduation requirements in institutions of higher education is complicated by the great variability in the way study materials are organized into courses and in the systems used to assign values or weights to individual courses in relation to the amount of effort required for completion. The U.S. system measures progress towards graduation in terms of courses satisfactorily completed. Graduation requirements depend on the student's major field of study and include required courses, electives to be chosen from various categories relevant to the major field, others to ensure breadth of study, and finally general or unrestricted electives to complete a prescribed number of courses. These requirements vary from one college to another.

It is usually after completion of the first two years of general studies in the arts and sciences that students declare the major field of study that they wish to pursue in their next two years. Introductory courses taken in the first two years often influence student's decisions, and tentative decisions made earlier may have changed by this time. If the student is still undecided, he may confer with school counselors and/or take aptitude tests that may help him determine his field of choice. Counselors can also provide information on employment opportunities, salary ranges, and so on. From this point on, because of the specialized nature of the last two years of study, it becomes more difficult for a student to change his field of study, although it is not uncommon. Behind all the diversity, several constraints tend to be binding: (1) the requirements set by various professional accreditation and certification associations, (2) the need to prepare students adequately for transferring to another institution for completion of the last two years of an undergraduate program or for commencing graduate study and, more generally, (3) the need to achieve a measure of success in placing terminating students in gainful employment.

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[1]By 1970, practically all community colleges had adopted some form of
open admissions policy.

Because the two-year colleges are often used as stages in a four-year educational program, their offerings must permit completion of the requirements that four-year institutions impose on their students before admitting them to the upper division (the last two of the four-year curriculum)--that is, to third-year standing. This means that standard introductory courses required for a major field must be successfully completed in addition to general requirements in mathematics, natural sciences (other than in the major field of study), social sciences and humanities. The two-year degrees generally require courses in a major field roughly equal to one-third of the total of courses required in that major in order to obtain a bachelor's degree.

The four-year colleges tend to permit a slightly greater degree of specialization and diversity in their lower division courses (those intended to be taken in the first two years) than is often possible in the two-year colleges. The two-year colleges tend to make greater use of general introductory courses. For example, one introductory college physics course might be designed to accommodate a variety of students including those planning a physics major, others preparing for secondary school teaching and selecting physics as a teaching minor (an area of competence for principal teaching assignments) and still other students desiring the course merely to satisfy a generalized science or breadth requirement. In the four-year schools, a different course may be offered to meet the needs of each group of students. The general survey course in physics for students who are not science majors will avoid mathematics and will be comprehensible to the intelligent layman. The student majoring in physics, on the other hand, will be required to take a more specialized and technical course and be responsible for first acquiring the necessary mathematics or other prerequisites for the physics course. Engineers may be required to take a specially designed course in Physics stressing engineering mechanics and other engineering applications.

In general, the students in lower division work in any department all tend to follow the same sequence of courses, but follow individual progressions in the last two years. These differences are advantageous because they permit students to tailor their full program to their educational goals, e.g., to selected graduate specialties or to intended postgraduate vocations. It should be noted, however, that these general observations are less significant for engineering specialties which tend to have heavier schedules and are more rigidly laid out.[1]

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[1]Some differences between U.S. education and that in the Soviet Union
and in Japan are discussed in the Appendix to this paper.

The differences between universities and four-year colleges are less important for lower division work than those between four- and two-year colleges. While the universities permit some slightly greater degree of flexibility in the lower division programs, the more significant differences between universities and four-year colleges relate to upper division work. Although the baccalaureate degrees offered are the same, the variety of specialties available as major fields is much greater in the university, permitting more (or narrower) specialization. This large number of recognized major fields is reflected in a greater variety of course offerings and in acceptable combinations of courses for meeting graduation requirements in the major field.

Table 2 shows data on entrance and completion of higher education from 1960 to 1980. In the late 1970s, over 75 percent of all high school graduates entered higher educational institutions, a major increase from the approximately 50 percent of high school graduates in 1960 who went on to higher education. Attrition rates, however, are high, with only about 50 percent of those admitted to higher educational programs going on to complete their bachelor's degrees.

Table 3 shows U.S. bachelor's degrees conferred by higher educational institutions, by major field of study, from 1960 to 1980. In 1980, over one million bachelor's degrees were conferred by U.S. institutions of higher education, with about a third of the total represented by science and engineering fields. Since 1976, there has been a major increase in bachelor's in engineering, reflecting increased demand by industry, particularly in the last several years. A major concern at the present time, however, is that because of the intense industry demand, a decreasing percentage of these graduates is going on to postgraduate education, thus resulting in a reduction of the supply of advanced degree holders to teach and train future specialists in these areas.

C. Graduate Training

In the United States, two advanced degrees are awarded for training beyond the completion of higher education: the Master's Degree and the Doctor of Philosophy Degree (Ph.D.). The master's degree program is generally from one to two years in duration, while the doctorate requires three to six years, depending on the field and institution. Specific requirements for graduate level degrees in the United States vary greatly from university to university and from department to department. The number and variety of course options, thesis proposals, written and oral preliminary and comprehensive examinations, language and research tool requirements, and academic standards is large. However, a number of general observations can be made.

Table 2

U.S. SECONDARY SCHOOL GRADUATIONS AND ENTRANCE AND COMPLETION OF HIGHER EDUCATION: 1960-1980

Year of High School Graduation	High School Graduates (Thousands)	First Time College Students (Thousands)	First Time College Students as a Share of High School Graduates (Percent)	Year of Graduation from Higher Education	Graduates from Higher Education (Thousands)	Graduates from Higher Education as a Share of Entrants (Percent)
1960	1,864	923	49.5	1964	502	54.4
1965	2,665	1,442	54.1	1969	770	53.4
1970	2,896	1,780	61.5	1974	1009	55.9
1971	2,944	1,766	60.0	1975	988	55.9
1972	3,008	1,740	57.8	1976	998	57.4
1973	3,043	1,757	57.7	1977	993	56.5
1974	3,081	1,854	60.2	1978	998	53.8
1975	3,140	1,910	60.8	1979	1000	52.4
1976	3,154	2,347	74.4	1980	1010	43.0
1977	3,154	2,394	75.9	1981	NA	NA
1978	3,147	2,390	75.9	1982	NA	NA
1979	3,134	2,503	79.9	1983	NA	NA

Sources: U.S. Department of Commerce, Statistical Abstract of the United States 1973, pp. 130, 137; 1979, pp. 159, 160, 168; 1981, pp. 157, 158, 165.

Table 3

U.S. BACHELOR'S DEGREES CONFERRED, BY MAJOR FIELD OF STUDY: 1960-1980

	1960	1965	1970	1975	1976	1977	1978	1979	1980
All Fields, Total[1]	394,889	538,930	833,322	987,922	997,504	993,008	997,165	1,000,562	1,010,777
Science and Engineering, Total	120,937	164,936	264,122	349,602	342,697	334,864	333,287	332,030	333,017
Physical Science	16,057	17,916	21,551	20,896	21,559	22,618	23,175	23,363	23,661
Engineering	37,808	36,795	44,772	47,303	46,717	49,677	56,009	62,800	69,265
Mathematics and Computer Sciences	11,437	19,668	28,109	23,385	21,749	20,729	19,925	20,670	22,686
Life Sciences	24,141	34,842	52,129	69,809	74,373	75,724	74,937	72,823	70,014
Social Sciences	31,494	55,715	116,561	188,209	178,299	166,116	159,241	152,374	147,391
All Other Fields, Total	273,952	373,994	569,200	638,320	654,807	658,144	663,878	668,532	677,760

[1] Includes first professional degrees.

Source: National Center for Education Statistics, Earned Degrees Conferred, annual series.

Most U.S. master's degree programs require the equivalent of two semesters of full-time study after completion of the bachelor's degree. In the case of a master's degree for some professions (i.e., a Master of Business Administration), however, study can extend to two or more full academic years.[1] For degrees in fields requiring a large amount of data work for a thesis, the program often includes a full year of course work and an additional year for thesis research. There is generally a time limit, usually about five years, within which all requirements for the degree must be completed.

Most U.S. graduate schools specify some combination of thesis and/or written or oral comprehensive examination to fulfill the requirements for the master's degree. A number of programs have two plans for the master's degree: one which includes a thesis or final project and one which does not. The master's thesis may take on a variety of forms. It may be a long research paper, an essay or a short report of a project, an exhibition of art work, a recital or musical composition, a seminar paper, or any combination of the above. A final comprehensive examination is given in almost all cases, although the form and content of the examination vary greatly.

The Doctor of Philosophy degree (Ph.D.) is the highest degree granted by universities in the United States. It represents superior attainment in one field and is a demonstration of the ability to conduct independent research and contribute to the body of knowledge in that area. The amount of time required to complete the course work for the doctoral degree varies greatly from school to school, but is usually about three years of full-time study or its equivalent beyond the bachelor's degree. Time in which the dissertation is to be written is usually allotted following this period. The time limit for completion of the dissertation and all other requirements for the Ph.D. is usually about seven years. Ph.D. programs in the United States require a thesis or dissertation. The doctoral dissertation is expected to be the result of exhaustive research into one specific field of interest which provides an original contribution to the body of knowledge in that area or which presents a new and significant interpretation. Most graduate programs require an oral defense of the dissertation following its completion.

Graduate student participation in research work in the United States varies for different institutions and different fields, with the highest participation in research activities occurring in the science fields. Many graduate programs have a requirement that students take a course in the application of research methodology,

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[1] An academic year normally runs from September to May or June, or approximately nine months. There are usually two semesters per academic year. Some universities and colleges are on a quarter system, which has three quarters in an academic year of nine months.

in which the student may perform certain laboratory experiments or gather or organize research materials. In addition, there is a form of financial aid for graduate students, known as a research assistantship, which may require that as much as one-half of the student's time be devoted to carrying out research responsibilities, normally under the close direction and supervision of a faculty member.

Candidates for the doctoral degree generally conduct at least some research work in the preparation of their dissertations. The amount of research and the nature of the work involved vary for different fields, different programs, and different institutions. Research conducted in the preparation of a dissertation is generally designed and implemented by the student independently, although he may receive guidance from his faculty dissertation advisor.

While the doctoral degree is the highest formal degree awarded in U.S. higher educational programs, since World War II there has been an increasing trend among doctoral degree recipients to extend their education beyond that of the doctoral degree program by obtaining temporary appointments to research positions at universities, government laboratories, research institutions or industrial laboratories. A number of factors have contributed to the popularity of postdoctorals in the United States. The rapidly accelerating growth of science and its continuing fragmentation into new fields of specialization have made it desirable for many students to try to remain in the academic environment for one or more years after receipt of the doctorate before beginning permanent, professional employment. The availability of Federal research grants and other sources of support after 1945 created many opportunities for Ph.D.s to obtain temporary appointments as research associates or as postdoctoral fellows. Shortage of openings in some fields on the faculties of colleges and universities or in industry further motivated students to seek such temporary positions. Finally, college science departments have found it convenient to create such positions as a holding pattern to retain exceptionally gifted Ph.D.s. The creation of such positions serves to strengthen the science departments at relatively low expense and provides an opportunity for the appointees to teach advanced courses and engage in independent specialized research.

Table 4 shows U.S. master's and doctoral degrees conferred, by major field of study, for 1960 to 1980. Since 1975, the total number of both master's and doctoral degrees conferred has remained relatively constant. During that period, there was little change in the breakdown of master's degrees by fields of science and engineering, with the exception of the social sciences, which declined by over 15 percent. At the doctoral level, however, there has been a significant decrease in the number of degrees awarded in certain science and engineering fields. From 1970 to 1980, the number of degrees awarded in the physical sciences and in mathematics and computer sciences declined by 28 percent, while in engineering, there was a decrease of 32 percent. As noted previously, this has resulted

Table 4

U.S. MASTER'S AND DOCTORAL DEGREES CONFERRED, BY MAJOR FIELD OF STUDY: 1960-1980

	1960	1965	1970	1975	1976	1977	1978	1979	1980
Master's Degrees									
All Fields, Total	74,497	112,195	209,387	293,651	313,001	318,241	312,816	302,075	299,095
Science and Engineering, Total	20,012	33,835	49,318	61,539	62,033	62,790	62,147	58,911	58,603
Physical Sciences	3,387	4,918	5,948	5,830	5,485	5,345	5,576	5,464	5,233
Engineering	7,159	12,056	15,597	15,359	16,349	16,251	16,409	15,510	16,250
Mathematics & Computer Sciences	1,765	4,148	7,107	6,637	6,466	6,496	6,421	6,101	6,515
Life Sciences	3,751	5,978	8,590	9,667	9,972	10,889	10,887	10,886	10,523
Social Sciences	3,950	6,589	12,076	24,046	23,761	23,809	22,854	20,950	20,082
All Other Fields, Total	54,485	78,360	160,069	232,112	251,000	255,451	250,669	243,164	240,492
Doctoral Degrees									
All Fields, Total	9,829	16,467	29,872	34,086	34,076	33,244	32,156	32,756	32,632
Science and Engineering, Total	6,056	10,252	17,639	18,950	18,420	17,810	17,042	16,401	17,195
Physical Sciences	1,838	2,829	4,313	3,628	3,433	3,344	3,137	3,104	3,095
Engineering	786	2,124	3,681	3,108	2,821	2,586	2,440	2,506	2,507
Mathematics & Computer Sciences	303	688	1,343	1,188	1,100	1,039	1,001	966	964
Life Sciences	1,647	2,474	4,131	4,375	4,325	4,296	4,284	4,498	4,629
Social Sciences	1,482	2,137	4,171	6,651	6,741	6,545	6,180	5,327	6,000
All Other Fields, Total	3,773	6,215	12,233	15,136	15,656	15,434	15,114	16,355	15,437

Source: National Center for Education Statistics, Earned Degrees Conferred, annual series.

from the drain of graduates in the job market in industry at the bachelor's degree level, and raises concern about the adequacy of the future supply of advanced degree holders to fill faculty positions at colleges and universities. It should also be noted that while the number of Ph.D.s conferred in these fields has dropped sharply during the decade, an increasing percentage of the degrees that have been awarded are going to foreign nationals. In 1980, foreign students accounted for 21.6 percent of the Ph.D.s conferred in the physical sciences, 26.7 percent of those in mathematics and computer sciences, and 46.3 percent of those in the engineering fields.[1]

D. Technicians

In the past, scientists and engineers worked directly with craftsmen and other skilled workers; however, as technology became more complex, it became increasingly difficult for craftsmen, who usually had a limited knowledge of science and mathematics, to work directly with scientists and engineers. A need thus developed for "technicians," persons specially trained to work with and perform some of the tasks that otherwise would be done by scientists and engineers. While there is some training specifically structured in terms of the technician role, the U.S. educational system relies more on the manpower trained under the general high school curriculum and undergraduate training at the university level to provide the technicians required by industry, educational institutions, the government, and other employment sectors.

In the United States, technicians are defined as such by the specific employer, with the criteria ranging from skills of a craftsman to those of a professional. Employers also vary a great deal in the levels of training they require for their technicians: some require a bachelor's degree, others require an associate's or vocational degree, and some require only a high school diploma. For this reason, there is no specific definition of a technician in general usage in the United States. The National Science Foundation has adopted the following definition of technicans employed in science and engineering for use in its statistical reports:

> Technicians include all persons employed in positions which involve technical work at a level requiring knowledge in any of the fields of engineering, mathematics, physical sciences, environmental sciences, life sciences, psychology, or social sciences comparable to that acquired through formal post-high school training (less than a bachelor's degree), such as that obtained at technical institutes and junior colleges or through equivalent on-the-job training or experience. All personnel performing the duties described above should be reported as technicians even if they hold a bachelor's or higher degree.

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[1]National Science Foundation.

The level of training of persons classified as technicians may range from formal four-year courses of post-secondary education to informal on-the-job training, where the individual has acquired skills while working in a technician's position. In addition, technicians are often prepared for their work through more than one type of training. Some workers are employed as technicians after having started training for another occupation, but which for various reasons they did not successfully complete. Other individuals are employed full-time as technicians while working toward professional status as a scientist or engineer. Finally, as the work of the technican becomes more complex, additional training is often required, and this training varies as much as the preemployment training.

The wide diversity in the educational background of the U.S. technician population is evident from the following data.[1] In 1972, about one-third had no post-secondary education while about one-sixth had at least a bachelor's degree, and about one-half fell somewhere between these two extremes. Of the total, 9.3 percent reported having an associate degree. Those who attended college in most cases reported having scientific or technical majors. However, in most fields, college study was not concentrated in a single major; a variety of related major fields was reported, indicating a more generalized background than is found among scientists and engineers.

As noted above, there is a wide diversity in the level of training of persons classified as technicians in the United States. The U.S. data on technicans employed in science and engineering used herein are based on a definition of technicians as persons engaged in technical work at a level requiring knowledge equivalent to training received through two years of post high school education. Persons engaged in such activities are included as technicians even if they hold a bachelor's or higher degree.

Table 5 shows the number of employed technicians in the United States, by occupation and employer, for 1970, the latest year for which such data are available. In terms of type of employer, 41.3 percent of all employed technicians were in manufacturing, 18.9 percent in government (9.8 percent in Federal, 6.5 percent in State, and 2.6 percent in local), 4.3 percent in universities and colleges, and 0.7 percent in nonprofit institutions.

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[1]Michael G. Finn, "1972 Professional, Technical and Scientific Manpower Survey" as reported in Science and Engineering Technicians in the United States: Characteristics of a Redefined Population, 1972, Manpower Research Programs, Oak Ridge Associated Universities, ARAU-138 (February 1978).

Table 5

U.S. EMPLOYED TECHNICIANS,[1] BY OCCUPATION AND TYPE OF EMPLOYER: 1970

Type of Employer	Total	Draftsmen	Engineering	Physical Sciences	Life Sciences	All Other
Employers, total	1,027,800	304,400	371,500	123,000	85,600	143,300
Mining	12,200	3,900	2,800	1,300	200	4,000
Contract construction	36,100	21,900	7,900	200	0	6,100
Manufacturing	424,600	144,400	161,400	63,800	7,200	47,800
Transportation, communications, and public utilities	69,500	10,200	46,700	2,600	200	9,800
Other industries	247,400	101,400	45,400	20,700	29,500	50,400
Medical and dental laboratories	24,900	0	0	0	22,400	2,500
Nonprofit institutions	6,800	700	900	1,500	2,800	900
Engineering/architectural services	115,800	81,200	8,900	1,000	0	24,700
Government	193,900	19,800	96,500	28,300	25,600	23,700
Federal	100,600	3,100	53,600	24,300	14,900	4,700
State	66,300	7,500	35,100	2,600	9,500	11,600
Local	27,000	9,200	7,800	1,400	1,200	7,400
Colleges and universities	44,100	2,800	10,800	6,100	22,900	1,500

[1] Generally defined as employed at a level equivalent to training received through two years of post high school education.

NOTE: Because of rounding, sums of individual items may not add to totals.

Source: Training and Utilization of Scientific and Engineering-Technical Personnel: Appendices, SRI International, p. 79 (November 1976), citing unpublished data from Bureau of Labor Statistics sources.

Of the U.S. employed technicians, 36.1 percent were in engineering, 29.6 percent in drafting, 12.0 percent in physical sciences, 8.3 percent in life sciences, and 13.9 percent in other types of fields. Draftsmen are technicians who prepare detailed drawings based on rough sketches, specifications, and calculations of architects, designers, and engineers; thus, it is not surprising that, although the majority worked for manufacturing firms, over one-quarter of them worked for engineering and architectural firms. Engineering technicians work in all phases of production, and most were employed by manufacturing firms. Within manufacturing, they were highly concentrated in electrical equipment. Physical and life sciences technicians are primarily laboratory assistants. The largest block of physical science technicians were in manufacturing, with about one-third of these involved in the manufacture of chemicals. More than one-quarter of the life science technicians worked in medical and dental laboratories, and another one-quarter worked for universities and colleges.

E. Utilization of Scientists and Engineers

U.S. published data on scientists and engineers rely on various definitions, depending on the organization that is collecting the statistics and the nature of the statistical study. In many cases, a complete statistical time series relying on the same definitions and methodology throughout is unavailable. The Bureau of Labor Statistics (BLS), for example, has published data on U.S. scientists and engineers, by field, covering the years from 1950 to 1970. These statistics classify individuals as scientists or engineers only if they are actually engaged in scientific or engineering work at a level which requires a knowledge of the science or engineering field in which they are engaged equivalent to that acquired through completion of a four-year college course with a major in that field of science or engineering, regardless of whether or not they actually hold a college degree. Persons trained in the sciences or engineering but currently employed in positions not requiring the use of such training are excluded.[1] BLS data for these years are shown in Table 6.

Data for 1970 to 1980 using a fairly compatible definition of scientists and engineers have been published by the National Science Foundation (NSF). These data are shown in Table 7. The major difference between the NSF series and the earlier BLS series is the inclusion in the NSF series of data on social scientists and psychologists.

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[1]U.S. Department of labor, "Detailed Reporting Instructions, "A Survey of Scientific and Technical Personnel in Industry, in 1969, Bureau of Labor Statistics, BLS 2716A (1971).

Table 6

U.S. SCIENTISTS AND ENGINEERS, BY FIELD: 1950-70 and 1974
(In Thousands)

Year	Total Scientists & Engineers	Engineers	Physical scientists: Total	Physical scientists: Chemists	Physical scientists: Physicists	Physical scientists: Geologists	Physical scientists: Other	Mathematicians	Life scientists: Total	Life scientists: Agricultural	Life scientists: Biological	Life scientists: Medical
1950	556.7	408.0	89.1	51.9	14.0	13.0	10.2	13.8	45.6	16.9	19.9	8.8
1951	611.8	450.6	97.6	56.8	15.2	13.3	12.3	14.7	48.9	18.2	21.2	9.5
1952	685.9	507.5	108.6	62.9	16.7	13.8	15.2	16.1	53.7	20.4	23.0	10.3
1953	748.7	556.2	118.3	67.9	18.0	15.5	16.9	17.7	56.6	21.5	24.1	11.0
1954	783.7	581.2	124.2	71.6	19.1	16.1	17.4	19.5	58.9	21.7	25.5	11.7
1955	812.6	601.4	128.3	73.9	19.9	17.1	17.4	21.1	61.8	22.2	27.3	12.3
1956	873.7	646.4	137.0	79.2	21.4	17.9	18.5	23.1	67.3	23.7	29.9	13.7
1957	958.9	707.9	148.4	84.5	23.7	19.6	20.6	26.1	76.7	25.6	34.8	16.3
1958	1001.2	730.3	157.4	90.6	26.1	20.1	20.6	28.5	84.9	27.3	39.0	18.6
1959	1057.9	768.0	166.2	95.4	28.6	20.9	21.3	31.7	92.0	29.5	42.5	20.0
1960	1104.0	801.1	172.0	99.7	29.8	20.4	22.1	34.2	96.7	30.4	44.8	21.5
1961	1151.5	833.3	178.8	102.8	31.6	20.6	23.8	36.3	103.3	32.3	46.9	24.1
1962	1210.3	873.2	186.0	106.8	33.9	21.1	24.2	39.8	111.5	35.3	49.0	27.2
1963	1280.8	922.7	194.1	110.0	36.3	22.5	25.3	43.6	120.3	38.5	51.3	30.5
1964	1327.0	945.5	203.7	115.0	39.0	23.4	26.3	47.2	130.5	41.5	54.4	34.6
1965	1366.3	969.8	209.2	116.7	39.9	25.5	27.1	50.3	136.9	44.1	55.6	37.2
1966	1417.5	999.6	217.0	119.6	42.1	26.2	29.1	53.9	147.0	46.9	56.9	43.2
1967	1476.7	1037.7	225.8	122.8	44.4	28.4	30.2	61.9	151.1	46.5	62.6	42.0
1968	1525.0	1062.4	236.1	127.3	46.2	29.0	33.6	67.1	159.4	47.2	65.8	46.4
1969	1567.7	1085.0	243.8	131.0	48.4	29.4	35.0	73.0	165.9	47.5	67.7	50.7
1970	1594.7	1098.2	248.8	132.9	49.1	30.6	36.2	74.3	173.4	49.3	71.1	53.0
1974	1631.9	1114.0	251.6	134.5	47.5	31.5	38.1	77.5	188.8	47.7	76.8	64.3

Note: Detail may not add to totals due to rounding; 0.0 is less than 50.

Source: (a) Data for 1974 in Occupational Outlook Handbook, 1976-77 Edition, Bureau of Labor Statistics Bulletin 1875.

(b) Data for 1950-70 in Employment of Scientists and Engineers, 1950-70, Bureau of Labor Statistics Bulletin 1781.

Table 7

U.S. SCIENTISTS AND ENGINEERS BY FIELD: 1970-80
(In Thousands)

Field	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Scientists and engineers, total	1,752	1,789	1,817	1,847	1,883	1,948	1,992	2,047	2,092	2,220	2,316
Scientists, total	657	681	708	741	764	803	849	869	891	906	956
Physical scientists	165	169	173	176	175	177	186	184	185	191	200
Chemists	105	110	113	117	117	118	128	125	126	130	137
Physicists/astronomers	47	46	47	46	46	46	45	44	44	45	47
Other physical scientists	13	13	13	13	12	13	13	15	15	15	16
Mathematical scientists[1]	38	35	38	33	37	38	39	43	43	46	47
Computer specialists	132	146	162	185	195	209	224	228	231	243	259
Environmental scientists	44	46	47	51	54	60	59	59	62	68	72
Earth scientists	37	38	39	44	45	51	51	51	53	58	63
Other environmental scientists[2]	7	7	7	8	8	9	9	8	9	9	10
Life scientists	154	159	162	162	164	169	184	194	202	193	201
Biological scientists	53	54	55	58	61	65	69	73	74	70	71
Agricultural scientists	64	65	67	65	63	63	75	81	86	79	84
Medical scientists	37	38	40	40	40	40	40	40	42	44	45
Psychologists	44	45	49	53	56	61	64	69	71	73	78
Social scientists	81	80	80	81	84	90	93	94	95	94	99
Economists	27	28	27	27	30	33	32	34	34	35	38
Sociologists/anthropologists	8	7	7	8	8	9	9	10	9	10	11
Other social scientists	47	46	46	46	47	48	51	51	53	49	50
Engineers, total	1,095	1,108	1,109	1,106	1,119	1,145	1,144	1,178	1,201	1,314	1,360

[1]Includes mathematicians and statisticians.
[2]Includes oceanographers and atmospheric scientists.
NOTE: Detail may not add to totals because of rounding.

Source: National Science Foundation, Science and Engineering Employment: 1970-80, NSF 81-310, p. 15.

During the 1950s, the number of scientists and engineers in the United States doubled, rising from about 600,000 to nearly 1.2 million. In the 1960s, employment increased by almost as much in absolute terms, but the relative gain was only half of that experienced between 1950 and 1960. In the 1970s, the number of scientists and engineers in the United States increased by about a third, with major increases in the number of computer specialists, which almost doubled, and environmental scientists, which increased by almost two-thirds. The least growth occurred in the number of physicists/astronomers, which remained relatively constant throughout the decade.

The National Science Foundation has classified the diversified types of organizations in which scientists and engineers are employed into the following sectors: federal government, industry, universities and colleges, federally funded research and development centers (FFRDCs), other non-profit institutions, state and local government, and foreign performers. Most of these categories are self-explanatory with regard to the nature and the scope of the R&D organizations they encompass. "Industry" is defined by NSF as "organizations that may legally distribute net earnings to individuals or to organizations." The industry sector is defined principally in contrast to non-profit institutions, which are private institutions chartered to perform public service, no part of whose net earnings may be distributed to a private stockholder or individual. The term "industry" as used in the NSF classifications includes, in addition to manufacturing proper, some non-manufacturing firms such as public utilities, mining, agriculture, and forestry and fisheries.

Federally funded research and development centers are organizations that perform research and development exclusively or substantially financed by the Federal Government in order either to meet a particular R&D objective or, in some instances, to provide major facilities at universities for research and associated training purposes. Some FFRDCs are administered by private industrial firms, some by universities, and some by other non-profit institutions.

The coverage of the state and local government category is specifically restricted to exclude state or locally supported universities and colleges, agricultural experiment stations, and medical schools and affiliated hospitals, all of which are treated as part of the university and college sector. Organizations are classified in the "universities and colleges" sector if their fundamental purpose is instruction or training above the secondary school level, without regard to whether or not they are profit-making institutions.

When data are aggregated on a national basis, the National Science Foundation uses the following four sector division: federal government, industry, universities and colleges, and other non-profit institutions. FFRDC's, with the exception of those administered by universities and colleges, are not reported separately but as part of the sector administering them. Because of the relatively small amount of state and local investment in, or performance of B&D other than that treated as part of the universities and colleges sector, as noted above, it is not reported as a separate sector when data are aggregated on a national basis, but as part of the "other non-profit institutions" sector.

The number of U.S. scientists and engineers, by primary work activity and by sector of employment for 1970 to 1980, is shown in Table 8. About 15 percent of the scientists and engineers are employed by educational institutions, 67 percent by industry, 7 percent by the federal government, and 10 percent by other non-profit institutions. In terms of primary work activity, about 9 percent are engaged in teaching, 30 percent in research and development, and the remainder in other types of activity.

In recognition of the importance of research and development (R&D) to technological progress and economic growth, a significant amount of attention in the United States has been devoted to the definition of R&D activity and the internal divisions differentiating basic from applied research and research as a whole from development. The National Science Foundation publishes a variety of annual publications and special reports providing quantitative data about the structure and growth of employment in R&D as well as R&D expenditures.

The National Science Foundation defines research as "systematic, intensive study directed toward fuller scientific knowledge of the subject studied" and development as "the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processed." NSF statistics on scientists and engineers engaged in R&D are based on the number of full-time and part-time employees conducting research and development or R&D management activities, reduced to full-time equivalents. The minimum standard for inclusion of scientists or engineers in the series is described as "the performance of professional scientific or engineering work in research and development, requiring a bachelor's degree, or its equivalent, in science or engineering." Fields of science included in the coverage are the natural sciences (life, physical, and engineering) and the social sciences and psychology, except in the case of the industry sector where coverage is limited to the natural sciences.

Table 8

U.S. EMPLOYED SCIENTISTS AND ENGINEERS BY PRIMARY WORK ACTIVITY AND BY SECTOR: 1970-80
(In Thousands)

Field	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Scientists and engineers, total	1,752	1,789	1,817	1,847	1,883	1,948	1,992	2,047	2,092	2,220	2,316
Total in research and development	521	528	535	543	550	561	577	605	632	662	694
Total in teaching (educational institutions)	135	145	149	149	160	169	177	189	194	196	197
Total in other	1,097	1,117	1,134	1,156	1,174	1,217	1,238	1,253	1,266	1,362	1,425
Educational institutions, total	250	261	266	268	276	290	304	317	328	336	352
Research and development	69	69	69	69	65	67	72	74	77	79	82
Teaching	135	145	149	149	160	169	177	169	194	196	197
Other	46	46	49	50	51	53	55	54	56	61	73
Industry, total	1,175	1,192	1,208	1,236	1,266	1,266	1,319	1,351	1,382	1,494	1,557
Research and development	375	380	385	391	394	396	407	430	451	477	504
Other	801	812	822	845	866	900	912	922	931	1,017	1,053
Federal Government, total	147	151	157	153	151	156	161	163	164	168	173
Research and development	49	47	45	43	44	45	45	45	46	46	47
Other	98	105	112	109	106	114	116	116	116	121	126
Other sectors, total	180	185	188	193	196	203	209	215	219	222	234
Research and development	28	32	37	41	47	53	53	58	58	59	61
Other	162	153	151	152	149	150	156	159	161	163	173

NOTE: Detail may not add to totals because of rounding.

Source: National Science Foundation, Science and Engineering Employment: 1970-80, NSF 81-310, p. 16.

Figure 2 shows the distribution of total funds used for performance of research and development in the United States, by R&D performer and by source of funds, for 1980. As illustrated by the figure, most of the funds for R&D originate in the federal government (48.7 percent in 1980) and in industry (47.6 percent). Industry, however, is the dominant performer of R&D, accounting for more than two-thirds of the total, followed by research laboratories of government agencies, with about 13 percent of the total, and universities and colleges, with about 13 percent. Other non-profit institutions represent a relatively small portion of the total, both in terms of source of funds and in terms of performance of R&D.

The distribution of full-time equivalent scientists and engineers employed in R&D by sector for 1954 to 1979 is shown in Table 9. As with the distribution of R&D funds by performer category, industry accounted for more than two-thirds of R&D scientists and engineers. The share of the total scientists and engineers employed by universities and colleges has risen since 1954, with 12.9 percent of the total in 1954 and 14.7 percent in 1980. The share of the total accounted for by research laboratories of government agencies, on the other hand, had been declining from 15.9 Percent in 1954 to 10.1 percent in 1980. About 4.4 percent of total R&D scientists and engineers were employed by the other non-profit institutions sector in 1979, as opposed to 2.2 percent of the total in 1954.

As noted above, the industry sector is the largest performer of R&D in the United States, accounting for about two-thirds of the total U.S. R&D effort. Industry is a particularly important contributor to the applied research and development components of the R&D effort, accounting for almost 60 percent of the applied research and almost 85 percent of the development performed in the United States in 1980. On the other hand, it accounted for only about 16 percent of U.S. basic research. Of the total R&D conducted by industry, over 77 percent consisted of development, about 19 percent was applied research, while only about 3 percent consisted of basic research.

The distribution of U.S. R&D scientists and engineers by industry for 1968 to 1979 is shown in Table 10. In 1977 more than 380,000 scientists and engineers were employed in R&D activities in industry. Those industries with the largest numbers of scientists and engineers engaged in B&D activities in 1979 were the electrical equipment, aircraft, machinery and chemicals industries, which together accounted for more than two-thirds of the R&D employment in industry.

Intersectoral transfers of funds used for performance of research and development, basic research, applied research, and development: 1980 (estimated)

RESEARCH AND DEVELOPMENT[1]

[Dollars in millions]

Sources of funds	Performers						
	Federal Govern-ment	Industry[2]	Univer-sities and colleges[3]	Associated FFRDC's[4]	Other nonprofit institu-tions[2]	Total	Percent distribution, sources
Federal Government	$7,830	$13,950	$4.100	$2,000	$1.520	$29.400	48.7
Industry	——	[5]28,300	210	——	200	28.710	47.6
Universities and colleges	——	——	[5]1,300	——	——	1,300	2.2
Other nonprofit institutions	——	——	440	——	[5]525	965	1.6
Total	7,830	42,250	6.050	2,000	2.245	60.375	
			8.050				
Percent distribution, performers	13.0	70.0	10.0	3.3	3.7		100 0
			13.3				

1 All data are estimated from reports by performers.

2 Expeditures for federally funded research and development centers (FFRDC's) administered by both industry and by nonprofit institutions are included in the totals of their respective sectors. FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.

3 Includes agricultural experiment stations.

4 Federally funded research and development centers (FFRDC's) administered by individual universities and colleges and by university consortia.

5 Includes State and local government funds.

Source: National Science Foundation, <u>National Patterns of Science and Technology Resources, 1980</u>, NSF 80-308, p. 14.

Figure 2. INTERSECTORAL TRANSFERS OF FUNDS FOR PERFORMANCE OF RESEARCH AND DEVELOPMENT: 1980 (estimated).

Table 9

U.S. FULL-TIME EQUIVALENT SCIENTISTS AND ENGINEERS EMPLOYED IN R&D, BY SECTOR: 1954-1980

	1954		1961		1965		1970		1975		1980[1]	
	Thousands	Percent of Total	Thousands	Percent of Total	Thousands	Percent of Total	Thousands	Percent of Total	Thousands	Percent of Total	Thousands	Percent of Total
Total	237.1	100.0	425.7	100.0	494.5	100.0	546.5	100.0	534.9	100.0	659.0	100.0
Federal Government	37.7	15.9	51.1	12.0	61.8	12.5	69.8	12.8	63.4	11.9	66.5	10.1
Industry	164.1	69.2	312.0	73.3	348.4	70.5	375.5	68.7	363.8	68.0	465.0	70.6
Universities and Colleges[2]	30.0	12.7	51.5	12.1	64.5	13.0	80.0	14.6	82.9	15.5	98.5	14.9
Other Non-Profit Institutions	5.3	2.2	11.1	2.6	19.9	4.0	21.2	3.9	24.8	4.6	29.0	4.4

[1] Estimate.

[2] Includes associated FFRDCs.

Source: 1970, National Patterns of R&D Resources 1953-1977, NSF 77-310, p. 34; all other years, National Patterns of Science and Technology Resources 1980, NSF 80-308, p. 33.

Table 10

U.S. FULL-TIME EQUIVALENT NUMBER OF R&D SCIENTISTS AND ENGINEERS BY INDUSTRY: 1968-79
(In Thousands)

Industry	January 1968	1970	1975	1976	1977	1978	1979
Total (January)	376.7	384.2	363.3	364.4	382.8	405.0	429.8
Total (Annual Average)	381.9	375.4	363.6	373.4	393.7	417.4	NA
Food and Kindred Products	6.3	6.3	6.8	6.9	6.9	7.0	7.4
Textiles and Apparel	2.5	2.9	1.8	1.8	1.7	1.7	1.9
Lumber, Wood Products and Furniture	.5	1.2	2.3	2.1	2.1	2.5	2.5
Paper and Allied Products	4.8	5.0	5.0	5.2	6.3	6.5	7.3
Chemicals and Allied Products	38.9	40.1	45.2	44.4	46.4	48.2	49.7
Industrial Chemicals	22.3	21.5	21.1	20.1	20.6	17.8	18.0
Drugs and Medicines	9.8	11.8	15.6	16.6	17.8	18.9	19.9
Other Chemicals	6.8	6.8	8.5	7.8	8.0	11.5	11.8
Petroleum Refining	9.2	9.9	8.4	8.6	8.9	9.9	10.8
Rubber Products	6.1	7.4	8.4	8.6	9.1	7.8	8.1
Stone, Clay and Glass Products	4.1	4.6	4.5	4.6	4.5	5.1	5.3
Primary Metals	5.9	6.5	6.3	8.1	8.4	8.1	8.2
Ferrous Metals and Products	3.1	3.2	3.3	3.9	3.9	3.6	3.7
Nonferrous Metals and Products	2.7	3.3	3.0	4.2	4.5	4.5	4.5
Fabricated Metal Products	5.6	5.9	7.4	6.8	7.1	7.2	7.3
Machinery	37.4	42.3	52.8	55.7	55.3	58.1	63.0
Office Computing and Accounting Machines	(1)	(1)	36.1	38.1	37.7	39.2	42.8
Other Machinery, Except Electrical	(2)	(2)	(2)	(2)	17.6	18.9	20.0
Electrical Equipment	98.4	100.6	82.6	80.3	84.1	85.5	89.2
Radio and TV Receiving Equipment	1.0	1.9	1.0	1.1	.9	.8	.8
Electronic Components			10.6	10.2	13.0	14.3	15.3
	67.4	64.8					
Communication Equipment			40.2	37.4	38.0	40.4	43.0
Other Electrical Equipment	30.0	33.9	30.8	31.6	32.2	30.0	30.1
Motor Vehicles and Motor Vehicles Equipment			26.0	25.4	28.2	30.7	33.5
	24.3	25.5					
Other Transportation Equipment			1.9	1.7	1.9	2.4	2.6
Aircraft and Missiles	101.1	92.2	67.5	66.9	72.0	81.5	86.2
Professional and Scientific Instruments	14.1	15.0	17.9	18.8	20.5	22.1	23.9
Scientific and Mechanical Measuring Instruments	3.8	4.1	5.9	6.7	7.2	7.8	8.7
Optical, Surgical, Photographic, and Other Instruments	10.3	10.9	12.0	12.1	13.3	14.3	15.2
Other Manufacturing Industries	2.4	2.6	3.7	4.2	4.5	4.6	4.9
	17.8	19.2					
Nonmanufacturing Industries	15.1	16.3	14.9	14.6	15.3	16.1	18.0

[1] Data not tabulated at this level prior to 1972.

[2] Data not tabulated at this level prior to 1977.

Source: National Science Foundation, National Patterns of Science and Technology Resources 1980, NSF 80-308, p. 51.

Like industry, the R&D performed by research laboratories of government agencies primarily consists of applied research and development. In 1980, about 52 percent of the R&D performed in this sector consisted of development, 32 percent was applied research, and 15 percent was basic research.[1]
Over half of the civilian R&D scientists and engineers in government agencies are employed by the Department of Defense. Except for biological scientists, who are primarily concentrated in the Department of Agriculture and the Department of Health, Education and Welfare,[2] the Department of Defense also employs the highest percentage of civilian R&D scientists employed by government agencies in each specific field.

The principal focus of R&D performed by the universities and colleges sector is basic research, which comprised about 61 percent of the R&D performed in the sector in 1980. About 26 percent of university R&D consisted of applied research and only about 13 percent consisted of development work. The largest percentage of the professional scientists and engineers engaged in R&D in universities and colleges are concentrated in the life sciences, which accounts for about 60 percent of the total.[3]

The research and development effort of the other non-profit institutions sector is fairly equally divided among basic research, applied research and development. Although current data on the breakdown by field of employment of R&D scientists and engineers in this sector are not available, the National Science Foundation estimates that more than half of the R&D personnel in this sector are life scientists and engineers.[4]

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[1]National Science Foundation, National Patterns of Science and Technology Resources, NSF 80-308, p. 14-15.

[2]This Department has since been divided into the Department of Health and Human Resources and the Department of Education.

[3]National Science Foundation, National Patterns of R&D Resources 1953-1977, NSF 77-310, p. 15.

[4]National Science Foundation, National Patterns of R&D Resources, 1953-1977, NSF 77-310, p. 16.

F. Future Supply of Scientists and Engineers

The National Center for Education Statistics has projected earned bachelor's, master's and doctoral degrees by field from 1977-78 through 1988-89.[1] The number of engineering degrees projected to be granted rises into 1981-82 and then subsides. Degrees awarded in the physical and life sciences follow a similar pattern of rising in the early 1980s and then falling.

Although the projected number of master's degrees awarded in all fields decreases from 1983 throughout the remainder of the projection period, the number of master's degrees projected in the science and engineering fields remains relatively stable throughout the period with the exception of a general downward trend in the 1980's in the engineering fields. Data for earned doctoral degrees by field show a gradual but steady decline in projected degrees throughout the 1980s, with a greater percentage decrease in the science and engineering fields than in all fields combined. Projected doctoral degrees awarded in the physical and life sciences and mathematics decline by almost 19 percent.

Projections of doctoral scientists and engineers have also been developed by the National Science Foundation.[2] The NSF data show the total science and engineering doctoral labor force, those employed in science and engineering, and those with science and engineering degrees but employed in non-science/engineering fields. It is important to note that the percentage of doctoral scientists and engineers not employed in occupations for which they were trained is projected to rise from 9 percent to 18 percent between 1979 and 1990.

Although the NSF projections generally indicate that the number of Ph.D's awarded in science and engineering will be sufficient to fill the demand for them, there is now evidence which seems to suggest that the number of Ph.D. engineers will fall short of demand, because of the many students terminating their education at the bachelor's level to take advantage of strong demand (manifested in high salaries) for bachelor's degree holders in engineering. A recent study which cites the NSF estimates suggests that because the NSF projections did not account for the continued strong demand for new B.S. engineers to

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[1]National Center for Education Statistics, Projections of Education Statistics to 1988-89, April 1980, pp. 62-94.

[2]These data prepared by NSF were published in Science and Engineering Education for the 1980s and Beyond, National Science Foundation and Department of Education, (October 1980). The projections represent an Engineering update of the Foundation's "Projections of Science", NSF79-303. Doctorate Supply and Utilization: 1982 and 1987," NSF 79-303.

enter the labor force, future graduate engineering enrollments and, thus, future doctoral supply, may be overestimated. As noted previously, there is also concern that an increasing number of total U.S. Ph.D.s are being awarded to foreign students, which could result in an even greater shortfall in the future supply of Ph.D.s in science and engineering. At the present time, many of these foreign nationals appear to be obtaining permanent employment in the U.S. labor market. The U.S. Department of Labor reports that the number of permanent labor certificates for engineering occupations issued to foreigners more than doubled from 1976 to 1980.[1] Thus, it appears that foreigners entering or remaining permanently in the U.S. labor market may be partially offsetting a shortfall in Ph.D's in engineering.

Projections of future supply and demand reflect the specific assumptions associated with the model as well as a forecast of the general economic environment. Therefore, specific statements with respect to projected shortages or surpluses must be carefully interpreted. Recent forecasts by NSF, for instance, have the general supply/demand balance going from surpluses to shortages if the economy returns to historical levels of real growth and increased defense expenditures occur.

It must also be noted that projections vary widely among specific fields. The existence and extent of shortages differ for specific fields, and policy prescriptions must correctly target the shortage fields. One area for which there are documented shortages is that of the U.S. electronic industries, where electrical and computer engineers are utilized. A study by the American Electronics Association projects an increasing gap between the supply and demand for electrical and computer engineers.[2] The study concludes that the number of graduates in these fields will have to triple in each year for the next five years to meet the needs of the electronics industries.

Ihe reliability of forecasts is somewhat better if the forecasts are for specific fields or industries. The data currently amassed lead to the conclusion that shortages of engineers and scientists currently exist in certain specific fields, and general shortages are likely to emerge if the U.S. economy enters a recovery period and defense expenditures expand as recommended by the current administration.

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[1]U.S. Department of Labor as cited in "Foreigners Snap Up the High-Tech Jobs?' New York Times, July 5, 1981, p. F-13.

[2]Pat Hill Hubbard, "Plan For Actions to Reduce Engineering Shortage...with Supporting Data", American Electronics Association, October, 1981.

G. Conclusion

This paper has attempted to provide a general overview of the system of training and utilization of scientific, engineering and technical personnel in the United States. Some data were presented to show recent trends in these processes. In addition, certain problems that are emerging with the current status of U.S. science, mathematics and engineering education, as well as supply problems on the utilization side, have been pointed out. These problems include the falling level of achievement in mathematics and science in the elementary and secondary schools; increasing shortage of Ph.D. graduates to fill vacant faculty teaching positions, particularly in the engineering schools; and projected shortages, at least in selected fields, of scientists and engineers to meet the demand later in this decade. It seems appropriate to conclude with a brief description of how these problems are beginning to be addressed in the U.S. system, which is decentralized, pluralistic, and heavily reliant on the existence and operation of markets.

A market is defined as the interaction of independent demanders and suppliers which has as the outcome the exchange of goods and services at prices which the participants are willing to accept. As related to training and employment of scientific and technical personnel, markets operate through the transmittal of information which attracts or discourages prospective entrants by raising or lowering salaries or by the degree of availability of jobs within certain fields. It is believed that market information is generally effectively transmitted, but that because the training of an individual for a specific occupation takes a certain amount of time, there are often significant time lapses before supply adjustments are completed.

The market economy is guided by the choices expressed by individuals and their representative government. Markets have generally received high marks for efficiency of allocation, although the nature of the market sometimes fails to take into consideration the national or societal interest. While individual decisions based on market conditions are the principal determinants of work force training and utilization in the U.S. economy, there is still significant government influence on these decisions. The government, at the local, state and federal level, provides public education from general tax revenues through the secondary education program. State and federal government funds heavily subsidize public institutions of higher education. Federal funds in many cases provide significant financial resources to private institutions of higher education. In addition, the activities of government in the marketplace has impact on the kinds and numbers of persons needed to provide the goods and services for the U.S. economy--for instance the defense-related industry. Thus, although the focus is on the individual and the market, the government plays an important role in economic decisions in the U.S. economy.

The marketplace is influential in solving problems such as those that have been noted above. For instance, more students are applying for places in engineering schools and more are graduating. This change in recent years reflects the fact that salaries for engineers have risen rapidly. This same cause and effect, however, has served to drain off Ph.D.s in engineering into industry and discourage students from continuing their education to earn Ph.D's.

The problems described can and are, in part, being solved by normal activities in the market. However, most analysts conclude that the market solutions will take time, perhaps a long time, and the national interest could be severely damaged in the meantime. Therefore, there are calls from many quarters--engineering associations, universities, scientific associations, private industry, Congressmen--for an enhanced role of government in partnership with industry and academe in dealing with the problems. The potential roles include special tax benefits to corporations for donations to educational institutions, government scholarship for science and mathematics students, special grants for new scientific and engineering instructional equipment, and greater funding for research and development.

The fact that the U.S. system is decentralized requires the commitment and coordination of a large number of different public and private organizations to solve problems such as those that have been noted. For instance, to change elementary and secondary school curricula to include a greater emphasis on science and mathematics requires that each school district revise its curricula. However, there are over 15,000 local school districts throughout the states. Higher education is funded principally by states and by private sources, primarily students and endowments, but there are thousands of such institutions under hundreds of jurisdictions. And finally, to increase teachers salaries and update laboratories will require shifts in resources from other competing uses.

A consensus seems to have emerged among scientists, engineers, industrial managers and policymakers in the United States that the present state of science, mathematics, and engineering education and the utilization of our scientific and engineering manpower is not meeting our current national needs and, without actions, will be seriously deficient in the near future. Currently there are a number of special government commissions and Congressional review panels as well as initiatives in the private sector searching for effective approaches to meet our national needs in science and technology. What appears to be lacking, however, is a unified policy at the national level to provide direction and guidance to the various efforts that are taking place. The next few years will hopefully mandate the establishment of a national science and engineering policy that will foster a fusion of activities in the private and public sectors to achieve the policy goals.

APPENDIX

COMPARISON OF U.S. EDUCATION WITH THAT IN THE SOVIET UNION AND IN JAPAN

In response to the question raised by the representatives of the People's Republic of China regarding similarities and differences between U.S. education and that in the Soviet Union and in Japan, the following brief comments can be made.

Education in the U.S.S.R.

There are several significant differences between the U.S. and Soviet systems. At the elementary/secondary level, perhaps the greatest difference--at least the one that is receiving the most attention in the U.S. at the present time--is the Soviet emphasis on science and mathematics for all students in the system and the grades at which they are introduced. The Soviet standard ten-year school curriculum requires multiple years of instruction in mathematics/science disciplines--the physics curriculum, for example, spans grades 6-10 with an average of three to four instructional periods per week, while the students concurrently study chemistry, with an average of 2-3 instructional periods per week. In the United States, chemistry is generally offered to 11th grade students and physics to 12th grade students, with the exposure to each field confined to the one-year program. Another important difference is that the entire school population is exposed to the mathematics/science oriented curriculum in the Soviet system, rather than only a small proportion of students who elect to pursue science/mathematics studies as is the case in the United States. Studies by the National Science Foundation have shown that of U.S. high school graduates, only 9.1 percent have studied one year of physics and 16.1 percent one year of chemistry.

At the level of higher education, perhaps the most noteworthy difference is the high degree of specialization characteristic of the Soviet program. There are currently about 360 specialties offered by Soviet higher educational establishments. Over 200 of these specialties are in engineering-industrial fields. Students choose a specialty at the time they apply for admission and, once admitted, follow a rigidly defined program of study preparing them for a professional occupation in that specialty. As with the elementary/secondary levels, Soviet higher educational training is far more heavily skewed toward the science/mathematics disciplines than is the case in the U.S.

At the level of graduate education, similar trends are evident. As opposed to the United States, Soviet graduate training is conducted not only at the universities and other institutions of higher education, but also at many of the research organizations maintained by the Soviet academies of sciences and various industrial ministries. Soviet universities, considered by both Soviet and foreign scholars to provide the highest quality training, enroll only about one-fourth of the persons pursuing advanced training, while the majority are trained at research institutions. It appears that the research-institute trained students are more oriented toward meeting the needs of the specific institutions at which they study than toward broader training with more theoretical and basic science content. Soviet graduate training includes a significant amount of laboratory research related to the current work of the research institutions or the contract work currently in progress at the universities, and appears to have more applied science content than U.S. programs, especially the U.S. doctoral degree. About 70 percent of Soviet graduate enrollment is in science and engineering fields as opposed to about 20 percent in the United States.

At the level of higher and graduate training, the heavy Soviet concentration on narrow occupational training represents a marked difference from U.S. higher education. The extremely narrow specialization, however, has often been faulted for its high susceptibility to obsolescence, and its failure to provide scientists with the ability to master new knowledge, assimilate new research methods, and cope with technological change. While the high degree of specialization and applied functional orientation of the Soviet higher educational process may be an asset in the development of specialists with the ability to attain the short-term, technological targets of the Soviet economic plan, the more flexible, theoretical, broader-based education received in U.S. higher educational institutions may produce specialists who are better prepared to meet the longer-term goals of a society with an ability to innovate, an adaptability to technological change, and a greater latitude for inter- field mobility as the demands of the economy change.

Education in Japan

As with the Soviet Union, one of the most noteworthy contrasts between education in the United States and in Japan is the high degree of Japanese emphasis on scientific and mathematics disciplines. Studies have indicated that overall achievement scores in science and mathematics of Japanese students are the highest in the industrialized Western world. With a population about half that of the United States, Japanese universities graduate almost one and one-half times the number of baccalaureate-level engineers. A study by the National Science Foundation and the Department of Education suggests that the large percentage of Japanese students who pursue scientific fields in higher education is directly related to the heavy emphasis on science and mathematics at the secondary level.[1]

Like U.S. higher education, higher education in Japan is four years in duration and provides a general education including social sciences, humanities and foreign languages in the first two years and more specialized training in a particular area in the following two years. In contrast to the Soviet Union, where criticism has been leveled at the high degree of specialization in higher educational training, widespread criticism has been voiced in Japan that Japanese higher education is overly directed toward abstract science with an emphasis on theory and principles, while students gain little or no laboratory experience. Thus, Japanese industrial managers frequently complain that the higher educational institutions are producing engineers who upon graduation are ill-equipped to take their place in industry.[2]

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[1]National Science Foundation and Department of Education, Science and Engineering Education for the 1980s and Beyond, NSF 80-78, October 1980.

[2]State of California Office Appropriate Technology, High Technology and High School: Preparing Students for California's Changing Economy, June 1982.

EDUCATION AND DEVLOPMENT OF S & T PERSONNEL

Hu Ping

Contents

I. Introduction

The development and rational utilization of human resources provide the basic condition for the existence and growth of any society. The experiences of countries over the world have proved that in building up a modernized nation, one must first of all have a sufficient number of highly qualified S and T personnel. With the rapid development of S and T and their increasing impact on socio-economy, the quantity and quality of these personnel have become one of the decisive factors in determining the pace and essence of a nation's development. Whoever desires a strong economy must acquire powerful science and technology capabilities, and whoever desires the latter must acquire strong abilities of education and training first.

Since the birth of New China, the Chinese government has been assigning great emphasis to the building up of an S & T contingent. Our superior socialist system and rich human resources are favourable in solving the problem of lacking S & T personnel. Yet at the same time, the traditional impact of several thousand years of feudal society and small peasant economy have caused some unique difficulties in the development of intellectual resources. Through our efforts over the past thirty years, China has brought up a considerable number of qualified S & T personnel in various fields and at various levels, the number of whom has risen from tens of thousands since the birth of New China to over five million at present, including some world eminent scientists, engineers and technical experts. They work selflessly in all walks of life for our socialist construction and have made great contribution towards the prosperity of our nation. Their hard work has resulted in some world achievements in many important areas within a short historical period in China.

However, on the whole, both the quantity and quality of our S & T personnel are far from meeting the needs of our socio-economic development. There exists an intellectual shortage in many areas in the course of our socialand economic construction. This is due at least to the following three reasons: 1) the extreme backwardness of culture, education and S & T in Old China had left us with a poor basis with regard to the education and training of S & T personnel: 2) the ten years of turmoil of the "Cultural Revolution" had caused suspense in the upbringing of high level S & T personnel: 3) the incompleteness and imperfection of our system concerning intellectual resource development have also affected to certain degrees such development.

Since the overthrow of the "Gang of Four" in 1976, the Chinese Government has formulated a series of policies and adopted measures aimed at the upbringing of S & T personnel and this has occurred rapidly.

II.History and the present state of S & T contingent in China

Old China is an economically poor, scientifically and technologically backward country. Under the Kuomintang Government from 1927 to 1949, there were only 180,000 university graduates. In 1949, at the time of nationwide liberation, there were only 117,000 students studying at various institutes of higher learning in China, with no more than 50,000 S & T personnel, among whom only a few hundred were engaged in scientific research.

After the founding of New China, the Chinese government made tremendous efforts to overcome the backwardness in education, science and technology. In 1951, the government issued a resolution concerning the reform of the educational system. Again in 1952, a resolution was adopted to reorganize the structure of departments and colleges among various Chinese institutes of higher learning, which was followed by a nationwide major reform in the old educational system and structure, making clear the respective positions and responsibilities of specialized institutes and technical colleges in training S & T personnel. To meet the needs of our national economic development, we established a number of specialized institutes in the areas of basic research, technical disciplines, emerging sciences and technologies, greatly increasing the nation's educational capability in theoretical, industrial, agricultural, medical disciplines and so on. We made rapid progress in the development of S & T personnel. From 1949 to 1952, the number of students studying at various institutes of higher learning in China rose from 229,000 to 636,000: that of S & T personnel from 50,000 to 425,000. At the eve of the "Cultural Revolution" in 1965, the number of college students had reached 670,000, with an annual increasing rate of 11.5 percent. At the same time, the number of S & T personnel in natural sciences reached 2.458 million, among whom were over 955,500 university graduates in theoretical, industrial, agricultural and medical disciplines, about 1.45 million graduates from vocational schools in industrial, agricultural and medical professions. The annual rate of increase was more than 12 percent.

The year 1966 saw the beginning of the "Cultural Revolution" which lasted for ten years and caused great damage to the development of S & T and education. Large numbers of schools and institutes were disorganized and recruitment of new students was suspended. During these ten years, the number of higher learning institutes went down from 434 in 1965 to 392 in 1972: students number from 670,000 to 565,000, which means a reduction of at least 1 million and a serious deterioration of student quality. This has become a direct cause of the temporary shortage of S & T personnel and the aging problem. In 1972, student recruitment in various institutes of higher learning began again, yet the system of entrance examination was abolished. Instead, a recommendation system was adopted. Under such a system, only workers, peasants, and soldiers with more than two years of working experience could be enrolled. This system has many defects which lead to a deterioration of quality of the newly enrolled students.

After the overthrow of the "Gang of Four", education in China gradually normalized. In 1977, the system of entrance by recommendation was abolished, that of entrance through unified examination was restored, and the policy of acceptance according to quality was adopted. As a consequence, the number of enrolled students rose year by year, and the quality of education improved remarkably. By 1980, there were 675 institutes of higher learning in China, with 1.144 million enrolled students, 17,700 post-graduates, 246,000 teachers among whom there were 3,600 full professors, 13,000 associate professors and 111,700 lecturers. The proportion of specializations among the students in various areas in those institutes is as follows: out of the total student number, there were 33.4 percent students in engineering, 7.4 percent in agriculture and forestry, 12.2 percent in medicine and health, 29.6 percent in education, 7.3 percent in pure sciences, 5.1 percent in arts and letters, 3.2 percent in economics and accounting, 6.5 percent in political sciences and law, and 1.3 percent in physical education and arts. By the end of 1981, there were 704 institutes of higher learning in China with 1.28 million undergraduates and 17,000 post-graduates.

Acccording to the statistics in 1979, there were 5.544 million S & T personnel working in the fields of natural sciences, out of which 4.7 million worked in state owned institutes and agencies. Among them, 38,000 were senior scientists and technicians who were at the equivalent level of associate professors; 440,000 at the equivalent level of university lecturers and 4.22 million at the basic level.

Over the past three years, thanks to the correct implementation of our government's policy, there has been a lot of progress in the development of China's S & T contingent. The structure of S & T personnel has improved and an increasing number of scientists and technicians have been promoted. By 1980, the number of S & T personnel working in state owned institutes of enterprises reached 5.296 million, a 12 percent increase over 1979. By 1981, the figure reached 5.71 million, a 7.9 percent increase over 1980.

Among the 5.71 million S & T personnel in 1981, 58,700 were senior scientists and technicians, 987,300 are intermediate ones and 4.664 million are at the basic level: out of which 43 percent were university or college graduates, totalling 2.748 million, and the rest were mainly graduates from technical colleges. Woman scientists and technicians made up 30 percent of the total. Their composition was as follows: 330,000 scientific research personnel, 2.07 million engineers and technicians, 328,000 agronomists, 1.68 million doctors and other health staff and 1.29 million teaching staff. Our S & T personnel work mostly in these five sectors: the Chinese Academy of Sciences, various ministries and commissions of the State Council, provinces and municipalities, higher educational institutes and the national defence system. Whereas more than half of them work in various institutes and agencies under either ministries or commissions of the State Council only a small proportion of them work on the production front. According to the statistics in 1981, there are only 75,000 scientific research personnel working in industrial enterprises.

Besides formal university education, another important way to train scientific and technical personnel in our country is to strengthen the in-service continuing education for the working staff and the social education for the young people waiting for jobs. In recent years, there has been progress in the in-service and spare-time education. Apart from the national universities over the radio and on TV, many regions and enterprises have set up various spare-time schools: workers' colleges, university by correspondance, evening schools and short-term training courses. According to the incomplete statistics, in 1980, more than 1.55 million people studied in the adult sohools of higher education, more than 8 million people attended spare-time secondary schools and over 16 million people joined spare-time elementary schools. The Chinese government has decided that its large numbers of staff in various ministries and commissions of the State Council should be trained by rotation so that all of them can reach at least the level of secondary vocational school graduates within 5 years.

In order to train a large number of highly-qualified scientific and technical personnel, our government has just established a degree system. In 1980, it issued regulations for evaluating graduates' quality and granting them degrees. A number of renowned key universities and research institutes have been authorized by the government to evaluate the academic excellence and to grant degrees. And they have already started their work in this respect. In China, we offer three kinds of degrees: bachelor's degree, master's degree and doctoral degree. University graduates with excellent academic records can receive bachelor's degrees. Post-graduate students, after training, practice and research in research institues and after passing oral defence of their thesis can get master's deqrees. Then, if they continue to study and receive training, through examination and oral defence of the dissertation, they can get their Ph.D.'s Over the past two years, we have come up with the first group of masters and doctors since the founding of New China.

For the purpose of learning from foreign countries the advanced science and technology and ways of management, China has in the last few years strengthend her work in the respect of sending students to study abroad. We have sent more than 5,600 university undergraduates, postgraduates and visiting scholars to 46 countries. Apart from that, even more people have obtained financial support from private sources to study abroad.

III. Some policies and measures for the improvement of the development of scientific and technological personnel

1. The adjustment of the disharmonious situation between education and economic development compares with the situation before liberation as our education has developed with leaps and bounds. Yet, it is still very backward in comparison with the economic development since liberation. Educational development and economic development are gravely out of balance. Education does not conform to the need of economic development.

From 1952 to 1978, the government's investment for the industrial capital construction increased from 1,880 million yuan to 29,450 million yuan, an increase of 15.7 times. During the same time, the government's fund for education increased from 895 million yuan to 6,560 million yuan, an increase of only 7.3 times. The percentage of educational funds in the national expenditure was 6.4 in 1966, 6.3 in 1976, and 5.9 in 1978. The figure in fact went down every year. Investment in education makes up a small proportion in the gross industrial and agricultural production value, less than 1.5 percent.

The cause of such a situation is that our country's financial resources are limited: we do not have many funds for education. However, this also reflects, to a certain extent, the tendency of emphasizing material construction and neglecting the development of intellectual resources. Because of this mistake, we cannot achieve ideal economic returns although we have invested a great deal in economic construction. Since there is a lack of technical and administrative personnel, there exists in some of our enterprises the phenomenon of high cost, high consumption, low quality, low efficiency and ill-management. This has resulted in tremendous losses in economic construction.

Since 1979, the government has been readjusting and restructuring the national economic system on a large scale. Backwardness in education has drawn the attention of the government and the people of the whole country. Responsible administrations have taken measures to adjust the disproportionate state between educational and economic development. During the past few years, although the country was facing financial difficulties, it did not cut down the educational budget. On the contrary, it has increased the fund for education. From 1977 to 1981, the annual increase of the number of full-time students in institutes of higher learning was 18 percent. In 1982, our universities are expected to enroll 300,000 students, a 12 percent increase over 1981. This shows that in our country, education has again drawn people's attention and has made progress. Of oourse, we still have to work hard for a long time to completely ovorcome the backward situation in education.

2.Adjustment and Reform of higher education

In the past 32 years, the average rate of increase of university students was eight percent. This shows a rather quick increase. However, our country's higher education is still backward. The proportion among higher education, secondary education and elementary education is gravely out of balance. Our higher education system and structure are far from perfect, curriculum and student enrollment are not reasonable. All this needs to be improved and adjusted.

In 1980, we had 146 million elementary school students and more than 57.4 million secondary students, but only 1.143 million university students. The university-secondary-elementary school student ratio was 1:50:128. Only 12 out of every ten thousand people in China are university students.

There are many reasons. Apart from the historical factors, including the damage brought about by thc "Cultural Revolution" there are some other factors. For instance, our institutions of higher learning have been practicing, for a long time, the full-time study system and boarding system. This is expensive and has greatly limited the number of students that can be enrolled. Another example, the potential of university teachers is far from being fully explored. At present, the teacher-student ratio in our universities is 1 to 4, i.e. one teacher teaches only 4 students, which is a very low ratio. Also our higher learning institutes regulate certain class hours for the students, require relatively longer years of studies and the students are left with no chance to take optional courses, jump courses and cannot be exempted from certain requirement courses. Therefore, this also hampered the development of intellectual personnel.

Besides the problems mentioned above, there are also problems of improper composition of specialities in our higher education. In the past, as we emphasized the development of heavy industry, our institutes of higher learning also focused on heavy industry in planning curricula, thus neglecting the training of S & T personnel for agriculture, forestry, light industry, textile industry, etc. For example, our light industrial output value constitutes 46.9 percent of the total industrial output value. However, the S & T personnel in light industry makes up only 1 percent of the entire working staff in light industry. From 1949 to 1979, the number of graduates from our light industry colleges and institutes was only 1.86 percent of the graduates from engineering institutes. Light industry can be divided into about a dozen major categories, and needs more than 40 kinds of special personnel, but our capability in higher educational institutions in this field is very limited. For instance, in the entire country only one educational institute offers courses in leather making. Again, there are 800 million peasants in China, but there are only 320,000 scientific and technical personnel in agriculture, the ratio being four to ten thousand. Such a composition of subjects in higher learning institutes was decided by our economic structure with heavy industry as its focus, but no longer conforms to the development of the present economy. In addition, the development of intellectual resources in areas such as economics, accounting, political sciences, law, management, etc, has also been neglected in the past.

In some disciplines, there are such shortcomings as the over-narrowing and over-specialization of subjects. The students trained in these areas do not have a wide range of knowledge, nor a solid base of theories. Their ability to work comprehensively and to adjust themselves to their jobs is rather poor. Modern science and technology are becoming more and more comprehensive and overlapping. Different disciplines are always penetrating into each other and splitting, while at the same time generating new elements. The cycle of renewing of knowledge is becoming shorter and shorter. Under such circumstances, university education should emphasise teaching the students the basic knowledge and skills, promoting their ability of comprehensive analysis. If the disciplines are divided too narrowly and too specifically, they are bound to separate from the ever changing reality, thus causing a separation of study from application.

There are also shortfalls in our university recruitment system. We lack a long-term plan for training specialized porsonnel who can meet the practical needs. The number of university enrollments is decided by the central government every year. But the specific numbers for each discipline are decided accordinq to the teaching ability and facilities of each university or institute that does not know the present and future needs of the country. The blindness in university enrollment has resulted in the inbalance of structure in terms of specialized personnel: some faculties have trained more personnel than needed whereas some fall short of demands.

The above-mentioned problems in our higher education were formed over a long period of time. Now they have drawn the general concern of our educational and scientific circles. Some measures have been taken to improve the situation. At present, we are adjusting our national economy. We should also adjust our educational structure, the S & T curriculum structure and the structure of scientific and technical personnel, so that we can change the situation in which education separates from economic development. In the past few years full-time universities have developed at a great speed. The number of universities has increased from 392 in 1976 to 704 in 1981, and the number of university students has increased from 565,000 in 1976 to 1.28 million in 1981. The average annual increase rate of students is 18 percent, which is rarely seen.

The government has mobilized social forces and resorted to all kinds of channels and methods to run schools. There are now non-boarding schools attached to universities, radio and TV universities, university by correspondance, evening schools, etc. The result is promising. Our higher educational institutions are on the one hand trying to increase the quantity of university students, while on the other hand trying to improve the quality of education and to improve curricula and teaching materials. From 1978 to 1980, the state re-examined and re-compiled the university teaching materials of science and technology, revised the teaching programmes, adding new materials reflecting the development of modern science and technology, and strengthened the teaching of basic theories and skills. There is more flexibility in the educational system and its methods. For instance, the schools have started the credit system and non-boarding system. The students are allowed to take optional courses, to jump courses and to graduate ahead of schedule. Our departments are conducting research on how to adjust the structure of specialities and the proper proportion among different disciplines and personnel, strengthening the planning and forecasting of future intellectual resources development. They are making an investigation into different areas to find out the need for specialized personnel so as to work out within a short period training plans suitable for economic and social development.

3. To strengthen in-service education

In order to expand the scale of higher education and to adjust the improper relations between education and economy, China has in recent years put special emphasis on the advanced training of working staff. We take this as an important addition to the usually full-time higher education, and have therefore put it into our national higher education plans. In 1979, our central educational administrative departments convened a national conference on the education of working staff. The conference decided to bring into full play the initiatives of various departments, local governments as well as the whole society in running schools. It also decided to further develop radio and TV universities, universities by correspondance, evening schools, etc. These institutes mainly enroll in-service working staff and young people at the secondary school level. They make use of the teaching materials, teaching plans and programmes of the full-time universities. They have set up strict examination systems so as to guarantee that their students reach the same level as full-time university graduates. After finishing their courses, the students in these institutes can take the graduation examination. Those who pass the examination can receive diplomas from the schools which are recognized by the government. Those with excellent academic records can even receive bachelor's degrees. The graduates from these universities will be treated the same as full-time university graduates in their job assignment and their work assessment. For those graduates who are still waiting for jobs, the state will employ them according to their merits.

With the encouragement and support from the government our country's higher education for working staff has been developing rapidly during the past few years. Take the radio and TV university for example, at present, besides the Central Radio and TV university run by the Ministry of Education and the Ministry of Radio and Television, each of the 29 provinces, except Taiwan province, and municipalities and autonomous regions has set up its own television university. All the lectures are broadcast by the Central TV station and are transmitted by TV stations in every province, municipality and autonomous region. The Central Radio and TV University offers 16 courses in science, technology and basic theories in specialized subjects. The programme lasts for 3 years and is carried out in credit system. Students are divided into classes according to their working units. Each class has about 20 to 30 students. They watch lectures on TV together and have professional or part-time tutors. Apart from attending classes, they need to do exercises, answer questions and engage in various experiments. By June 1982, our TV universities had enrolled 3 batches of students totalling 800,000. Among them, 113,000 were enrolled in 1979, some of whom have completed their 3 years of studies and have obtained diplomas. The workers' colleges throughout the country have also developed at tremendous speed. In 1980, there were more than 200 workers' colleges in Shanghai. They offer more than 100 special subjects for studies, have 3,200 full-time teachers and about 50,000 students.

The Shanghai Spare-time Industrial Institute has 4 departments, 10 affiliated schools and 12 specialities. These institutes have played an important role in training specially and urgently needed scientific and technical personnel for the local areas, and in reforming the structure of our cadre system.

4. Reform of the structure of secondary education

A great proportion of our country's S & T personnel are constituted by secondary technical college graduates. Secondary technical schools train special personnel in various technological fields. They offer courses in natural science, courses in engineering, agriculture, forestry, medicine,etc. Their students are able to reach the senior high school graduation level and to master certain basic theories and knowledge in certain areas. This is a basic channel to train junior technicians. Before 1966, our secondary schools were already well developed. The students in secondary technical colleges agricultural colleges and other vocational schools make up 34.7 percent of the total number of secondary school students. During the "Cultural Revolution" a large number of secondary technical colleges were either disorganized or converted into secondary senior high schools. This resulted in a sharp decrease of the numbers of secondary technical colleges. In 1976, secondary technical school students make up only 1.16 percent that of the total secondary school. Obviously, the secondary education structure was unbalanced. In 1978, there were 65.48 million students in the ordinary secondary schools across the country, but only 889,200 students in the secondary technical colleges and 381,900 students in secondary engineering schools. Only 4 percent of the ordinary senior high school graduates can get into universities, almost all the rest are unable to continue their education or acquire specialization or technical training and therefore it is difficult to find jobs for them.

In recent years, the various educational departments concerned have made great efforts to change this situation. They have reduced the number of ordinary high schools, and developed on a large scale secondary technical and engineering colleges and vocational schools. The number of students in ordinary senior high schools has decreased from 18 million in 1977 to 9.69 million in 1980, while the number of students in secondary technical colleges has increased from 689,000 in 1977 to 1.243 million in 1980, and that in secondary engineering colleges has increased to 689,000. We should certainly continue our efforts in this respect, and it will have a positive influence on the quantitative increase of S & T personnel and the structural reform of our S & T contingent.

CHARACTERISTICS OF THE UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA AND ITS ROLE IN TRAINING SCIENTIFIC AND TECHNICAL PROFESSIONALS OF CHINA

Ren Zhishu and Si Youhe

The University of Science and Technology of China (USTC), founded in 1958, is a university under Academia Sinica of physical sciences combined with engineering. It is characterized by its unique guideline of "mobilizing the entire Academy of Sciences to run the University, and integrating institutes with departments," its establishment of rare specialties needed in China and its students of high quality--all this has attracted attention from all walks of life. Its founding has been honored as a "significant event in the history of education and science in China."[1] USTC was listed in the nation's key universities the year following its founding and has now become one of the most prestigious universities in the country. Despite its short existence and the destruction encountered in the "ten years of disaster," more and more attention has been paid to its excellent students and its achievements in scientific research in the international, academic, and educational circles. During the past twenty-four years, USTC has played a rather active part in training scientific and technical professionals in China and has formed its own distinguishing features.

FILLING THE GAPS IN THE SPECIAL FIELDS OF STUDY IN CHINA

Two key policy-making factors drove Academia Sinica to found USTC: filling the "Gaps" in the special fields of study in our country as quickly as possible and accelerating the training of scientific and technical professionals badly needed by the country.

In 1956, the Chinese government formulated "the Plan for Scientific and Technological Development in the Period of 1956-1967," which clearly pointed out the important urgently needed subjects which were lacking or underdeveloped must be established first, while immediate measures should be taken for the technologies which had newly developed in the world and would have a significant bearing in every field.[2] To materialize the plan, in addition to the founding of institutes of Modern Physics and Mechanics in the early 1950s, Academia Sinica successively set up the institutes of Semi-Conductor, Automation, Computing Technology, Electronics, etc. However, there was an acute lack of scientific and technical professionals requiring immediate reinforcement.

As far as the then educational circle was concerned, since New China had just been founded and there were only a small number of colleges and universities, which still remained at a stage of reorganization and initial development. Among the 200 universities and colleges or so in the country, there were only 15 offering both programs in sciences and humanities,[3] of which the proportion of science programs was even smaller if those in the humanities were excluded. In the engineering colleges, the number of subjects was relatively small and most of their contents were out of date, and subjects dealing with new technologies were even fewer. Meanwhile, the advance of modern science and technology required the closer combination of science and engineering subjects. Thus, there once existed a bad match between the situation of higher education and the number of scientific and technical professionals demanded by scientific and technological development.

In order to improve the situation, many efforts were made by the Chinese educational circle. By 1958, Chinese education had seen many new developments; a number of institutions of higher learning meeting the needs of the country's construction came into existence, USTC was one of them.

When preparing to set up this new type of university, the founders of USTC determined that the most important policy-making factor was that the university should establish majors aimed at filling the gaps in utilization of atomic energy and space science and technology and improving backward technology.

Zhang Jing-fu, former vice-president of the Academia Sinica and current head of the State Economic Commission, stated in his report to the Party Central Committee on the Academia Sinica's intention to establish USTC: "In order to meet the needs of the rapid development of our scientific work, bring into full play the potentials of the existing scientists, accelerate the training of scientific professionals of weak and blank subjects in the fields of new technology and promote the development of those subjects, it is proposed that a new-type university be founded by Academia Sinica."[4] Guided by this policy, in keeping with the needs of developing atomic energy and space technology, USTC has established 13 departments with 41 specialities. Among them, such specialties as nuclear physics, nuclear engineering, atomic power, radiochemistry, radiation chemistry, semi-conductor physics, low-temperature physics, chemical physics (high-speed reaction dynamics, physical meachanics), high-speed aerodynamics, chemical fluid dynamics, electronic computers, engineering logic, biophysics, atmospheric physics at high altitudes, weather control, computing technology, geophysics, etc. were new technical specialties, which were established either for the first time or were very weak in the country at that time.

Since then, in regard to specialty-establishment, USTC has maintained the concept formed in its initial stage. Early in the 1960s, when laser technology had just emerged, USTC noted this promising subject and in no time added a laser specialty to the physics department. In the 1970s, when plasma physics was thriving, USTC spared no efforts to establish a plasma physics program, which so far has been the only program in China and is playing a leading role in the field of plasma physics and diagnosis.

The fact that all those specialties concerning modern science and technology could first be established in USTC was basically due to the successive foundings of the institutes of those subjects by Academia Sinica The conditions were thereby created, such as qualified faculty and equipment, for the establishment of those specialties. This was also the policy-making basis for the founding of USTC.

LAYING EMPHASIS ON TRAINING HIGHLY QUALIFIED SCIENTIFIC AND TECHNICAL PROFESSIONALS

USTC, "unlike average colleges of science and engineering, primarily trains personnel of the world's most sophisticated sciences" and "thus enables our country to catch up with the level of advanced countries in the capacities of the blank and newly emerging subjects badly needed by the state."[5] That is what was said by Vice Premier Nie Rong-zhen who was then in charge of the science affairs of China. Therefore, the training of highly qualified scientific and technical personnel has always been the objective of USTC.

Over the 20 years since it began hosting graduates in 1963, USTC has provided the country with 10,772 graduates. Notwithstanding the limited number of its graduates, it has to a certain extent, satisfied the needs of the state in terms of specialization and quality. From now on, it will continue to adhere to the principle of "few but good," that is to say, undergraduate enrollment should not be too big, but must be trained better so that they will become graduates of higher quality.

The graduates of USTC have not failed to live up to the state's expectations. Most of them are now engaged in scientific research and have become backbones in their respective units.

Let us take the first three years' graduates of USTC for an example. According to USTC's academic system, the full-time study period for students was five years; so the first three years' graduates graduated in 1963, 1964, and 1965 respectively. As they had completed their 5 years' study before the "ten years of disaster," they were assigned jobs according to their specialties. (Table 1)

TABLE 1

The assignments of the first three years' USTC graduates[6]

Year of Graduation	1963	1964	1965	Total
Academia Sinica	605	551	514	1670
Science Commission for National Defense	128	135	37	300
State Science Commission	44	6	8	58
1st-7th Ministry of Machine Building	252	295	600	1147
Other Ministries	127	159	188	469
Colleges	122	107	71	300
Local Units	64	62	135	261
TOTAL	1342	1315	1558	4215

Table 1 shows that most of the graduates were assigned to work in units of departments of scientific research. However, considering the fact that the graduates who have been assigned to various ministries or local units may not be engaged in scientific research work, we have made a further investigation on the present status of the graduates. Among the questionnaires we have received, there are 365 from the first three years' graduates. 91.3 per cent of them are conducting their scientific research in research institutions or colleges. (Table 2)

Meanwhile, we have also made inquiries into two institutes. In the Physics Institute of Academia Sinica, there are 60 first three years' USTC graduates, amounting to ten percent of the total scientific researchers in the institute; one holds a leading position in the institute, one has been appointed chief of the personnel section, three are associate directors of the research sections and most of them are leaders of their topic groups. In the Electronics Institute of Academia Sinica, there are 59 first three years' USTC graduates 11.8 percent of the research personnel; one is chief of the scientific research section, two are associate directors of research sections, many of them are leaders of topic groups.

TABLE 2

The practical work engaged in by part of the first three years' USTC graduates

	Number of Persons Investigated	Research Institutions	Colleges	Factories	Publishing Houses	Middle Schools	Miscellaneous
Number of Persons	365	311.0	22.0	17.0	5.0	3.0	7.0
Percentage	100	85.2	6.1	4.6	1.4	0.8	1.9

In practical work, satisfactory achievement has been attained by USTC graduates. (Table 3)

TABLE 3

The achievements in scientific research attained by part of USTC graduates

Levels of the achievements of scientific research	
World's advanced level	86
Domestically advanced level	335
Filling the gaps at home	236
Theses or works	
Published abroad	170
Published at home	1184
Various works	111
Awards received	
Ministry or commission level	257
Province level	75
County or institute level	126

Note: the number of persons investigated is 449.

Speaking more concretely, the USTC graduates have participated in the work of developing A-bombs, man-made satellites, and intercontinental ballistic rockets for our country. Five USTC graduates have participated in Professor Samuel C.C. Ting's experiment in which he discovered evidence of the existence of gluons; some USTC graduates have associated themselves with the work of making synthetic ox-insulin and Ala transfer RNA. In short, the young personnel trained by USTC have played and are playing an active part in the construction of China.

Nevertheless, USTC graduates may have certain deficiencies. For example, as a result of emphasis only on the natural sciences, the scope of the students' knowledge is not broad enough, especially in the area of the humanities. Because our country has generally paid little attention to training students, including those of USTC, in their ability to carry out experiments, they are relatively weak in this area. Recently, the increase in international academic exchcanges has demonstrated the USTC students' ability in using computers and foreign languages. Those problems are to be solved as soon as possible.

HAVING A UNIQUE GUIDELINE OF RUNNING SCHOOL

In order to develop Academia Sinica's function in training personnel, before the founding of USTC, Academia Sinica and the Ministry of Education jointly worked out relevant regulations, according to which researchers are also expected to give lectures in colleges.[7]

Guo Moruo, the late President of Academia Sinica, President and one of the founders of USTC, when proposing to the Party Central Committee that a university be run by the Academia Sinica, said "The Academia Sinica possesses powerful scientific capacities and advanced experimental equipment. However, simply lecturing in other colleges still cannot bring the researchers' potentialities into full play."[8] If the Academia Sinica itself runs a university, thereby integrating the research institutions with that educational institution, it will be able to make the best use of its scientific capacities and experimental equipment in running schools.

Vice-Premier Nie Rongzhen also said, "As we have suggested, a new type of university should be founded. That university will stand side by side with research institutions. Junior and senior students should take part in the practical work in related research institutions so that they can rapidly grasp a good command of knowledge."[9]

That is precisely the case. With the full support of all organs of Academia Sinica and many outside units, after careful but fast preparations within the short time of only three months, USTC was founded and began to enroll undergraduate students. Since then, practices embodying this guideline have been the following:

1) The president and vice-presidents of the Academia Sinica,

the directors and vice-directors of its institutes and celebrated scientists simlutaneously take up corresponding posts in the university, such as president, vice-presidents, chairmen, and vice-chairmen of departments as well as chiefs of pedagogic research units. They must practically give concrete guidance and be engaged in teaching work. This includes defining the size of the university and the establishment of specialities, making teaching plans, lecturing, compiling teaching materials, drawing up teaching programmes, participating in teaching administration, etc. Through these activities, they have interconnected the institutes and the university, and they work out the teaching plan of each department in accordance with the orientation of development of their institutes and thus train desirable professionals for their respective subjects.

2) The lecturing of researchers in the university has not only solved the difficulties caused by the shortage of qualified teachers at its initial stage, but also enriched the contents of teaching and raised the academic level. In return, the researchers who have assumed teaching work through their contacts with the young people, have been enlightened in their academic ideas, and heightened their level by constantly summing up. According to incomplete statistics, during the first five years since the founding of USTC, the researchers undertaking teaching work in the university numbered about 300. In recent years, approximately 200 researchers lectured in the university.

3) Senior students are required to do scientific research work in the institutes, while those of graduating classes have to go to the institutes to prepare for their graduation designs or theses. In general, members of their thesis committees are researchers appointed by the institutes, and advisers choose thesis topics in accordance with the research projects in the institutes and students' interests. The students of the fifth grade spend most of their time in the institutes under the guidance of advisors to make investigations, do experiments with the advanced equipment of the institutes, and directly participate in the scientific research work and academic activities of the institutes. This measure has guaranteed a domestically higher level of the students' theses and enabled the students to receive practical training of scientific work before their graduation.

4) The teachers of the university cooperate with the researchers of the institutes to compile teaching materials or jointly carry on scientific research projects.

The practice of USTC has proved that this guideline is an effective one in training scientific and technical professionals, which constitutes a basic condition for USTC to grow rapidly. Since its removal to Hefei, despite its distance from Beijing, the university has been continuing to pursue this guideline. As usual, the president of Academia Sinica, the directors of its institutes and celebrated scientists still hold posts in the university and give lectures. The researchers continue to undertake teaching work in the university, and the students keep going to the institutes to practise and write theses. In the past few years, a new form of "integrating institutes with departments" has emerged: the institutes and the university jointly enroll post-graduates who mainly attend claasses in the university but make experiments in the institutes. By doing so they train both master and doctoral students.

Certainly, in terms of the lecturing of researchers in the university, there are still some shortcomings. Firstly, some researchers, owing to the lack of teaching experience, are not so efficient in teaching, though their academic level is relatively high. Secondly, the growth of a contingent of qualified teachers would be adversely affected if the university relies too heavily on the researchers' lecturing for a long time. However, those two shortcomings are being overcome. At present, a contingent of qualified teachers, with middle-aged teachers as the mainstay, has grown up; they can independently undertake tasks of both teaching and scientific research. But the university still holds that it cannot do without the guidelines of "mobilizing the entire Academia Sinica to run the school, and integrating institutes with departments," even if the contingent of qualified teachers of the university itself has become very powerful in the future.

The practice of integrating scientific research institutions with educational institutions is not rare in developed countries, but in a developing country like China, this approach deserves special attention. In our country, because of economic backwardness, the capacities of scientific research (including manpower, materials, and finance) have to be concentrated in a number of scientific research institutions controlled by the state. As for average universities and colleges, especially those newly founded after liberation, their capacities for scientific research are comparatively weak; accordingly, it is more difficult to solve the problem of integrating scientific research with education through establishing research institutes in those schools. On the contrary, there are certain realistic possibilities to run universities by the state-controlled scientific research institutes. The establishment of USTC by Academia Sinica serves as an example.

CONSTANTLY SUMMING UP AND IMPROVING FOR MORE NEW ROLES

Since the downfall of the "gang of four," the entire faculty, staff, and students of USTC have overcome all kinds of difficulties encountered by them after the removal of the university (to Hofei), and constantly summed up experiences to raise the level of teaching management.

In August 1977, Academia Sinica, in light of the USTC's practices of running school and with the approval of the State Council, took a series of measures to put everything which was adversely affected by the "gang of four" in order, such as: continuing to implement the guideline of "mobilizing entire Academia Sinica to run school, and integrating institutes with departments;" strengthening the teaching of basic courses; restoring the pedagogic research units of basic courses; changing the school system from three years into five years; directly enrolling the current year's graduates from senior middle schools through an entrance examination; restoring the system of post-graduates;[11] restoring the presidency of the university, etc.[12] Those were significant measures at that time, which had the effect of taking the lead in the educational world of China to put everything hindered by the "gang of four" in order.

Subsequently, the university summed up its practices since its founding, especially methods which had proved to be effective, and made some improvements on this basis, so that it could continue to put them into practice. The following are the four main points:

1) Keen attention must be paid to enrolling excellent students. In the past, many ways and means were employed by the university. For example, it usually kept in close touch with several hundreds of key middle schools throughout the country, advising them to send excellent graduates to USTC. Every year it carefully prepared introductory materials for enrollment so as to strengthen the university's propaganda and during the time of recruitment, sent able and experienced teachers to various places to select students. This ensured the quality of the enrollment. After the restoration of the system of nation-wide unified admission through entrance examination in 1978, every year the overall average score of USTC newcomers in the entrance examination belongs to the highest notch in China. Many provinces and municipalities send the students who take the first place in the entrance examination to study in USTC. (Table 4)

TABLE 4

The USTC new-comers (1978-1982) who got the first place in entrance examination in various provinces or municipalities.

YEAR	1978	1979	1980	1981	1982
Number of Persons	3	8	16	9	15

The admission of excellent students has laid the foundation for improving student quality.

2) Efforts were made to strengthen the basic courses. The universities and colleges of sciences or engineering in China classify the courses which the students have to take into three kinds: basic courses, basic courses of specialty and courses of specialty. USTC has always attached importance to the teaching of basic courses; under the five-year school system, basic courses are taught in three and a half years (70 per cent). Even during the period of the "gang of four" who desperately opposed the study of books and basic courses, USTC still insisted on students' laying a solid foundation; it helped the then "worker-peasant-soldier students" to make up for their difficiencies in knowledge. Since the downfall of the "gang of four,"

USTC has quickly recovered and restored the pedagogic research units of basic courses. Within the framework of the university, teachers with a high vocational level and rich experiences have been selected to teach basic courses so as to ensure the quality of those courses. With the development of modern science and the increase in interdisciplinary permeation of subjects, the students are required to have a solid foundation. This has been confirmed by USTC's practice. As is generally reflected by the units where the graduates have been assigned, there is much "knowledge in reserve" for USTC graduates who can adapt themselves to the work easily; that is to say, they have a solid foundation the USTC graduates can quickly take up the subject in any new field which is not exactly what they have studied.[13]

3) Flexibility is sought in teaching management. With regard to teaching management, the USTC is both strict and flexible; whatever is done is to bring into play the students' initiatives and facilitate improving their talent. Since 1980, the university has been carrying on a unit-credit system. In the meantime, it is no longer confined to the established rules and has applied such methods as course-wavering, selective studies, status skipping, etc. If a student has a good command of a certain course and has passed a special examination, he is entitled to be credited for that course without actually taking it. Thus the students who have a high academic standing may take courses for senior students or from other departments according to their own preferences. Furthermore, those who have earned fine grades of which a half or more are in advanced courses may skip a year. Those senior and graduating students who have gained distinction may be recommended to take the graduate school entrance examination before they complete their undergraduate studies.

4) Teaching is integrated with scientific research. When it was founded, the USTC stressed that both teachers and students should carry on scientific research so as to broaden their academic vision, enrich the contents of their studies and activate teaching concepts, thereby to improve the quality of teaching. In the past few years the proportion of post-graduates in the university has increased step by step, and scientific research has been further enhanced in quantity and quality.

At present, over half of the teachers in the university are engaged in scientific research. They choose research topics and obtain financial support in various ways. Most of the topics are relatively new and in harmony with the orientation of the subjects they are teaching. Therefore, they are quite helpful to the academic development of these teachers.

Since 1978, the USTC has accomplished 155 significant research projects among which 19 reached the international level, 136 matched the advanced domestic standards or filled the gaps at home. For example, Associate Professor Wu Xiaoping and her research group have succeeded in the experiment and theoretical research on "the movement of laser speckle," and have recently won a national prize of natural sciences. The researchers in the Electron Synchrotron Radiation Laboratory have also made marked successes in the physical design and trial manufacture of the major components of the electron synchrotron radiation device.

Thanks to the fore-going practice as well as to the painstaking efforts of the students, the teaching quality at USTC has improved to a great extent. In 1980 and 1981, 712 students from USTC were enrolled at home or abroad to pursue graduate studies. Among them, 473 had been students of the 1977 class, amounting to 66 per cent of the total number of students in that class; another 237 were chosen from among the students of the 1978 class (26%) who had been scheduled to complete undergraduate studies one year later; the remaining two had been juvenile undergraduates belonging to the 1979 class. The 212 students and teachers from USTC who are studying in eleven foreign countries--the United States, Japan, France, and West Germany included--have made excellent achievements, and are highly appreciated by their universities. For example Wang Mingxu and two other students in the University of Maryland (College Park) in the U.S., and Li Leping in the State University of New York at Stony Brook are all honored students.

In respect of the post-graduates trained by the university itself, 137 graduated in 1981; they had completed nearly 200 research projects and written over 250 theses. Among them Li Shangzan, Zhao Lincheng, Bai Zhidong, Fan Hongyi, and Feng Yulin found themselves among the first group of Ph.D.s in Physical Sciences and Engineering trained in New China.

EXPLORING NEW APPROACHES OF TRAINING PROFESSIONALS

The juvenile class founded in March 1978 is an exploring test for USTC to train quality personnel within the shortest possible time.

The juvenile class has for six terms successively enrolled 190 juvenile students, including 24 girls. Their average age of entrance is below fifteen; the youngest among them is named Xie Yanbo, who was only eleven when he entered the university. Through several years of practice, the juvenile class has been constantly improving and gradually perfecting itself in respect to enrollment, entrance age limit, enrolling methods and teaching methods.[14] Ninety percent of them got excellent or good results; those who got bad results are very few in number. (Table 5)

The statistics in Table 5 are based on the per capita average of the examination results of the juvenile students in each grade after entering the university. As compared with the elder students of general classes, quite a number of juvenile students have achieved better results in examination. Among them, two have won Guo Moruo Scholarships; two got the second and fifth places in the 1981 nationwide examination of post-graduates who will subsequently study physics in the United States; three were enrolled as post-graduates who will study biochemistry in the United States. Among the post-graduates enrolled at home in 1981 and 1982, there were another 43 USTC juvenile students. Xie Yanbo, whose age of entrance is the youngest, was also enrolled as one of the post-graduates at the Theoretical Physics Institute.

TABLE 5

The examination results of various courses of the juvenile students when at school [15]

Classification of scores	Excellent over 85	Good 75-84	Middle 65-74	Bad 60-64	Failed under 59	Total
Number of Persons	95	53	17	1	1	167*
Percentage	56.9	31.6	10.2	0.6	0.6	100.0

*The results are incomplete because a student went to study abroad at an earlier stage and the students of the sixth term have just entered. Thus, 23 students are not included.

Note: The cutting line of the data was July 1981.

The school-running practice of the juvenile class demonstrates:

1) There objectively exist youngsters who are intellectually gifted in sciences.[16] These youngsters are very self-confident, full of vigour in making progress and thirsty for knowledge. They are good at self-study and can absorb knowledge easily. To discover and select them timely and created conditions to cultivate them immediately is a new approach of training highly qualified personnel. Of course, running juvenile classes is merely a form of creating such conditions; there can be other forms, such as: training them individually, arranging for them to study in general classes etc. Of late years, the average age of entrance of the students in USTC's general classes is only seventeen under. Those who are under fifteen number about 230; most of them got excellent or good results in their studies.

2) 90.5 percent of the juvenile students are from primary schools or the first grades of junior or senior middle schools; they have not gone through the whole middle school stage. However, their successful passing of the strict entrance examination of higher educational institutions indicates that they have acquired, de facto, the cultural level of the senior middle school graduates, and that the intellectually gifted youngsters may go through the middle school stage one year or two years ahead of schedule, even three or four years. Therefore, the middle school stage may be and should be shortened for the youngsters who are intellectually gifted in the sciences.[17]

The present school systems of primary and middle schools have both been extended to six years and, in conformity with the government regulations, the middle school students cannot take part in the entrance examination of universities and colleges before their graduation from senior middle schools, in general, at the age of nineteen but they can be enrolled as the students of juvenile classes. Therefore, the running of juvenile classes has offered a chance to enter universities or colleges earlier for a small part of intellectually gifted youngsters who have already completed middle school courses. For this reason, it is worth trying to run middle schools of science which will enroll the intellectually gifted youngsters and train them so as to shorten the training cycle.

3) After entering the university, the juvenile students have maintained their original vigor, many of them complete their studies ahead of schedule; consequently, many juvenile students have requested to take part in the examination of post-graduates one year or two years before their scheduled graduation. Indeed, they have really been enrolled to be post-graduates ahead of time. This fact has proved that the college stage of intellectually gifted youngsters can as well be shortened; they can enter the stage of post-graduates younger than normal in their teens. Hence a man's time of study can be further shortened; he can enter the research stage earlier. If a man duly enters the research stage at a time when his intelligence is in full flourish, it would be helpful to bringing his inventive abilities into full play.[18]

4) The physical development of juvenile students has not been affected by their early entrance into the university. They are growing healthily.

TABLE 6

Comparison between the values of physical conditions of the juvenile students and the standard values specified by the state for juveniles throughout the country.

Sex	Male Students					Female Students		
Age	14	15	16	17	18	15	16	17
Height	+	+	+	+	+	+	+	-
Weight	+	+	+	+	-	+	+	+
Chest Line	+	+	+	+	+	+	+	-
Vital Capacity	+	+	+	+	-	+	+	-
60 m. dash	-	+	+	+	+	+	+	+
Sit-ups	-	+	+	-	+	-	+	+
Arm bending and hanging	+	+	+	+	+	+	+	-
Standing broad jump	-	+	+	+	-	+	+	+
400 m. dash	-	+	+	+	+	+	+	+

Notes: 1. "+" means "over" and "-" means "under"
2. The cutting line of the data was the end of 1981.

Table 6 was drawn up after taking the second overall measurements of the juvenile students' physical shape, quality, and function and comparing the values of their physical conditions with the standard values of corresponding items specified by the states for the juveniles of the same age group throughout the country. It can be seen from the table that the juvenile students' values of physical conditions are generally higher than the standard values specified by the state for the juvenile of the same age group in China. The items of height, weight, and chest line show that the juvenile students are taller and more strongly built as compared with the juveniles of the same age group in the country; they belong to the thickset type.[19]

We hope the view that the approach of training talented people revealed by the school-running practice of the USTC juvenile class may be of universal significance. According to the statistics made by certain psychologists, the number of intellectually gifted youngsters amounts to 0.3 per cent of the age group. This figure cannot be in the least neglected. How to discover and select those youngsters in good time and give them specially trainings so as to meet the demand of the state for scientific and technical personnel is really a topic deserving special attention.

TEACHING BOTH KNOWLEDGE AND IDEOLOGY

According to the educational policy of China, those who receive an education should not only be taught knowledge but also educated ideologically, so that they can become useful people serving the socialist motherland. The students must be enabled to understand that they are striving to acquire knowledge not merely for themselves but also for the thriving of the Chinese nation and the prosperity of the socialist motherland; they must be enabled to realize the meaning of their study and have a strong sense of responsiblity to get rid of the backwardness of the Chinese nation. Only thus can they have a durable impetus in their study, and learn well by overcoming conscientiously the difficulties they encounter. That is why the higher educational institutions generally attach importance to the work of ideological education of the students. USTC is no exception.

The contents of ideological education is quite extensive, including political thinking, ideals and aspirations, moral quality, working style and sentiment, etc.

The following points are the main methods USTC has used:

1) Entrance orientation. Each year's freshman have to receive a three-day entrance orientation. The students are educated to have ideals, aspirations, and discipline. They should love their own majors, observe the rules and regulations of the university, especially inherit its style of hard work, plain life, diligence in study, unity, and mutual help. As many students remarked, "we are most deeply impressed by two points in entrance orientation: one is the university's excellent style of diligence in study and the other is the aspirations of scaling the heights of the world's science."

2) Selecting advanced students and setting up examples. Students

of "three goods" ("Keeping fit, studying hard, and working well") and the winners of "Guo Moruo Scholarship" are selected through annual appraisal in the university. The advanced students have performed the function of encouraging more or less the entire student body.

3) Educating students through manual labor. The students of each year are arranged to take part in manual labor on the school-run farm or in the school-run factories for a certain period of time. Apart from giving the students chances to learn skills, the aim of this arrangement is, first and foremost, to make the students love the labouring people and have a correct attitude towards manual labour.

4) Appointing student instructors. They should find out in good time what is happening among the fellow students, become their intimate friends, help them to cultivate such ideas of collectivism as mutual help, unity and fraternity, love for the motherland and the spirit of fearing no difficulty in their daily studies.

5) Requiring the professors to teach both knowledge and ideology. The political teachers, in particular, should combine their teaching with the living thoughts of the students. In their daily teaching work, the teachers should, through their words and behaviours, foster in the students a rigorous working style, a meticulous and solid working method and an idea of studying for the socialist motherland. However, in this respect, there is still much room for improvement, we must make further efforts and do a better job.

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TECHNOLOGICAL DEVELOPMENT STRATEGY OF AGRICULTURE IN CHINA

Xi Huida and Wu Mingyu

China is a country with vast territory and 800 million peasants, but the cultivated land is only about 1,600 million mu, almost 2 mu per peasant, in some places even less than 1 mu per peasant. Most of the arable land has been cultivated already. For a long time the principal approach to increase agricultural production was to raise the per unit yield.

Under the influence of monsoon, the rainfall of the main agricultural area in China fluctuates greatly and severe natural conditions exist in most of the pastoral land where natural calamities occurred frequently before liberation. Since liberation the output of principal farm produce has increased tremendously by augmenting investment and improving production techniques. Main measures that have been taken are as follows:

1. Improving the agricultural environment. Large-scale water conservancy projects and farm land construction have been undertaken to expand the capacity of irrigation, flood resistance and flood draining.
2. Increasing the cropping index and using some refined strains of seeds.
3. Increasing the application of chemical fertilizer.
4. Scientific farming and control of insects and pests.
5. Using farm machinery and improving farm tools.

In addition, various techniques related to "culture protection" (including greenhouse and pastic membrane) have been extensively applied not only in vegetable production but also in the seedling stage of crops. Great achievements have been made in agriculture over the past 30 years, but the pace of development is still falling short of demand. The nutrition content of people's food is not high. Part of the cotton and food grain needed in China have to be imported from abroad. There is considerable difference between cities and most of the rural areas in the country.

With the objective of making China a modernized country, what kinds of technological developments should be adopted for China's agriculture? This is a question that has aroused heated discussion in recent years. The following are the author's points of view on some of these questions.

Diversified Economy: Extensive Utilization of Resources and Stereo Complex Agriculture

China's agriculture has a tradition of developing a diversified economy. In many regions the complex economic structure consists of agriculture, forestry, animal husbandry, fishery and sideline occupations (mainly handicrafts using agricultural products as raw materials) has been farmed long ago in China's history. This structure is based on a technical system which may be called "stereo agriculture." "Stereo agriculture" here not only refers to an overall development of agriculture according to different altitudes, such as mountainous area, plains and water surface, but also means to get maximum "comprehensive productivity" on minimum land by extending the scope of utilization of resources and increasing utilization. For example, on the low-lying plain of the Pearl River delta stereo utilization of land has been accomplished by building mulberry field-fish ponds (digging a pond and building a carth dyke, growing mulberry trees on the dyke for raising silkworms and raising fish in the pond, using silkworm feces to feed fish and using pond sludge as manure for mulberry trees). A further examination will show that the utilization of fish ponds is also "stereo" for example, raising different breeds of fish which live in different water levels and have different feeding habits in one pond. Chinese peasants are quite successful in making a pond of one mu worth several mu. Raising ducks and fish in the rice fields is another example of stereo utilization of farm land. The intercropping and multiple cropping which have been extensively applied in different regions is a way of "stereo utilization" of both farm space and growing time sequence of different crops. As to the resources of products through raising livestock, poultry, edible fungi and medicinal plants and animals and processing the products. Chinese peasants utilize different main and sideline farm products repeatedly, turning them from low value to high value, from useless to useful and from harmful to beneficial. The technical road of such a comprehensive utilization of agricultural resources was the secret of feeding more people with less land in many areas in Chinese history.

Chairman Mao pointed out long ago that agriculture, forestry, animal husbandry, sideline occupation and fishery should develop alongside of each other and that agriculture should develop both in depth and width in terms of production. However, since the sixties diversified the rural economy has been disrupted in many places of China. At that time there was a popular view that the peasants should first grow abundant grain before they engage in other occupations. As a consequence vast areas of land, water, manpower and funds were devoted to grain production, which results in the shortage of some industrial raw materials, meat, fruits and handicrafts and worsening the environmental problems such as erosion of water and soil, grassland desertization.

Needless to say, the expansion of grain production would increase the total output of grain to some extent in the beginning. But after a certain period, the negative effect gradually appeared. The area of grain production was too large, which disrupted the rational crop rotation and increased the area of late and continuous crops. As a consequence the unit yield decreased and the production cost increased; irrigation, application of fertilizers and management were too concentrated to accomplish in a short time, in addition some areas of cultivated land are not suitable for growing grain and raising unit output.

The heavy concentration of manpower in grain production caused the decrease in productivity, the price of grain was low, and the diversified economy declined. All this affected the income of peasants and their accumulation of funds. The mistake of developing grain in isolation was gradually realized by a majority of the people. In recent years the way of emphasizing grain production and actively developing a diversified economy has been reconsidered as the only way for developing agriculture in China. It has already had a good effect on the development of agriculture. The output of our grain or other agricultural products has increased remarkably.

It is said that in the process of agricultural modernization agricultural production must go towards specialization and carry out a single planting system in a large area in order to raise the productivity and commodity rate. This idea does not fit the actual situation in China, in which the bulk of the population, most of whom do not have the opportunity of leaving the countryside even in the future, lives in the rural areas, . The goal of modern techniques of agriculture in China is to provide utmost employment opportunities at per unit area and get the highest output and value of output. Modern agriculture in China will be the exploitation and utilization of resources to the maximum extent by using modern techniques.

The modernization of the processing of agricultural products will play an important role in changing the structure of a diversified economy in China. It was estimated that ladder type gradational processing distribution of agricultural products i.e. spreading in large and small towns and not complete concentrating in large cities, not only better solves the problem of unemployment in rural areas but is also advantageous to the opening up of new ways for utilizing agricultural resources and waking up resources which are still sleeping. For example, small type processing factories of dairy products, meal refrigeration and storage and fruits processing factories which were established over the last few years have played an important role in developing dairy sheep, rabbit and fruit products in mountain areas.

Give Full Play to Superiority of Regions and Develop Appropriate Technology

"Suit measures to time and local condition" is a well known saying in Chinese agronomy. "Give full play to superiority of regions" means that the distribution of agricultural products must be in accordance with the natural and social economic differences of various places, to give full play to the advantages and avoid the disadvantages in order to develop the most beneficial profession and products. We cannot impose the same mode in all places. Through division of labour, cooperation, mutual help and complement among different areas maximum effect can be obtained on the whole.

"Appropriate technology" refers to the technology which is most suitable to the actual needs and conditions of a particular time and place. It mainly includes three factors: (1) to identify a proper goal (2) to choose measures that are practical (3) to aim at maximum economic returns. In other words "appropriate technology" means technology that "suits the given time and local conditions." Appropriate technology has many aspects. We can consider "give full play to superiority of region" as an appropriate technology, namely technology of distribution of region.

We should not consider the concept of "intermediate technology" as the same with "appropriate technology." Technologies, at whatever level and whatever state, become "appropriate technologies" only conditionally. Appropriation always varies with time and place.

"Suit measures to local conditions" means extremely great potential for increasing production. For example, some farmland was considered poor in the past. After growing suitable crops or running forestry, animal husbandry, fishery it became "treasure land." Some regions which were poor for a long time in the past have quickly become rich in recent years. With the development of science the "most appropriate technology" is without definite limit.

At present, China's industry and transportation are still underdeveloped and the agricultural commodity rate is low. This limits, to a large extent, the role of regional superiority. From now on with the gradual improvement in these aspects regional superiority will further play a more important role. China has varied and colorful areas of different types which, with cooperation among them, will produce larger economic returns.

In addition the appropriate technology also includes the following concepts:

1. Adaptation to nature while changing it

On the one hand we should actively change the production conditions, for example, to construct farmland and agricultural environment, which are capable of resisting natural calamities, flood and drought. On the other hand, we should reform the nature of plants and animals, for example, to adapt some plants and animals to the new environment. However, we cannot do all these without considering the economic results. We should pay a lot of attention to making agricultural technology adapt to nature and utilize nature in the best possible way and obtain the best results with lowest costs.

According to this idea, the study on the rational utilization of resources has received much attention and has come into play in production. For example, in certain places in the south the area of two crop rice was too large and in some years the accumulate temperatures was not enough. By growing some hybrid mid rice instead of two crop rice yield has been increased. In some northern regions there was too much corn which was susceptible to cold weather. The resistance to natural calamity has been strengthened by growing soybeans instead of corn.

2. The unit of high yield and low costs

China's agriculture has to take the road of intensive management. We must pay a lot of attention to high yield techniques. In the past, some high yield techniques were actually high energy and high material consuming techniques and because there was little effect it could not be used in large area production. In recent years high yield, stable yield and low cost are taken into account as a goal to make proper measures. This is called the "high, stable, low" techniques which have been extended in a number of provinces and to many crops and has seen satisfactory results.

Because there is abundant manpower in the rural areas in China and the prices of industrial products are high, low cost often emphasizes reducing the material consumption per product, namely the consumption of chemical fertilizers, pesticides, oil and electricity, rather than the consumption of labour. From a long-term point of view, due to the limited land and the high population, to raise the yield per unit area continuously, material consumption has to be increased. To maintain "high pay," after increasing material consumption will be more and more difficult and will become a long-term subject of study. It does not mean that China does not need to save manpower, to raise productivity and to accomplish mechanization. However, China's mechanization must be selective. The machinery should first be used to these links in the production chain which can give the best economic results. Generally speaking, the mechanization of irrigation and draining, transportation, harvest and post-harvest processing of products is in urgent need. Therefore, mechanization cannot be limited to cultivation alone. In addition, it is also important to improve the efficiency and function of different small type machinery whether operated by man, animal, wind, or water, etc.

Modern Technology and Ecological Agriculture

Emphasizing the whole and considering the long run are another tradition of Chinese agronomy. As mentioned above, the arrangement of the traditional agriculture in China considers not only the direct economic effect of one profession but also takes each profession as a part of the whole. A whole (system) with relatively high productivity is formed by giving play to each technical function. For example, accumulating manure should be considered while raising pigs. Utilization of grain lost in the field and preying on insect pests are part of the aim for raising chickens and ducks. As mentioned before, a mulberry fish pond is a typical example with the objective to create the highest system productivity.

To keep the "system productivity" lasting without decline it is emphasized in China's traditional agronomy that the principal of combining, using, and raising must be run through all agricultural technology. It means that the function of all agricultural techniques may be summarized into two opposite but supplementary aspects: one is to create the highest system productivity i.e. "utilization;" the other is to maintain and improve production conditions and to keep the ecological balance, namely "raising." The point of view which considers Chinese traditional agriculture as "ecological agriculture" has a solid ground.

Although traditional Chinese agronomy emphasized the ecological balance, historically it can only give play to small farmland through farmers' activities. When the ecological balance in large areas was out of control, it was certainly very difficult to maintain the rational ecological balance on farmland.

After liberation, the people's government has made great efforts to improve the agro-ecological environment in its vast territory. This guaranteed the formation of a new, highly effective ecological structure of farmland in many regions. However, during the past 30 years, we have not had enough knowledge of the law of ecological variations. We have made a great effort to develop water conservancy engineering, but not paid enough attention to biological engineering. Consequently, the situation of conservation of soil and water is not satisfactory. In addition, we lack foresight on the ecological effect caused by using modern tools (chemical fertilizers, pesticides and machinery) in agricultural production, and on the new problems in agriculture caused by city construction and industrialization. All this requires that from now on we should pay attention not only to the renovation of territory in vast regions but also to the ecological balance of farmland in small areas. We should establish a complete set of ecological agricultural system, protect and improve the agricultural environment, conserve and develop the agricultural resources.

We do not agree with the view which confuses ecological agriculture and organic agriculture and that China's agriculture is generally organic agriculture. We think that the real organic agriculture existed only in history. A lot of historical experiences are still full of vitality, but high productivity results only when historical experiences have been combined with new measures. Our goal is a modernized ecological agricultural, an agriculture not only with a very high productivity and commodity rate, but also capable of guaranteeing continuous environmental improvements and lasting development of production.