A. Hunter Dupree

SCIENCE AND THE EMERGENCE OF MODERN AMERICA, 1865-1916

The Berkeley Series in American History

Edited by CHARLES SELLERS

THE BERKELEY SERIES IN AMERICAN HISTORY

Science and the Emergence of Modern America 1865-1916

Edited by

A. HUNTER DUPREE

UNIVERSITY OF CALIFORNIA AT BERKELEY

RAND McNALLY & COMPANY · CHICAGO

The Berkeley Series in American History
Charles Sellers, editor

Rand McNally

Printed in U.S.A. by Rand McNally & Company
Library of Congress Catalog Card Number: 63-8250
Third Printing, 1967

CONTENTS

CHRONOLOGY

1851 Kelly process of steel manufacture.
1856 Bessemer process of steel manufacture.
1862 Act creating Department of Agriculture.
Morrill Land Grant Act.
1864 First Bessemer converter built in the United States.
1868 Open-hearth process brought to the United States.
1870 John D. Rockefeller organizes Standard Oil Co.
1871 American Institute of Mining and Metallurgical Engineers.
1874 First electrically powered streetcar, operated in New York City.
1875 Josiah Willard Gibbs, *On the Equilibrium of Heterogeneous Substances.*
1876 Alexander Graham Bell patents telephone.
American Chemical Society organized.
1878 Edison patents phonograph.
1879 Edison invents incandescent light bulb.
1880 American Society of Mechanical Engineers.
1884 American Institute of Electrical Engineers.
Bureau of Animal Industry, Department of Agriculture.
1886 Charles Martin Hall discovers electrolytic process of refining aluminum.
1887 Hatch Act for Agricultural Experiment Stations.
Interstate Commerce Act.
1889 Elevation of head of Department of Agriculture to cabinet rank.
1890 Sherman Anti-Trust Act.
1892 People's (Populist) Party organized.
1894 Niagara Falls harnessed for commercial power.
1896 William Jennings Bryan defeated by William McKinley.
1897 Klondike gold rush.
1898 Spanish-American War.
1901 United States Steel Company organized.
Theodore Roosevelt becomes President.
1906 Pure Food and Drug Act.
1908 White House Conservation Conference.
1914 Smith-Lever Act authorizing extension work.
1916 National Research Council established.
1917 Entry into First World War.

INTRODUCTION

THE UNITED STATES IN THE MID-TWENTIETH CENTURY IS NOT THE SAME kind of country it was in the mid-nineteenth century; the one thing on which all can agree, whether they look at politics, the economic system, or the life of the mind, is change. How did this change come about? Most people, in trying to describe the changes in American civilization over the last century, sooner or later mention the rise of science. There is hardly a more conspicuous factor in American civilization or a more potent force on the world scene than science. How did this force which affects all other forces get loose in American culture? This is not the kind of historical problem that can be answered by analyzing a particular decisive battle, by counting the votes in one particular election, or by matching the arguments in one particular debate. The change that we are looking for did not occur at one place or at one time, nor was it limited only to the actions of statesmen and generals. What we are looking for is a change of relationship, one that took place almost unawares in obscure places as well as in the light of publicity.

Science itself is of course much older than 1865. As a tradition embodying organized knowledge about nature, it had been widening its control of data and refining its methods of reasoning in a spectacular way since at least the seventeenth century. And there were scientists in the United States before 1865 who had developed institutions for communication and education.

Likewise, the industrial revolution was already far advanced in 1865. The textile industry had converted to the factory system long before the Civil War, the railroad network was rapidly covering the continent, and the iron and steel industry was rapidly becoming a massive operation at the base of a machine economy. Yet the innovations which made the industrial revolution possible—the inventions of the pre-Civil War era—did not in most cases originate with science. They sprang from a tradition of practical invention far removed from the scientists of the day. Reorganization, rather than technological innovation, was the major tool of the captains of industry such as Andrew Carnegie and John D. Rockefeller. Why, then, when they look at the twentieth century, do most observers see the hand of science at work? We are seeing here neither science nor technology, but a changed relationship between them.

The documents in this collection were first written or spoken by men who were observing some facet of this subtle but fundamental change in the relationship between science and technology which was destined to change the twentieth-century world. In reading the documents you should remember that the writers did not have your opportunity for hindsight, that many of them were actors in the period in which we are interested. Try to work out your own answers to questions sucn as:

(1) What is the difference between science and technology?

(2) What role does innovation play in American technology, and where do innovations come from? Did they come from the same place in the early years of the period 1865–1916 as they did in the later years?

(3) Do you see by 1916 the development of a relationship between science and technology which has become more pronounced in the years since then? Or do you feel that in the First World War the United States had not discovered the potentialities of the application of science to industry?

(4) What changes in American life in these years made the harnessing of science to industry possible?

1

THE PROBLEM: THE APPLICATION OF SCIENCE TO TECHNOLOGY— ALFRED NORTH WHITEHEAD

IN ITS GENERALITY, THE PROBLEM OF THE APPLICATION OF SCIENCE TO practical life is far broader than the short span of American history. The philosopher Alfred North Whitehead was thinking of its full sweep when he examined it in a famous series of lectures in the mid-1920's. Notice the sense in which he uses the terms "science," "technology," and "invention." Also remember that Whitehead does not seem to be thinking about the United States or about any particular country in the Western World. He is talking about a period of time. And yet before he finishes, when he has made clear the relationship he is looking for, he does get down to a particular national case. To him, the leader in establishing the new relationship is Germany. Is it possible to speak of science in terms of nations? Can you justify Whitehead's doing so? (Alfred North Whitehead, *Science and the Modern World* [Cambridge. England: Cambridge Univ. Press, 1946], p. 120. Reprinted with permission of the Macmillan Company, New York.)

WHAT IS peculiar and new to the [nineteenth] century, differentiating it from all its predecessors, is its technology. It was not merely the introduction of some great isolated inventions. It is impossible not to feel that something more than that was involved. . . . The process of change [had been] slow, unconscious, and unexpected. In the nineteenth century, the process became quick, conscious, and expected. . . .

The greatest invention of the nineteenth century was the invention of the method of invention. A new method entered into life. In order to understand our epoch, we can neglect all the details of change, such as railways, telegraphs, radios, spinning machines, synthetic dyes. We must concentrate on the method in itself; that is the real novelty, which has broken up the foundations of the old civilisation. The prophecy of Francis Bacon has now been fulfilled; and man, who at times dreamt of himself as a little lower than the angels, has submitted to become the servant and minister of nature. It still remains to be seen whether the same actor can play both parts.

The whole change has arisen from the new scientific information. Science, conceived not so much in its principles as in its results, is an obvious store-house of ideas for utilisation. But, if we are to understand what happened during the century, the analogy of a mine is better than that of a store-house. Also, it is a great mistake to think that the bare scientific idea is the required invention, so that it has only to be picked up and used. An intense period of imaginative design lies between. One element in the new method is just the discovery of how to set about bridging the gap between the scientific ideas, and the ultimate product. It is a process of disciplined attack upon one difficulty after another.

The possibilities of modern technology were first in practice realised in England, by the energy of a prosperous middle class. Accordingly, the industrial revolution started there. But the Germans explicitly realised the methods by which the deeper veins in the mine of science could be reached. They abolished haphazard methods of scholarship. In their technological schools and universities progress did not have to wait for the occasional genius, or the occasional lucky thought. Their feats of scholarship during the nineteenth century were the admiration of the world. This discipline of knowledge applies beyond technology to pure science, and beyond science to general scholarship. It represents the change from amateurs to professionals.

There have always been people who devoted their lives to definite regions of thought. In particular, lawyers and the clergy of the Christian churches form obvious examples of such specialism. But the full self-conscious realisation of the power of professionalism in knowledge in all its departments, and of the way to produce the professionals, and the importance of knowledge to the advance of technology, and of the methods by which abstract knowledge can be connected with technology, and of the boundless possibilities of technological advance,—the realisation of all these things was first completely attained in the nineteenth century; and among the various countries, chiefly in Germany.

II

THE RISE OF SCIENCE IN INDUSTRY

SINCE ENGLAND WAS THE FIRST TO GET THE INDUSTRIAL REVOLUTION STARTED, and, if Germany was the country which first realized the full utilization of science, observers such as Whitehead whose viewpoint is European usually overlook the American experience. It is important to understand that Americans were not unique in what they were doing to apply science to technology, but it is more important to understand that in their efforts they transformed American civilization itself. To try to bring Whitehead's generalizations to earth, we can test them against the American setting.

A.

THE BESSEMER PROCESS

The great increase in steel as the basis of heavy industry after 1865 was dependent on two processes: the Bessemer and the open hearth. To test the amount of science which was applied in the crucial innovation of the Bessemer process, we shall look at two contemporary comments. The process itself was known before the onset of our period, both through the work of Henry Bessemer in England and William Kelly in the United States. Hence our quest is not simply for an inventor, but rather for those continuous subsidiary adaptations which change an idea into an industrial reality. The real question is to determine how much of the knowledge on which these innovations were based sprang from the scientific tradition and how much was the product of cut-and-try experiment by managers and mechanics. The man skilled in the art of steel-making can do a great deal with his own native wit and with such experimenting as he can do on an existing process in the midst of actual production. But such a man, however shrewd, is not a professional innovator. Both of the following passages were written by 1877 and reflect the opinion of practical steel men in the very midst of the shift to heavy industry.

The technological influence of the British example is also important to note. Much information had to come from the British; tales of their accomplishments hung over the American innovators. Yet we can also see American practice rather quickly departing from the European model. Note also the amount of resistance which the innovators encountered, both from management and labor.

1. "*American Push.*" Our first commentator, Robert W. Hunt, was General Superintendent of the Albany and Rensselaer Iron and Steel Company, Troy, New York. (Robert W. Hunt, "A History of the Bessemer Manufacture in America," *Transactions of the American Institute of Mining Engineers,* V [1876–77], 201–16.)]

THE MEMORABLE features of American history have been rapidly emerging during the last century, and notably so since 1860; and they are by no means confined to political or to any one branch of scientific development. Of all the industrial arts, none show a greater change or a mightier progress than the Bessemer manufacture. And this year, while we are celebrating the first centennial of our national life, we can also celebrate the first decennial of American Bessemer practice. While not forgetting or undervaluing what has been done in other countries, I have thought that a brief history of the introduction and development of the Pneumatic or Bessemer process in America would be of interest.

In 1863 the Kelly Pneumatic Process Company was formed and an arrangement entered into with William Kelly, who had taken out letters-patent. . . .

Previous to the application of William Kelly for a patent, Henry Bessemer, of England, had taken out patents dated February 12th, 1856, and August 25th, 1856, in this country. Kelly claimed priority in the discovery of the principles of the process, and the Patent-office allowed his claim by granting him his patents.

In the autumn of 1862 Mr. Alexander L. Holley, while in England, was impressed with the importance of Mr. Bessemer's invention, and so fully foresaw its future, that, upon his return to the United States, he induced Messrs. John A. Griswold and John F. Winslow, of Troy, New York, to join him in endeavoring to possess Bessemer's American patents. . . .

But, before entering into chronological details of subsequent works, I must here state that, after building the first experimental plant at Troy, Mr. Holley seems to have at once broken loose from the restraints of his foreign experience, and to have been impressed with the capabilities of the new process. The result is that mainly through his inventions and modifications of the plant we, in America, are to-day enabled to stand at the head of the world in respect of amount of product.

But to return to the detailed history. As before stated, there were, in 1865, the two rival organizations claiming control of the process in this country,—the Kelly Process Company, through their Kelly and Mushet's patents, and Messrs. Winslow, Griswold & Holley, through their Bessemer and Holley American patents. Both parties felt strong in their respective positions, and in possessing the necessary means to maintain them. But, after spending large sums of money in counsel fees, they wisely concluded that their fight would at best be a "Kilkenny cat" affair, and so, early in 1866, they combined their respective interests, the

Bessemer, or Winslow, Griswold & Holley, party taking 70 per cent., and the Kelly Process Company 30 per cent. of all royalties collected. To this wise compromise may we attribute the subsequent establishment of many works. . . .

But great difficulty was even yet experienced in inducing capitalists and manufacturers to attempt the introduction of the new manufacture. While the metal produced was wonderful in its qualities, still the necessary first outlay was so large, and the details of the process were so uncertain, and the time-honored prejudice against anything new, held such powerful sway, that our people hesitated, doubted, and waited. Wonderful tales came to us of what was being done abroad, and some venturesome railway managers even dared to import and place in their tracks trial lots of foreign Bessemer rails.

Messrs. Winslow, Griswold & Holley had, from the very first erection of their works, wisely pursued the plan of extending every facility to blast-furnace owners, in all parts of the country, to have their irons tried for steel; and under this system many brands were tried, and most were found wanting. These failures to obtain good results, of course, built up still greater barriers against the spread of the process. In the light of our present chemical knowledge of the manufacture, it is amusing to think of firms sending a few tons of iron to Wyandotte, Troy, or even England, to be tried in actual practice, when a few hours of laboratory work would have settled the entire question. But still it was this very blind using of unknown irons that first opened the eyes of steelmakers to the possibility of making good products from metals pronounced unfit by the then authorities. . . .

After building the original experimental plant at Troy, Mr. A. L. Holley seems to have appreciated that the manufacture was capable of a development far beyond that which had been attained in those countries in which it was already considered a success.

Even if his mind did not fully realize this conclusion, his mechanical intuition was alive to the possibilities of improvement, and the result of his thought gave us the present accepted type of American Bessemer plant. He did away with the English deep pit and raised the vessels so as to get working space under them on the ground floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power. He changed the location of the vessels as related to the pit and melting-house. He modified the ladle crane, and worked all the cranes and the vessels from a single point; he substituted cupolas for reverberatory furnaces, and last, but by no means least, introduced the intermediate or accumulating ladle which is placed on scales, and thus insures accuracy of operation by rendering possible the weighing of each charge of melted iron, before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant, he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments, the result was the Holley Vessel Bottom, which, either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production.

Then he tried many forms of cupolas at Troy, adopting in the original plant a changeable bottom or section below the tuyeres, and developing this idea still further in the first 5-ton works; then later, at Harrisburg, assisting Mr. J. B. Pearse the furnace was improved to a point which rendered these many bottoms unnecessary, chiefly by deepening the bottom and enlarging the tuyere area. Upon his rebuilding the Troy works after their destruction by fire, Mr. Holley put in the perfected cupolas. At this time the practice was to run a cupola for a turn's melting, which had reached eight heats or forty tons of steel, and then dropping its bottom. This was already an increase of one hundred per cent. over his boast about the same amount in twenty-four hours.

The Cambria works were now running, and Mr. Holley had become officially connected with them as consulting Bessemer engineer. Many discussions and consultations took place between Mr. George Fritz, Mr. Holley, and the writer, as to the possibility of increasing the product of the works. Among other things, tapping cinder from the cupolas was thought of, and decided upon. These works had already placed their turn's work at nine instead of eight heats. The Pennsylvania works under Mr. J. B. Pearse's management, followed with an increased production. The Cambria works applied the cinder tap, and the production went up to the unanticipated amount of thirty heats, or one hundred and fifty tons in twenty-four hours. Grand as we thought this, it is only about one-half of the present yield of each of several works. During all this time many details were modified, and as the new ways proved successful they were adopted in the regular practice. I think one thing which had a strong bearing on the increased production was the labor organization of the Cambria works. In compliance with the policy decided upon, I started the converting works without a single man who had ever seen even the outside of Bessemer works, and, with a very few exceptions, they were not even skilled rolling-mill men, but on the contrary were selected from intelligent laborers. The result was that we had willing pupils with no prejudices, and without any reminiscences of what they had done in the old country or at any other works. Of course when one works went ahead, the others had to follow. Mr. George Fritz was the embodiment of push, and with such men to call on as William R. Jones, J. E. Fry, Charles Kennedy, Alexander Hamilton, and D. N. Jones, his efforts were ably seconded, and Cambria for a long time maintained the lead. . . .

While I am not able to mention all of the very many good things accomplished by the gentlemen at each and all the various works, I am, at the same time, well aware they have all done their share toward achieving the great end; and, fortunately, their mutual relations have been so pleasant, that each one's experiences have been freely imparted to the others. This has done wonders to advance the science. But without one element, all skill and all mechanical talent would have been wasted, and with it nearly all things have been possible. That element has been, and is, "American push."

[2. "*Engineering Science and Art*." Another view of the relation of science to technology is presented by A. L. Holley, who has already been introduced as the hero of the preceding account. (A. L. Holley, "The Inadequate Union of Engineering Science and Art," *Transactions of the American Institute of Mining Engineers*, IV [1875–76], 191–207.)]

The application of scientific methods to the investigation of natural laws and to the conduct of the useful arts which are founded upon them, is year by year mitigating the asperity and enlarging the outcome of human endeavor. More notably, perhaps, are these the facts in that system of productive and constructive arts of which engineering is the general name. In metallurgical engineering especially, within the period of our own recollection, how rapid has been the rate and how wide the scope of progress: the scientific discovery and mining of metalliferous veins; the economical separation and reduction of ores of every grade; the production and regulation of high temperatures; the varied improvements in the manufacture of iron, in saved heat and work, in uniformity and range of products; and, most important of all, the creation and the utilization, to be counted by the million tons a year, of the cheap constructive steels.

Wonderful as this range and degree of development may appear to the public eye, the close and thoughtful observer must, nevertheless, conclude that neither the profession nor the craft of engineering may congratulate themselves too complaisantly, but that they should rather acknowledge to each other the embarrassing incompleteness of the union between engineering science and art.

There is a small school of philosophers whom we may designate as original investigators, men who come close to nature, who search into first principles, and who follow that scientific and therefore fruitful method by which the relations of matter and force are discovered, classified, and brought within the reach of practice. These wonderful men do not indeed create the laws of nature, as they sometimes almost seem to, but they go up into the trembling mountain and the thick darkness and bring down the tables upon which they are written.

There is a larger class of men whom we may designate as the schoolmen; they are learned in the researches and conclusions of others, and skilled in reasoning or speculating from these or from abstract data upon the certain or probable results of physical and chemical combinations.

And there is the great army of practicians, almost infinite in its degrees of quality, ranging from the mere human mechanism by which mind lays hold of matter and force, through all the grades of practical judgment and power.

Let us first consider the matter from the "practical" man's standpoint. Every day's experience teaches him that the men who speculate, from secondhand data, upon the probable results of combinations of forces and materials, are not the men who can best make these combinations in practice, who intuitively know all the concealed pitfalls, such as friction, that trick of nature which like the thousandth part of phosphorus, alters all the conditions of use in iron; nor are they the men who can determine the completeness of these combinations, or read the record of their results, as in the character of a flame, in the feeling of a refractory mixture, in the behavior of a metal under treatment; nor are they the men who, by familiarity with objects and phenomena, are best fitted to pursue that original investigation which is the foundation of even theoretical progress. The expert who delights to call himself "practical," is honestly amazed at the attempts of experts by school graduation, who have not been graduated in works, to solve the engineering problems of the day. And from his standpoint there are numerous and conspicuous illustrations. While metallurgists are still disputing over the nature and sequence of reactions in combustion and reduction, the practical ironsmelter has felt his way from the barbarous practice of a century ago, to the vast and economical production of to-day. The attainment of powerful and sufficiently hot blast by means of waste heat, the adaptation of shape and proportion of stack to different fuels and ores, labor-saving appliances and arrangements,—all these have grown out of the constant handling, not of books, but of furnaces.

Proceeding upon a chemical knowledge little superior to that of the average schoolboy, Bessemer developed his revolutionary process. Not knowing for years that the combustion of silicon or of manganese are the chief sources of the necessary heat; ignoring the fact that not alone the reaction but the presence of manganese is a cause of soundness and malleability in steel; magnifying the hypothesis that silicon should promote soundness; instructing his licensees to avoid all irons containing above 0.02 per cent. of phosphorus; and sharing the ignorance of the whole metallurgical profession as to the sequence of reactions in the converter and the probability of changing their character, Bessemer and his followers, during the first fifteen years of their practice, nevertheless brought this difficult art, which the metallurgical schools call a chemical art, to a high degree of commercial success, and this in the absence of any metallurgical change or chemical improvement whatever, in the treatment of the metal. During all this time, there was almost no literature of the Bessemer manufacture, and no instructor save that grim sphinx the converter and the well-nigh inscrutable process. It was a hand-to-hand fight, involving mechanical details, refractory linings, celerity of operations, regularity of melting and conversion and economy of labor. With every fact written in his book, the closeted scientist could no more adequately prescribe the practical conditions of improvement, than could the student in optics specify in words and formulae the glory of an Italian sunset.

Here is a cupola-furnace, an old and exceedingly simple device; but one may know all the laws of combustion and fluxing that are written in the cyclopedias, and yet fail to change its working at will, or fail to detect the coming change, until by long familiarity, the phenomena reveal themselves as it were instinctively. One may have learned every law of the reactions of oxides and fluxes upon a refractory material, yet until his practiced hand and eye and ear can nicely detect its physical qualities and measure the results of new ingredients and temperatures, he may wander for years in a maze of uncertainties. Notwithstanding all our previous knowledge about the inevitable combustion of carbon and oxygen in the presence of heat enough to ignite them, the Siemens-Martin process, both in its calorific and in its metallurgical aspects, was as purely unpractical as the direct utilization of sun-heat is to-day, until after years of patient observation, not chiefly by scientists but by men unacquainted with books and knowing nothing at second-hand, innumerable small increments of improvement at last produced a sufficient temperature in a durable furnace.

In the development of machinery, the same history is repeated. The proportions of parts, in fact, the modern formulae themselves, are derived from the study of innumerable experiments. The adaptation of machinery can only be perfected by him who, as it were, enters into it, making it an incarnation of himself. This enlargement of a man's organism is most strikingly illustrated in the locomotive. Oliver Wendell Holmes has happily described this putting of his life into his "shell" boat, his every volition extending as perfectly into his oars as if his spinal cord ran down the centre of its keel, and the nerves of his arms tingling in the oar-blades. The thoughtful locomotive-driver is clothed upon, not with the mere machinery of a larger organism, but with all the attributes of a *power* superior to his own, except volition. Every faculty is stimulated and every sense exalted. An unusual sound amid the roaring exhaust and the clattering wheels tells him instantly the place and degree of danger, as would a pain in his own flesh. The consciousness of a certain jarring of the foot-plate, a chattering of a valve-stem, a halt in the exhaust, a peculiar smell of burning, a sudden pounding of the piston, an ominous wheeze of the blast, a hissing of a water-gauge—warning him respectively of a broken spring-hanger, a cutting valve, a slipped eccentric, a hot journal, the priming of the boiler, high water, low water, or failing steam—these sensations, as it were, of his outer body, become so intermingled with the sensations of his inner body, that this wheeled and fire-feeding man feels rather than perceives the varying stresses upon his mighty organism.

Mere familiarity with steam-engines is not, indeed, a *cause* of improved steam-engineering, but it is a *condition.* The mechanical laws of heat were not developed in an engine-house, yet without the mechanism which the knowledge derived *through this familiarity* has created and adapted, the study of heat would have been an ornamental rather than a useful pursuit. So in other departments. When one can feel the completion of a Bessemer "blow" without looking at the flame, or number the remaining minutes of a Martin steel charge from the bubbling of the bath, or foretell the changes in the working of a blast-furnace by watching the colors and structure of the slag, or note the carburization of steel by examining its fracture, or say what an ore will yield from its appearance and weight in the hand, or predict the lifetime of a machine by feeling its pulse; when one in any art can make a diagnosis by looking the patient in the face rather than by reading about similar cases in a book, then only may he hope to practically apply such improvements as theory may suggest, or to lead in those original investigations upon which successful theories shall be founded.

These are the conclusions of the "practical" man, and they are none the less true because they are not the whole truth. That they are too little considered by the schoolmen and the graduates of schools is also true, but happily, less conspicuously so as the years advance.

The evil consequences of this mistake develop themselves in various ways. The recent graduates of schools do not, indeed, expect immediate positions of responsibility and authority, but they often demand them after too short a term of object-teaching. Perhaps the greatest advantage of their scientific training is that they can learn from objects and phenomena faster than can the mere workman, who, although full of the elements of new and useful conclusions, lacks, if I may so say, the scientific reagent which precipitates the rubbish and leaves a clear solution of the problem. It is however true—in the iron manufacture, perhaps, especially true—that men of wide learning and of great mental dexterity, unless they have studied at least as many years in the works as they have in the school, do not successfully compete for the desirable places with the men who have come up from the ranks. Narrow, unsystematic, and fruitless of new results as his knowledge may be, he who has grown up steadily from the position even of puddler's helper, will be selected to take the manager's post in preference to him whose reputation is founded solely on the school.

Nor does this prove, as the schoolmen too often believe, that the owners and directors of metallurgical enterprises are generally unappreciative of scientific culture. It rather proves that the lowest functions, as in the case of poor humanity, must first be considered; that the conditions of maintenance and regular working, which constant familiarity with objects and phenomena alone can provide, are earliest in order. Conservation first and improvement afterwards.

Another consideration in this connection is that scientific aid appears to be more readily provided for the "practical" man than practical aid for the "scientific" man. The trained scholar can the more readily adapt himself to the situation. He should suggest many more improvements than would ever crystallize in an equally good but undisciplined mind. Yet his attempt, with mere scholastic aids, to carry these improvements out, might disorganize a whole establishment. As there must be one final authority, judgment founded on experience almost universally ranks the wider and more fruitful culture of the school. And if we ask those great masters whose experimental knowledge is as wide as their scientific culture, they will tell us, that as the inert and clumsy flywheel, that typical conservator, is more helpful to a steam-engine in the long run, than a valve-gear so highly organized that it seems to know what it ought to do, so in their own undertakings, plodding, practical economics must sit in judgment upon theory and limit the reaches of imagination.

Another evil growing out of the inadequate regard of mere schoolmen for practice, is the frequent failure of their works or their inability to complete them. Inventions and constructions, designed after a scientific method and under the light of organized facts and detailed history as laid down in books, may fail simply in default of a practical knowledge of how far the capital at hand will reach, or what the means at hand will do, or what the materials at hand will stand, or what the labor and assistance at hand can be relied on to accomplish. A vast number of facts about the operation of forces in materials are so subtle, or so incompletely disentangled from groups of phenomena, that they cannot be defined in words, nor understood if they could be formulated. But after long familiarity with the general behavior of materials under stress, a practical expert can, by a process more like instinct than reason, judge how far and in what directions he may safely push his new combinations. Thus while the unschooled practician so usually wastes his energies in unscientific methods and on impossible combinations, but generally carries into successful use his comparatively few well-founded attempts, the student merely of principles and abstract facts so usually originates the ideas upon which progress is founded, and so rarely clothes them with practical bodies. In this chasm between science and art, how much effort and treasure, and even life, are swallowed up year by year.

These are not theoretical considerations. The blast-furnace, the converter, and the open-hearth have already been referred to; let us observe some other illustrations. A bridge-builder will tell us that few structures in his department of engineering fail by reason of mistakes in calculating the strain-sheet, but that the majority of failures arise from vibrations, buckling, rapid wear of important parts, shapes that weaken the material, inequalities in the material, and similar causes which are not stated in books, which assume different aspects under every change of proportions and dimensions, and which can only be inferred by means of a long familiarity with the behavior of similar structures during varying periods of service, and with the processes by which materials and members are fabricated. The builder of a machine like a marine engine, or a locomotive, or a roll-train, or a steam-hammer, will tell us that, in designing new adaptations, after every stress that can be distinctly analyzed is provided for, mass to resist vibration, changes of shape to insure sound casting, and various modifications which cannot be formulated for the want of even approximately complete knowledge of their conditions, must still be supplied, simply by judgment founded on long observation of phenomena under similar conditions. And he will thus explain nine-tenths of the failures. Who can imagine the volume of a book, or of an author, which should adequately teach the principles of construction as affected by the chiefest of all practical considerations—the economics of the foundry, the forge, and the machine-shop? With the tools and facilities at hand, what divisions of a particular structure, what shapes and sizes and methods of joining can be made cheaply as well as strong and efficient, in all the infinite forms of mechanism? Obtaining such facts from any other source than personal practice, would be like an oarsman studying a book to know when and how in the race he must husband his power, or like a wrestler looking out in a cyclopedia the probable feints of his antagonist. The successful constructor will assure us that no possible training in the school, nor any genius in invention can build economically without such a knowledge of the shop as the athlete has of the possibilities of muscular strength and agility.

These arts have been selected as examples, not because they chiefly depend on skill, but because they so largely involve the highest formulated mathematical knowledge. How much more important, then, is practical training in those departments where physical laws are very incompletely understood and formulated. How far short of practical success will abstract science stop in sinking pneumatic piles through wrecks and boulders, in tunnelling rocks traversed by subterranean streams and beds of quicksand, in cheaply applying hoisting, ventilating and draining machinery to mines where the scene and conditions of operation are constantly shifting, in firmly founding heavy and vibrating machinery on treacherous ground, in handling and casting melted steel, in constructing refractory metallurgical vessels, in delivering bars red-hot and crooked in infinite directions to a roll train, in fabricating durable breech-loading cannon, in building boilers that shall provide for vaporization, circulation, separation, cleaning and durability, in designing enginery like the horseshoe machine to shape metals, in proportioning gas-furnaces, in submarine warfare, in aerial navigation, in machine tools, in traction engines, in scaffolding and erection, in railway running-gear, in forming artificial stone under water, in permanent way, in coal-cutting, in dredging machinery, in moulding and casting, in brick machinery, in tube-drawing, in coal-burning, in pavements? Limited or impossible as would be the progress of engineering arts in the absence of that knowledge and those methods which are imparted in schools, delay and failure would hardly be less conspicuous if the schoolmen should stay in the schools and thence attempt the application of abstract science, or expect mere workmen to apply it by hearkening to their directions.

I hope it may not seem that the dignity of abstract scientific investigation is undervalued by the utilizers of nature's powers and materials, or that any considerations of profit obscure, even in the average commercial mind, the splendor of those achievements made in the mere love of truth, with thought of neither commercial application nor pecuniary reward—achievements which distinguish such names as Faraday, Bunsen, Leverrier, Mayer, Joule, Henry, Darwin, and Tyndall. Do not their successes rather encourage us, in our lower sphere, to more persistently pursue the method of these great discoverers—the original investigation of Nature's truths? Not less literally than in the poet's fancy,

> "To him who in the love of Nature holds
> Communion with her visible forms, she speaks
> A various language."

To the skilled artisan she reveals herself as truly though not as widely as to the philosopher. In the aphorism of Goethe, "Mankind dwell in her and she in them. With all men she plays a game for love, and rejoices the more they win."

But the undervaluation of the study of objects and phenomena by schoolmen, is not the principal hindrance to the complete union of science and art. A greater obstacle is the combined misapprehension and ignorance on the part of a large class of "practical" men, of what they are pleased to call "theory," meaning by theory, something which is likely to be discordant with fact—or possibly with the interests of the craft. We can hardly complain that their objection is ill-grounded, as far as it is grounded upon the practice of theoretical men; but the world has a right to complain of their narrowness of observation, of their stolid incomprehension of the results of science, of that pride of ignorance, of that bigotry, of that positive fear of the diffusion of knowledge, which is the normal condition of those who range only within the sphere of their own practice, and to whom analysis and generalization, in their business affairs, as well as in morals and politics, are an unknown thing. It is unfortunately true that a large number of managers in metallurgical enterprises—men who are deemed indispensable, and who probably, are indispensable, in the average state of practical science, are thus not incorrectly characterized. Conscious of their power as conservators, ignorant of the elements of improvement, and not unfrequently jealous and blindly fearful for the interests of their craft, they sit triumphant on an eminence (the steady undermining of which they cannot observe), and sneer at the too frequently condescending magniloquence of recent graduates and book men. The best of this class are the workful and painstaking men who come up from the ranks—men who are plucky in emergencies and regulative of labor—men whose unconscious reasoning or intuition covers the ordinary exigencies, and who, perhaps for this very reason, never inform themselves outside of their own range of observation, nor observe in a methodical or fruitful manner. . . .

In the enlargement . . . of mutual respect and instruction, to a certain extent lies the solution of the problem under consideration; but it is a complex method, only actively operative under several important conditions, such as:

1. A *public opinion* among schoolmen that a course of object and phenomena study in works is to be reckoned, not as a matter of mere business sequence, but as a large and equal feature of that curriculum which is essential to a degree of professional graduation.

2. A diffusion, among the class which we have termed the "practical" class, of a real appreciation of an organized system of information and of the scientific method of making this information useful to all classes of men and noxious or unimportant to none; such a general explanation to that vast, preponderating class of workmen and of foremen and managers, who are foremen and managers simply because they have been efficient workmen, as will ever prevent their indiscriminate and contemptuous application of the term "theory" to whatever a schoolman proposes.

3. An understanding among the owners, directors and commercial managers of engineering enterprises, that it is not a matter of favor, but a matter of as much interest to themselves as to any class, that young men of suitable ability and of suitable preliminary culture, however acquired, should have opportunity and encouragement to master the practical features of technical education in works, not as mere apprentices, but under reasonable facilities for economy of time and completeness of research.

But these conditions do not largely exist, and are only growing with general civilization. They must be hastened and magnified by some better means than merely stating the case again and again, as some of us, I confess, are too fond of doing; than perpetually repeating, in a manner more sentimental than efficient, that scientists should appreciate practice, and practicians should appreciate science, and capital should join the hands of science and practice, saying: "Bless you, my children," in the expectation that this will prove a fruitful union. Let us rather inquire if some new order of procedure in *technical education*, some revolutionary innovation, if need be, will not put the coming race of engineers on a plane which is lifted above the embarrassments from which we are slowly emerging.

B.

EDISON, THE PROFESSIONAL INVENTOR— GEORGE PARSONS LATHROP

[Although Thomas A. Edison is easily the most famous technological innovator in American history, placing him in the proper perspective in the application of science to technology is not easy. He differed in important ways both from the old-style inventor and the new-style scientist in industry. In this passage he uses the words "discovery" and "invention" in a very special way which probably do not fit with the other definitions which you may be able to formulate. You should even entertain the possibility that Edison has interchanged the usual definitions of these words. (George Parsons Lathrop, "Talks with Edison," *Harper's New Monthly Magazine*, LXXX [1890], 432–34.)

How do Edison's ideas about discovery and invention fit into the definitions of science and technology as indicated in the Bessemer story where the innovation was done, not by specialists in innovating, but by practical men on the job?]

Edison has often been spoken of as a discoverer; and in one sense he may appear to have discovered things by reaching out into the realm of what to other persons was the unknown. But he himself dislikes the term as applied to himself. "Discovery is not invention," he once said to me, "and I dislike to see the two words confounded. A discovery is more or less in the nature of an accident. A man walks along the road, say from the laboratory here to Orange station, intending to catch the train. On the way his foot kicks against something, and looking down to see what he has hit, he sees a gold bracelet imbedded in the dust. He has discovered that, certainly not invented it. He did not set out to find a bracelet, yet the value of it is just as great to him at the moment as if, after long years of study, he had invented a machine for making gold bracelets out of common road-metal.

"Goodyear *discovered* the way to make hard rubber. He was at work experimenting with India-rubber, and quite by chance he hit upon a process which hardened it—the last result in the world that he wished or expected to attain. Bell's telephone was a discovery too, not an invention. He was engaged with the possibilities of sending sound waves over a telegraph wire, and filed an invention by which this could be done. Then, by accident, it was discovered that articulate speech could be sent over the wire—and there was the telephone. But Bell did not set out to make an instrument by which talk could be transmitted, and therefore I say he discovered instead of inventing the telephone. In a discovery there must be an element of the accidental, and an important one too; while an invention is purely deductive. An abstract idea or a natural law, I maintain, may be *invented;* for, in my opinion, Newton invented but did not discover the theory of gravitation. He had been at work on the problem for years, and had no doubt invented theory after theory to which he found it impossible to fit his facts. Then he constructed the theory to which all facts corresponded, and thus invented it by deductive reasoning. Of course the old story of the apple dropping from a tree, and Newton's jumping up with a species of 'Eureka,' I reject absolutely.

"It is too much the fashion to attribute all inventions to accident, and a great deal of nonsense is talked on that score.

"In my own case but few, and those the least important, of my inventions owed anything to accident. Most of them have been hammered out after long and patient labor, and are the result of countless experiments, all directed toward attaining some well-defined object. All mechanical improvements may safely be said to be inventions and not discoveries. The sewing-machine was an invention. So were the steam-engine and the typewriter. Speaking of this latter, did I ever tell you that I made the first twelve typewriters, at my old factory in Railroad Avenue, Newark? This was in 1869 or 1870; and I myself had worked at a machine of similar character, but never found time to develop it fully." . . .

Not long ago I asked Mr. Edison which of his inventions had caused him the greatest amount of study, and required the most elaborate experiments.

He replied, promptly: "The electric light. For, although I was never myself discouraged, or inclined to be hopeless of success, I cannot say the same for all of my associates. And yet, through all those years of experimenting and research, I never once made a discovery. All my work was deductive, and the results I achieved were those of invention pure and simple. I would construct a theory and work on its lines until I found it was untenable. Then it would be discarded at once, and another theory evolved. This was the only possible way for me to work out the problem, for the conditions under which the incandescent electric light exists are peculiar and unsatisfactory for close investigation. Just consider this: we have an almost infinitesimal filament heated to a degree which it is difficult for us to comprehend, and it is in a vacuum, under conditions of which we are wholly ignorant. You cannot use your eyes to help you in the investigation, and you really know nothing of what is going on in that tiny bulb. I speak without exaggeration when I say that I have constructed *three thousand* different theories in connection with the electric light, each one of them reasonable and apparently likely to be true. Yet only in two cases did my experiments prove the truth of my theory. My chief difficulty, as perhaps you know, was in constructing the carbon filament, the incandescence of which is the source of the light. Every quarter of the globe was ransacked by my agents, and all sorts of the queerest of materials were used, until finally the shred of bamboo now utilized by us was settled upon. Even now," Mr. Edison continued, "I am still at work nearly every day on the lamp, and quite lately I have devised a method of supplying sufficient current to fifteen lamps with one horse-power. Formerly ten lamps per horse-power was the extreme limit." . . .

In boyhood he was a diligent and omnivorous reader, and to some extent he keeps up this habit. He has not confined himself, however, to scientific works; and often, when some book entirely literary in character is mentioned, he will surprise the listener by speaking of it with evident familiarity. As for the scientific works, he has collected a large library of them, and does not affect disdain for their accumulations of knowledge. "Yet, somehow," he says, "I don't seem to find what I want in books." I once asked him, also, how he made his calculations. The answer was: "I don't know exactly; but I can't do them on paper. I have to be moving around." That he does them efficiently, however, is shown by the results. I have also in mind at this moment the incident of a well-known physicist of my acquaintance, a man of high scientific rank and rare mathematical attainments, who had done an immense amount of figuring on some point which he mentioned to Edison, without being able to reach a satisfactory conclusion. Edison at once, though having only a few minutes for consideration, gave him the result and convinced him of its accuracy, much to his surprise and admiration.

C.

ELECTRICAL RESEARCH IN THE EARLY TWENTIETH CENTURY—IRVING LANGMUIR

[Edison lost control of his electric light in the early 1890's, and out of the merger of his interests with those of several others came the General Electric Company. By early in the new century, General Electric was pioneering in the development of the institution which was to become the major vehicle of science in industry—the industrial research laboratory. Because the whole domain of electricity was largely inaccessible to man before basic scientific research revealed it, the electrical industry in all its forms was more a congenial home for science than those industries, such as steel, which were based on centuries of empirical practice. Compare the attitude of Irving Langmuir, one of the bright stars of the early General Electric laboratory, with that of Edison when he talks of basic science. But consider also that Langmuir does *not* find that basic science is an automatic cure for industrial problems and that the conversion of theory into practice—the heart of the new relationship between science and technology—is by no means a simple process. What is the professional connection of the men doing the innovating in the early General Electric laboratory as compared to those connected with the Bessemer process? (Irving Langmuir, "Fundamental Research and Its Human Value," *Scientific Monthly*, XLVI [1938], 358–62.)]

UNTIL THE beginning of the present century, applications of science had almost always been made by inventors and engineers who had utilized the stock of scientific knowledge available to them and who did not themselves contribute to fundamental science. Pure science was mainly the outgrowth of work carried on in universities by those who were not primarily interested in the applications. Newton, the great French mathematicians and physicists Laplace, Ampere, Poisson, the chemical pioneer Lavoisier, the great English scientists Faraday and Maxwell, are names selected at random of those who laid the foundations for present science. Engineers and inventors, men like Edison, Elihu Thomson, Marconi and Bessemer, have applied science to meet human need, but not many of them made great contributions to science itself. Pasteur is perhaps the most important exception. He was one of the greatest of scientists, and at the same time he made applications of science having the utmost direct value to mankind.

Beginning about 1900, many industries established research laboratories whose object was primarily to apply existing scientific knowledge to the solution of industrial problems. Only a small fraction of this total knowledge had received industrial application, and it must have seemed to the leaders of industry as though the supply of available unused knowledge was almost inexhaustible. The industries felt no need or obligation either to contribute to or to extend the fundamental knowledge; it was only necessary to develop the applications to their particular needs. The age, after all, was one of unscrupulous exploitation of natural resources. . . .

In the year 1900, Mr. E. W. Rice, Jr., established within the General Electric Company at Schenectady an organized industrial research laboratory for the purpose of carrying on fundamental industrial research. It was planned that this laboratory should be devoted exclusively to original research or to the study of natural phenomena in search for new facts and principles. Mr. Rice was thus not content to draw from the storehouse of scientific knowledge built up in universities but wished to have a laboratory in which scientific progress could be accelerated and the frontiers of knowledge extended in directions which would be likely to prove useful to the industry. Such research can not usually be directed toward definite goals, for it involves unknown factors. Success in such research, if attained, is often reached by wholly unexpected methods, and the problem which is finally solved is not the problem which is foreseen.

As this laboratory developed it was soon recognized that it was not practicable nor desirable that such a laboratory should be engaged wholly in fundamental scientific research. It was found that at least 75 per cent. of the laboratory must be devoted to the development of the practical applications. It is stimulating to the men engaged in fundamental science to be in contact with those primarily interested in the practical applications. It is also important that the engineers in the organization should be in close contact with those having the broader scientific outlook.

Let me give an example of the useful interaction of the two groups of men. Let us suppose that through the discovery of a new scientific principle or fact the possibility of some new application is opened up. The men trained in pure science are usually not the men to make most rapid progress in the applications; on the other hand, it is not possible to turn the work over immediately to a separate engineering research laboratory. The growing idea, like a child, must not be weaned from its mother too soon. Before the continued development of the idea can be assured in the hands of an engineering staff, it is necessary for a relatively large amount of engineering research to be carried out by the originators of the idea or those closely associated with them, for only these have the necessary familiarity with the subject and the deep personal interest required for success.

If, however, some provision is not made for a separate engineering research department there is great danger that the engineering research may grow to such proportions as to undermine the spirit of fundamental research which should dominate the research laboratory if its proper functions are to survive. In the General Electric Company we have been fortunate in having several such engineering departments which are capable of taking over any problem from the research laboratory as soon as its ultimate success seems assured.

I will give you some examples from my own personal experience to illustrate how fundamental scientific work undertaken without definite applications in view can result in discoveries that are of direct benefit to mankind. I want to show you how, . . . the practical result could hardly have been reached in a laboratory in which the workers were assigned definite work directed towards a goal. There was no one who had the vision to see the goal until we had nearly reached it.

When I started to work in our research laboratory, Dr. Whitney, who was then director, instead of assigning me to a definite problem, suggested that I spend several days in the various rooms of the laboratory becoming familiar with the work that was being done by the different men. He asked me to let him know what I found of most interest as a problem to work on.

I was particularly interested in the work that was going on in the laboratory with tungsten-filament lamps of the high-vacuum type. Much work had shown that the higher the vacuum the better was the lamp—that is, the less rapidly the bulb blackened. What interested me most, however, were the wonderful possibilities opened up to the scientist by having a material like tungsten, which could be heated to temperatures over 3400 C. If residual gases produced harmful effects in a lamp, it seemed to me that it was a fascinating field for investigation to study the effects produced by each different gas separately introduced into the bulb. This work was not undertaken with a definite idea that it would lead to an improvement in the lamp; it was merely done to satisfy my own curiosity as to the interactions between gases at low pressures with filaments at high temperatures, a field of study which, I believe, never had been undertaken before. From Dr. Whitney's point of view it was a useful line of research for the General Electric Company because it would give us increased knowledge of the type of phenomena that are presumably occurring in lamps. The whole consensus of opinion in the laboratory, however, was that the direction that should be followed in seeking to improve the lamp was to obtain a far better vacuum than had previously been possible.

I worked for about three years studying these chemical reactions at low pressures with filaments at high temperatures, and published several scientific papers giving the results of this work. I was particularly interested in the results obtained by introducing hydrogen into the lamp, for this gas caused a very great heat loss from the filament. I was able to show that this was caused by the dissociation of hydrogen molecules into atoms. In order to make sure of the correctness of this explanation, I was led to experiment with nitrogen and with mercury vapor over a wide range of temperatures and pressures up to and including atmospheric pressure. At this time no one in the laboratory had any idea that any benefits could result from such gases. . . .

I want to call your attention particularly to the fact that there were many separate lines of pure scientific work which contributed to this successful result. There was nothing from the prior knowledge that suggested that any benefit would result from the addition of gas to the lamp; in fact, there was no lamp made in 1911 which would have been given an improved life or efficiency by the introduction of nitrogen. It required the construction of an entirely new type of lamp based on new scientific principles before this benefit could be obtained.

As soon as we received positive indications that an improved efficiency of the lamp would be possible through the use of argon and nitrogen, a large group of men in the laboratory worked on the development of this type of lamp. It took about six months of intensive work on the part of about twenty-five men before their results could be turned over to the development laboratories of the incandescent lamp factories, and it was about a year before these lamps were ready for manufacture.

D.

CHEMICAL RESEARCH IN THE EARLY TWENTIETH CENTURY— W. A. HAMOR

[In the late nineteenth century, Germany had built her technological power, which so impressed A. N. Whitehead, largely on chemical research. German hegemony was still unassailable in 1915 when W. A. Hamor assayed the role of chemistry in American industry and discussed some of the barriers to a fuller utilization of chemical research. What institutions does he see as the main alternatives for the support of industrial research? Significantly, Mr. Hamor's affiliation was with the Mellon Institute of Industrial Research in Pittsburgh, which, although endowed from the profits of the aluminum industry, was attached to a university rather than to a single corporation. Do you see any similarity between the institutional coupling of science and technology in chemicals with that in electricity? (W. A. Hamor, "The Value of Industrial Research," *Scientific Monthly*, I [1915], 86–90.)]

The aim of all industrial operations is toward perfection, both in process and mechanical equipment, and every development in manufacturing creates new problems. It is only to be expected, therefore, that the industrial researcher is becoming less and less regarded as a burden unwarranted by returns. Industrialists have, in fact, learned to recognize chemistry as the intelligence department of industry, and manufacturing is accordingly becoming more and more a system of scientific processes.

The accruement of technical improvements in particularly the great chemical industry is primarily dependent upon systematic industrial research, and this is being increasingly fostered by American manufacturers.

Ten thousand American chemists are at present engaged in pursuits which affect over 1,000,000 wage-earners and produce over $5,000,000,000 worth of manufactured products each year. These trained men have actively and effectively collaborated in bringing about stupendous results in American industry. There are, in fact, at least nineteen American industries in which the chemist has been of great assistance, either in founding the industry, in developing it, or in refining the methods of control or of manufacture, thus ensuring profits, lower costs and uniform outputs. . . .

Without the chemist the corn-products industry would never have arisen and in 1914 this industry consumed as much corn as was grown in that year by the nine states of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey and Delaware combined; this amount is equal to the entire production of the state of North Carolina and about 80 per cent. of the production of each of the states of Georgia, Michigan and Wisconsin; the chemist has produced over 100 useful commercial products from corn, which, without him, would never have been produced. In the asphalt industry the chemist has taught how to lay a road surface that will always be good, and he has learned and taught how to construct a suitable road surface for different conditions of service. In the cottonseed oil industry, the chemist standardized methods of production, reduced losses, increased yields, made new use of wastes and by-products, and has added somewhere between $10 and $12 to the value of each bale of cotton grown. In the cement industry, the chemist has ascertained new ingredients, has utilized theretofore waste products for this purpose, has reduced the waste heaps of many industries and made them his starting material; he has standardized methods of manufacture, introduced methods of chemical control and has insured constancy and permanency of quality and quantity of output. In the sugar industry, the chemist has been active for so long a time that "the memory of man runneth not to the contrary." The sugar industry without the chemist is unthinkable. The Welsbach mantle is distinctly a chemist's invention and its successful and economical manufacture depends largely upon chemical methods. It would be difficult to give a just estimate of the economic effect of this device upon illumination, so great and valuable is it. In the textile industry, he has substituted uniform, rational, well-thought out and simple methods of treatment of all the various textile fabrics and fibers where mystery, empiricism, "rule-of-thumb" and their accompanying uncertainties reigned. In the fertilizer industry, it was the chemist who learned and who taught how to make our immense beds of phosphate rock useful and serviceable to man in the enrichment of the soil; he has taught how to make waste products of other industries useful and available for fertilization and he has shown how to make the gas works contribute to the fertility of the soil. In the soda industry, the chemist can successfully claim that he has founded it, developed it and brought it to its present state of perfection and utility, but not without the help of other technical men; the fundamental ideas were and are chemical. . . .

Sufficient has been presented to show that certain industries of the United States have been elevated by an infusion of scientific spirit through the medium of the chemist, and that manufacturing, at one time entirely a matter of empirical judgment and individual skill, is more and more becoming a system of scientific processes. The result is that American manufacturers are growing increasingly appreciative of scientific research, and are depending upon industrial researchers—"those who catalyze raw materials by brains"—as their pathfinders. It is now appropriate to consider just how industrialists are taking advantage of the universities and the products of these.

When an industry has problems requiring solution, these problems can be attacked either inside or outside of the plant. If the policy of the industrialist is that all problems are to be investigated only within the establishment, a research laboratory must be provided for the plant or for the company. At present, in the United States, probably not more than one hundred chemical manufacturing establishments have research laboratories or employ research chemists, although at least five companies are spending over $100,000 per year in research. In Germany, and perhaps also in England, such research laboratories in connection with chemical industries have been much more common. The great laboratories of the Badische Anilin und Soda Fabrik and of the Elberfeld Company are striking examples of the importance attached to such research work in Germany, and it would be difficult to adduce any stronger argument in support of its value than the marvelous achievements of these great firms.

A frequent difficulty encountered in the employment of researchers or in the establishment of a research laboratory, is that many manufacturers have been unable to grasp the importance of such work, or know how to treat the men in charge so as to secure the best results. The industrialist may not even fully understand just what is the cause of his manufacturing losses or to whom to turn for aid. If he eventually engages a researcher, he is sometimes likely to regard him as a sort of master of mysteries who should be able to accomplish wonders, and, if he can not see definite results in the course of a few months, is occasionally apt to consider the investment a bad one and to regard researchers, as a class, as a useless lot. It has not been unusual for the chemist to be told to remain in his laboratory, and not to go in or about the works, and he must also face the natural opposition of workmen to any innovations, and reckon with the jealousies of foremen and of various officials.

From the standpoint of the manufacturer, one decided advantage of the policy of having all problems worked out within the plant is that the results secured are not divulged, but are stored away in the laboratory archives and become part of the assets and working capital of the corporation which has paid for them; and it is usually not until patent applications are filed that this knowledge, generally only partially and imperfectly, becomes publicly known. When it is not deemed necessary to take out patents, such knowledge is often permanently buried.

In this matter of the dissemination of knowledge concerning industrial practise, it must be evident to all that there is but little cooperation between manufacturers and the universities. Manufacturers, and especially chemical manufacturers, have been quite naturally opposed to publishing any discoveries made in their plants, since "knowledge is power" in manufacturing as elsewhere, and new knowledge gained in the laboratories of a company may often very properly be regarded as among the most valuable assets of the concern. The universities and the scientific societies, on the other hand, exist for the diffusion of knowledge, and from their standpoint the great disadvantage of the above policy is this concealment of knowledge, for it results in a serious retardation of the general growth and development of science in its broader aspects, and renders it much more difficult for the universities to train men properly for such industries, since all the text-books and general knowledge available would in all probability be far behind the actual manufacturing practise. Fortunately, the policy of industrial secrecy is becoming more generally regarded in the light of reason, and there is a growing inclination among manufacturers to disclose the details of investigations, which, according to tradition, would be carefully guarded. These manufacturers appreciate the facts that public interest in chemical achievements is stimulating to further fruitful research, that helpful suggestions and information may come from other investigators upon the publication of any results, and that the exchange of knowledge prevents many costly repetitions.

E.

BASIC SCIENCE AND INDUSTRIAL RESEARCH: A 1916 VIEW—J. J. CARTY

[The year 1916 gave unusual pause to the observer of the rise of science in American industry. The grisly drama of the world's most highly developed industrial nations hurling efficient destruction at one another in Europe made Americans look on their own research with new eyes. At the same time, the consolidation of American business enterprises into giant corporations had called forth not only the gestures of Theodore Roosevelt but the efforts of Woodrow Wilson to combat the curse of bigness with the enforced competition of the Clayton Act. Advocacy of small business and unbridled competition did not rest comfortably with advocacy of science in industry. For only large concerns could afford research establishments of their own, and for small business the only hope was some form of cooperation among competitors. J. J. Carty, one of the pioneers of telephone research, whose career spanned the whole period from lone inventor to highly organized laboratory, managed to comment on both the impact of the War and the advantages of bigness in his 1916 presidential address to the American Institute of Electrical Engineers. Compare his version of the relation of basic science to industrial research with that of Langmuir. Also compare his ideas on the organization of industrial research with those of Hamor. (J. J. Carty, "The Relation of Pure Science to Industrial Research," *Science*, N. S. XLIV [1916], 511–16.)]

It is not strange that many years ago Huxley, with his remarkable precision of thought and his admirable command of language, should have indicated his dissatisfaction with the terms "pure science" and "applied science," pointing out at the same time that what people call "applied science" is nothing but the application of pure science to particular classes of problems. The terms are still employed, possibly because, after all, they may be the best ones to use, or perhaps our ideas, to which these expressions are supposed to conform, have not yet become sufficiently definite to have called forth the right words.

It is not the purpose of this address, however, to suggest better words or expressions, but rather to direct attention to certain important relations between purely scientific research and industrial scientific research which are not yet sufficiently understood.

Because of the stupendous upheaval of the European war with its startling agencies of destruction—the product of both science and the industries—and because of the deplorable unpreparedness of our own country to defend itself against attack, there has begun a great awakening of people. By bringing to their minds the brilliant achievements of the membership of this institute in electric lighting and power and communications and by calling their attention to the manifold achievements of the members of our sister societies in mechanical and mining and civil engineering, and the accomplishments of our fellow-workers, the industrial chemists, they are being aroused to the vital importance of the products of science in the national defense.

Arising out of this agitation comes a growing appreciation of the importance of industrial scientific research, not only as an aid to military defense but as an essential part of every industry in time of peace.

Industrial research, conducted in accordance with the principles of science, is no new thing in America. The department which is under my charge, founded nearly forty years ago to develop, with the aid of scientific men, the telephone art, has grown from small beginnings with but a few workers to a great institution employing hundreds of scientists and engineers, and it is generally acknowledged that it is largely owing to the industrial research thus conducted that the telephone achievements and developments in America have so greatly exceeded those of other countries.

With the development of electric lighting and electric power and electric traction which came after the invention of the telephone, industrial scientific research laboratories were founded by some of the larger electrical manufacturing concerns and these have attained a world-wide reputation. While vast sums are spent annually upon industrial research in these laboratories, I can say with authority that they return to the industries each year improvements in the art which, taken all together, have a value many times greater than the total cost of their production. Money expended in properly directed industrial research, conducted on scientific principles, is sure to bring to the industries a most generous return.

While many concerns in America now have well organized industrial research laboratories, particularly those engaged in metallurgy and dependent upon chemical processes, the manufacturers of our country as a whole have not yet learned of the benefits of industrial scientific research and how to avail themselves of it.

I consider that it is the high duty of our institute and of every member composing it, and that a similar duty rests upon all other engineering and scientific bodies in America, to impress upon the manufacturers of the United States the wonderful possibilities of economies in their processes and improvements in their products which are opened up by the discoveries in science. The way to realize these possibilities is through the medium of industrial research conducted in accordance with scientific principles. Once it is made clear to our manufacturers that industrial research pays, they will be sure to call to their aid men of scientific training to investigate their technical problems and to improve their processes. Those who are the first to avail themselves of the benefits of industrial research will obtain such a lead over their competitors that we may look forward to the time when the advantages of industrial research will be recognized by all.

Industrial scientific research departments can reach their highest development in those concerns doing the largest amount of business. While instances are not wanting where the large growth of the institution is the direct result of the care which is bestowed upon industrial research at a time when it was but a small concern, nevertheless conditions today are such that without cooperation among themselves the small concerns can not have the full benefits of industrial research, for no one among them is sufficiently strong to maintain the necessary staff and laboratories. Once the vital importance of this subject is appreciated by the small manufacturers many solutions of the problem will promptly appear. One of these is for the manufacturer to take his problem to one of the industrial research laboratories already established for the purpose of serving those who can not afford a laboratory of their own. Other manufacturers doing the same, the financial encouragement received would enable the laboratories to extend and improve their facilities so that each of the small manufacturers who patronizes them would in course of time have the benefit of an institution similar to those maintained by our largest industrial concerns.

Thus, in accordance with the law of supply and demand, the small manufacturer may obtain the benefits of industrial research in the highest degree and the burden upon each manufacturer would be only in accordance with the use he made of it, and the entire cost of the laboratories would thus be borne by the industries as a whole, where the charge properly belongs. Many other projects are now being considered for the establishment of industrial research laboratories for those concerns which can not afford laboratories of their own, and in some of these cases the possible relation of these laboratories to our technical and engineering schools is being earnestly studied.

Until the manufacturers themselves are aroused to the necessity of action in the matter of industrial research there is no plan which can be devised that will result in the general establishment of research laboratories for the industries. But once their need is felt and their value appreciated and the demand for research facilities is put forth by the manufacturers themselves, research laboratories will spring up in all our great centers of industrial activity. Their number and character and size, and their method of operation and their relation to the technical and engineering schools, and the method of their working with the different industries, are all matters which involve many interesting problems—problems which I am sure will be solved as they present themselves and when their nature has been clearly apprehended.

In the present state of the world's development there is nothing which can do more to advance American industries than the adoption by our manufacturers generally of industrial research conducted on scientific principles. I am sure that if they can be made to appreciate the force of this statement, our manufacturers will rise to the occasion with all that energy and enterprise so characteristic of America.

So much has already been said and so much remains to be said urging upon us the importance of scientific research conducted for the sake of utility and for increasing the convenience and comfort of mankind, that there is danger of losing sight of another form of research which has for its primary object none of these things. I refer to pure scientific research.

In the minds of many there is confusion between industrial scientific research and this purely scientific research, particularly as the industrial research involves the use of advanced scientific methods and calls for the highest degree of scientific attainment. The confusion is worse because the same scientific principles and methods of investigation are frequently employed in each case and even the subject-matter under investigation may sometimes be identical.

The misunderstanding arises from considering only the subject-matter of the two classes of research. The distinction is to be found not in the subject-matter of the research, but in the motive. The electrical engineer, let us say, finding a new and unexplained difficulty in the working of electric lamps, subjects the phenomenon observed to a process of inquiry employing scientific methods, with a view to removing from the lamps an objectionable characteristic. The pure scientist at the same time investigates in precisely the same manner the same phenomenon, but with the purpose of obtaining an explanation of a physical occurrence, the nature of which can not be explained by known facts. Although these two researches are conducted in exactly the same manner, the one nevertheless comes under the head of industrial research and the other belongs to the domain of pure science. In the last analysis the distinction between pure scientific research and industrial scientific research is one of motive. Industrial research is always conducted with the purpose of accomplishing some utilitarian end. Pure scientific research is conducted with a philosophic purpose, for the discovery of truth, and for the advancement of the boundaries of human knowledge.

The investigator in pure science may be likened to the explorer who discovers new continents or islands or hitherto unknown territory. He is continually seeking to extend the boundaries of knowledge.

The investigator in industrial research may be compared to the pioneers who survey the newly discovered territory in the endeavor to locate its mineral resources, determine the extent of its forests, and the location of its arable land, and who in other ways precede the settlers and prepare for their occupation of the new country.

The work of the pure scientists is conducted without any utilitarian motive, for, as Huxley says, "that which stirs their pulses is the love of knowledge and the joy of discovery of the causes of things sung by the old poet—the supreme delight of extending the realm of law and order ever farther towards the unattainable goals of the infinitely great and the infinitely small, between which our little race of life is run." While a single discovery in pure science when considered with reference to any particular branch of industry may not appear to be of appreciable benefit, yet when interpreted by the industrial scientist, with whom I class the engineer and the industrial chemist, and when adapted to practical uses by them, the contributions of pure science as a whole become of incalculable value to all the industries.

I do not say this because a new incentive is necessary for the pure scientist, for in him there must be some of the divine spark and for him there is no higher motive than the search for the truth itself. But surely this motive must be intensified by the knowledge that when the search is rewarded there is sure to be found, sooner or later, in the truth which has been discovered, the seeds of future great inventions which will increase the comfort and convenience and alleviate the sufferings of mankind.

By all who study the subject, it will be found that while the discoveries of the pure scientist are of the greatest importance to the higher interests of mankind, their practical benefits, though certain, are usually indirect, intangible or remote. Pure scientific research unlike industrial scientific research can not support itself by direct pecuniary returns from its discoveries.

The practical benefits which may be immediately and directly traced to industrial research, when it is properly conducted, are so great that when their importance is more generally recognized industrial research will not lack the most generous encouragement and support. Indeed, unless industrial research abundantly supports itself it will have failed of its purpose.

But who is to support the researches of the pure scientist, and who is to furnish him with encouragement and assistance to pursue his self-sacrificing and arduous quest for that truth which is certain as time goes on to bring in its train so many blessings to mankind? Who is to furnish the laboratories, the funds for apparatus and for traveling and for foreign study?

Because of the extraordinary practical results which have been attained by scientifically trained men working in the industrial laboratories and because of the limited and narrow conditions under which many scientific investigators have sometimes been compelled to work in universities, it has been suggested that perhaps the theater of scientific research might be shifted from the university to the great industrial laboratories which have already grown up or to the even greater ones which the future is bound to bring forth. But we can dismiss this suggestion as being unworthy.

Organizations and institutions of many kinds are engaged in pure scientific research and they should receive every encouragement, but the natural home of pure science and of pure scientific research is to be found in the university, from which it can not pass. It is a high function of the universities to make advances in science, to test new scientific discoveries and to place their stamp of truth upon those which are found to be pure. In this way only can they determine what shall be taught as scientific truth to those who, relying upon their authority, come to them for knowledge and believe what they teach.

Instead of abdicating in their favor, may not our universities, stimulated by the wonderful achievements of these industrial laboratories, find a way to advance the conduct of their own pure scientific research, the grand responsibility for which rests upon them. This responsibility should now be felt more heavily than ever by our American universities, not only because the tragedy of the great war has caused the destruction of European institutions of learning, but because even a worse thing has happened. So great have been the fatalities of the war that the universities of the old world hardly dare to count their dead.

But what can the American universities do, for they, like the pure scientists, are not engaged in a lucrative occupation. Universities are not money-making institutions, and what can be done without money?

There is much that can be done without money. The most important and most fundamental factor in scientific research is the mind of a man suitably endowed by nature. Unless the scientific investigator has the proper genius for his work, no amount of financial assistance, no apparatus or laboratories, however complete, and no foreign travel and study, however extensive, will enable such a mind to discover new truths or to inspire others to do so. Judgment and appreciation and insight into character on the part of the responsible university authorities must be applied to the problem, so that when the man with the required mental attributes does appear he may be appreciated as early in his career as possible. This is a very difficult thing to do indeed. Any one can recognize such a man after his great achievements have become known to all the world, but I sometimes think that one who can select early a man who has within him the making of the scientific discoverer must have been himself fired with a little of the divine spark. Such surely was the case with Sir Humphry Davy, himself a great discoverer, who, realizing the fundamental importance of the man in scientific discovery, once said that Michael Faraday, whose genius he was prompt to recognize, constituted his greatest discovery.

I can furnish no formula for the identification of budding genius and I have no ready-made plan to lay before the universities for the advancement of pure scientific research. But as a representative of engineering and industrial research, having testified to the great value of pure scientific research, I venture to suggest that the university authorities themselves might well consider the immense debt which engineering and the industries and transportation and communications and commerce owe to pure science, and to express the hope that the importance of pure scientific research will be more fully appreciated both within the university and without, for then will come—and then only—that sympathetic appreciation and generous financial support so much needed for the advancement of pure scientific research in America.

III

THE RISE OF SCIENCE IN AGRICULTURE

One of the great themes of American history from 1865 to 1916 is the clash of the hitherto dominant agrarian interest with the rising power of mass industry and the growing urbanization which accompanied it. After viewing the Populist revolt and the crusade of William Jennings Bryan in the election of 1896, most observers are content to award the palm of victory to the forces of industrialism. An easy consequence of this judgment is the assumption that the rise of science in industry, which the comments above have chronicled, somehow caused the conquest of the agrarian interest by a mechanical and mechanized industrial system. However, we should ask the question: Did the coupling of science to technology occur in agriculture as well as in industry? An abundance of evidence indicates not only that the coupling did take place, but also that it took place as early as in industry and that the results were more thoroughgoing if not more spectacular. The difference lies in a completely diverse institutional pattern with the Federal government instead of the modern corporation providing the decisive support for the experiment stations and laboratories for agriculture research. The year 1896 which marked the defeat of the farmer's last bid for political domination was the end of an era. At almost precisely the same time, the Federal government was molding itself into a research agency for the benefit of the American farmer, who by 1916 had the services of science in a way not possessed either by industry or by the farmers of most other countries.

A.

AN EARLY DEMAND FOR AGRICULTURAL RESEARCH

¶Even before the Civil War the possible usefulness of chemistry in agriculture was a commonplace in agricultural literature. At that early time some conception of the institutional arrangements needed to apply research to agriculture appeared in the widespread discussion. Only after the South seceded, however, was it possible to get action in Congress in the form of the act creating the Department of Agriculture and the Morrill Land Grant Act assisting the states to create agricultural and mechanical colleges. The following passage shows the kind of idea which lay behind the action of Congress and the expectation, even then, that the government was the agency best fitted to mount the program. Note, too, that even in the 1850's—thirty-five years before Frederick Jackson Turner published his first important essay on the frontier—an observer could see that science was the most promising alternative to unoccupied land as an antidote to soil exhaustion. Yet, is there any similarity in the use of chemistry in technology as envisaged here with that described previously by Hamor? ("Necessity of Agricultural Reform," *De Bow's Review*, XXV [1858], 158–63.)]

We have a numerous, increasing, and industrious farming population; we rejoice in a comparatively rich soil; our agricultural machinery and implements are eminently practical, time and labor-saving ones. Let us add theoretical knowledge, science, *system* to skill, experience, and inventive mood, and we shall not only be safe, but may reach the climax.

But while yet surrounded by favorable circumstances, while yet living in a country, the area of which is blessed to a great extent with a most productive soil, requiring comparatively little toil and skill to make it yield abundant crops, experience as well as scientific research, do forewarn and admonish us, not to trust too implicitly to this apparently most prosperous state of things, for rapid are the changes that may come over us, while we are dreaming or boasting of our prodigious condition. The happiest, wealthiest land may become poor and miserable, and the most prolific soil exhausted in the lapse of time, "if not certain constituent elements are returned to it in proportion to the extent to which they have been carried away by successful crops."

The restitution of the continually disturbed equilibrium alone secures fertility *in infinitum;* and wherever nature does not supply means to that end, human industry and human skill must take its place. We have striking examples for either relation. Thus in China and certain parts of Europe, it is chiefly manure, and to a great extent artificial manure, by means of which the soil is kept productive; in Hungary and [a] few other regions, it is owing to the quick disintegration of peculiarly adapted sub-soils or rocks, that a constant supply of nourishment for certain crops is furnished; in the Nile valley and certain river bottoms of the United States the yearly inundations secure fertility; and in the Netherlands the same result is chiefly due to a regular system of irrigation. But most of these examples do not form the rule, but rather the exception, and the majority of agricultural regions are wont to imitate China, if the yield of their soils shall not gradually decrease.

That the latter course is not more generally, and more timely adopted in the United States, that there, some of the most fecund tracts have been suffered to be laid waste, is easily explained. The immense area of unoccupied and unimproved land in the great West, together with the many other inducements to a settlement in those splendid, rising regions, make part of our people indifferent to the fate of the Atlantic States, and dazzle others to such an extent, that they see no danger in the exhaustion and final abandonment of their former homes; at least they see no danger for them and that is about all they mean to care for. To look to posterity is none of their business, neither do they dream that retribution may ever visit them in their new abodes; and perhaps it will not during *their* lifetime.

But wherein does consist the gain, if the annexation of a new agricultural district is analogous to the exhaustion and partial desertion of another? What have Virginia, Massachusetts, New York, &c., gained by the access and development of new Territories and States? Has the process of exhaustion been retarded or checked in consequence? The population, the fertility, produce, wealth, and general prosperity increased in the ratio of her original capability? Not at all. The acquisition and occupation of new Territory has only tempted and enabled people to be the more regardless of the mother State, and to quit it at the first signs of its receding prosperity, or its slower progress. . . .

That our great confederacy cannot, without serious, vital injury to its imposing and still growing agricultural industrial and commercial interests, long remain behind other countries in nursing that branch of the natural sciences, which is the teacher, guide and benefactor of almost every trade and craft, requires no argumentation in this place, nor do we think to have failed to make it manifest, that no species of human pursuit is more depending and more indebted to *chemistry* than the agriculture. Chemistry does not only give instruction to the farmer on everything that there is, but it teaches him what is wanting, and how it can be got. It makes known unto him the *constituents* in the composition of the surface soil, its fertility in general, and its adaptability to certain plants. It makes him acquainted with the *proportions* in which certain constituent and fertilizing elements are contained in the soil; and with the extent to which they are withdrawn from it, by each succeeding crop, when he subjects the ashes to an analytical inquiry. It tells him how far, and in which time a subsoil can be made capable of replacing the withdrawn minerals, earths, and alkalies, and gives him the information, whether this is to be effected by deep-ploughing, rotation, fallow, irrigation, manuring, or any other contrivances or applications. It gives him certain knowledge of the capability of a soil to absorb and to retain moisture, and discloses unto him its power of capillary attraction. It points out to him all the sources from which fertilizers or manures can be drawn, and suggests the most practical and efficient modes as to the quantities, forms and combinations, in which such fertilizers have to be brought upon the field in order to restore it either to its former productivity or to increase the same, &c.

These are but a few of the advantages and benefits to be derived from an appeal to science, from an application of chemistry to the art of [agri]culture.

. . . The establishment of *Agricultural Laboratories* is the great desideratum for any successful initial step towards material improvements in the state of our agriculture. Single, solitary investigations of soil and ashes, and subsequent devices to turn them to account, will benefit locally or individually, and should be more frequently resorted to than heretofore; but the whole object, the national aim, cannot be attained by this means. To accomplish that desirable and great end, a perfect *chemical survey* is wanting.

If but a single series of such investigations would be undertaken on the part of the Federal or a State Government, we do not for one moment doubt but that its results would be looked at with astonishment, and hailed with delight by either legislators, statesmen, and practical agriculturists.

B.

THE DEPARTMENT IN 1882

[In the first twenty years of its existence (1862 to 1882), the Department of Agriculture struggled along modestly, convincing few that it had much to offer the American farmer. Two issues especially were still undecided. The first was whether or not that part of the Federal government closely associated with party politics could be trusted to administer an agricultural research program which could command the respect of scientists in general. The second issue was how to organize the Department. For the first two decades, the Department had general-purpose divisions which corresponded roughly to academic disciplines in the universities which were developing largely as a result of the stimulus of the Morrill Land Grant Act. The following review of a biennial report of the Commissioner of Agriculture renders a negative judgment on both of these issues. Note that it appeared in a new journal founded as a spokesman for the university scientists. ("The Government Agricultural Report," *Science*, I [1883], 142–43.) Is it always true that science applied to technology yields answers which are worth the effort?]

Inasmuch as the present commissioner, when he entered upon his duties, "found the work for the season, both regular and special, elaborately laid out by my [his] successor," his report not unnaturally bears a strong resemblance to the reports of preceding years. It contains the usual reports of the entomologist, the superintendent of grounds, the botanist, the chemist, and the statistician, besides special reports relating to the diseases of animals and to the boring of artesian wells on the arid lands of the west. The tone and matter of the special reports and of the reports of special character compare so favorably with most of those of the old-style 'regulars,' that the thought suggests itself, that a much larger proportion of the work of the department than has hitherto been customary could best be done by special commissioners outside of Washington and far away from its influences. From the very nature of the situation and surroundings of the Department of Agriculture; the irregularity of its income; and its dependence for support upon the favor of political parties,—let alone the merciful dispensation that the tenure of office of its chief is short,—it cannot be accounted competent to carry on continuous scientific researches; and it is in no sense desirable that it should do so. Works of *longue haleine* such as must necessarily run on consecutively from year to year are beyond its powers; and it will be well for Commissioners of agriculture, present and future, to accept the fact. Rather than try to grasp the unattainable, it will assuredly be wiser to study special finite questions as they present themselves; and to this end the best means is the employment of special scientific men of approved competency, each one to grapple with his own particular question in such place and manner as he may deem fit.

One commendable feature of the present volume is the comparative brevity of the reports of the superintendent of grounds and the botanist (of the report of the entomologist we shall speak at another time). The report of the chemist, on the other hand, is extended, and it has somewhat the effect of a twice-told tale. It was interesting and important to prove that the proportion of true sugar in sorghum-stalks increases continually until the plant is well advanced toward maturity; but the evidence of this fact presented in previous reports seemed convincing, and many of the results recorded in the present volume have the effect of being little more than refinements upon good work. The reader is inclined to ask whether it is not about time for the department to let its scientific corps drop sorghum, and to relegate the subject to the artsmen proper; that is to say, to those farmers and manufacturers who are specially interested in this line of business.

From a letter of the 'commissioners for locating artesian wells upon arid and waste lands,' as well as from the statements of the commissioner of agriculture himself, it appears that in their opinion the first trial-well at Fort Lyon in Colorado was not a success. The onus of this 'failure' is made to rest, of course, on the shoulders of a preceding administration; but the lesson it teaches is none the less instructive. It suggests the reflection, that while one important function of the Department of agriculture has been to show the American people 'how not to do it,' there are various ways in which the lesson is enforced. Impracticable borings in Colorado undoubtedly represent one mode of tuition, but in the appointing and changing of employés for political reasons we have another; and to the same end must inevitably work all changes of base which are hasty, spasmodic, and inconsequent. It will be of interest to notice how far down the next borings will be permitted to reach before a new incumbent says, 'Hold, enough!'

From a couple of modestly printed tables on pp. 25 and 692, it appears that the Department of agriculture disbursed $256,129.68 during the year ending June 30, 1881, and $353,748.60 during the year ending June 30, 1882. It will convey no new information, either to scientific men or to the agricultural community, when we say that the results obtained by this class of expenditures have hitherto been, out of all proportion, small.

C.

THEOBALD SMITH AND TEXAS FEVER

[Despite the gloomy predictions of practical men and scientists alike in the early 1880's, agricultural research began to pay off. Just as the development of bacteriology in Europe had its agricultural side, American scientists in the Department of Agriculture eventually demonstrated that a fruitful attempt to solve a practical problem could result in a basic contribution to knowledge. The most conspicuous early accomplishment of the Department came when a team of scientists of various specialties working in the Bureau of Animal Industry under the direction of Theobald Smith solved a problem of pressing importance to the post-Civil War cattle empire and at the same time proved the role of the secondary host in the transmission of disease. The colorful open-range cattle industry with its long drive of millions of animals from the fever-infected South to the susceptible North was quite as close to the scientific frontier as it was to the geographic frontier. For instance, compare the pattern of organization and the relation of science to practical results as shown in the following example to the pattern described in industry by Langmuir. (Hans Zinsser, "Biographical Memoir of Theobald Smith, 1859–1934," National Academy of Sciences, *Biographical Memoirs,* XVII [1937], 261–303.)]

When Smith, in association with Kilborne, first approached the problem experimentally (1889), there was already some information about this disease and interest in it was stimulated by its great economic importance.

There had been, for a long time, an impression among cattle ranchers, vague but persistent, that ticks were in some manner related to the infection. In 1885, the geographical distribution of the disease had been approximately established by Salmon and its northern limits defined. In 1889, Curtice, the entomologist of the Bureau of Animal Industry (4th and 5th Annual Reports, Bureau Animal Industry, p. 436) spoke of an experiment carried out in the Chicago Stockyards, in which five cows were placed into a pen in which Texas cows had been held, with the result that four of them died of the cattle fever. This experiment had been suggested by the "oft repeated experiment of allowing native cattle to live in the trail of Texas cattle." A similar experiment was reported in the same year by Kilborne but, in this attempt, northern cattle were mixed, in one pen, with southern cattle rendered free of ticks—while in another pen the ticks were left on the infected animals. The result was no infection in the former, death of the animals in the latter. Again, in the same year, Smith, undoubtedly working in close association with his colleagues, described (Medical News, Philadelphia) the little bodies in the red cells of infected cattle which he later (1891) recognized as protozoa and eventually named Prioplasma Bigeminum. In announcing this discovery, Smith with the fairness and generosity of character to which "priority" squabbles were abhorrent suggests that these bodies were probably identical with those seen by Stiles in 1869, but probably unlike those of Babes (1888) because the latter claimed to have succeeded in cultivating the organism he had observed. In the longer report of 1891 Smith, with Kilborne, reported on a more extensive and thorough series of transmission experiments in which four animals were infected by the direct application of ticks. Further, they had placed southern cattle in pens with northern stock—in some cases after the removal of ticks, while in other enclosures the ticks were left on the infected animals. Also, native cattle were kept in fields in which infected ticks had been scattered on the ground. The report which is one of the classics of medical literature, established beyond question the role of the tick as the carrier of the disease. And not the least of the achievements of these experiments was the observation that the infection could pass, in ticks from mother to offspring, a new and extraordinary phenomenon of parasitism which has found its analogy in tick infection with the Rickettsia of Spotted Fever. It is certainly not a disparagement of Smith's greatness to correct the erroneous impression created in some popular accounts which belittle the merits of his associates, by stating that these fundamental discoveries were in fact collaborations between a group of well-trained and intelligent men, rather than entirely the work of Smith alone. In doing so it is quite certain that we are stating the case in the manner in which he would have wanted it told. Moreover, from what we know of him and his experimental acumen, it seems more than likely that his was the leading spirit in this collaboration by which, for the first time, the complete cycle of transmission of disease by insects was established. It is true, of course, that as early as 1877, Manson had discovered that embryo filaria, taken up from the blood of infected men by mosquitoes, developed in the insects into the final larval stages. But Manson's studies did not show how the filaria again reached man. . . . The investigations of Smith and his collaborators were, therefore, the first to establish the complete cycle of transmission by arthropod vectors —a discovery which represents one of those fundamental steps forward that alter the entire course of a science, and which has practical consequences of inestimable and permanent importance. We have presented this particular work with a certain degree of emphasis upon the parts played by others than Smith and upon the significance of earlier discoveries which undoubtedly helped to shape Smith's thoughts and experiments.

D.

THE SHIFT TO THE PROBLEM APPROACH— CHARLES W. DABNEY

¶During the 1880's and 1890's the Department of Agriculture went through a distinct evolution in its organization. In place of the divisions representing academic scientific disciplines, the Department developed new bureaus around distinct problems. Scientists of more than one discipline were grouped around particular problems of importance to American farmers. You may feel that this evolution was one which was away from basic science in the direction of narrow practicality. But consider also that the reorganization may possibly have led not only to the practical results with their consequent political support, but also to an increased specialization which meant higher scientific standards in the Department. Note that the following account, touching on the shift to the problem approach, was written in 1895, fairly early in this reorganization. This politician-spokesman for science in the Department had to be particularly careful to defend the Department against the charge of extravagance in the early 1890's, and he represents one commentary on the events of that stormy decade in the general history of the American farmer. (Charles W. Dabney, "The Scientific Work of the Department of Agriculture," *Bulletin* No. 24 [Washington: Department of Agriculture, Office of Experiment Stations, 1895], pp. 63–67.) Do you see anything emerging here which is comparable to the industrial research laboratories?]

One of the Western newspapers made a remarkable announcement last March, to the effect that the Department of Agriculture had just "elected a professor of astrology." We have long known that the moon was supposed to have a great influence on some departments of agriculture, but we had never heard it suggested before that the stars had anything to do with crops. It did not take us long, however, to find out that the usually infallible editor referred to our new officer, the "agrostologist"—a title that the country newspapers have been struggling with ever since.

The Department of Agriculture has always recognized the importance of the investigation of our forage resources, and through its Division of Botany it has made many valuable contributions to our knowledge of them. In view of the growing importance of grasses and forage plants at the present time, when the methods and objects of farming in many sections of our country are undergoing a radical change, the honorable Secretary of Agriculture recently decided that this subject required more attention than the Department was able to give it with the present force of the Division of Botany. He therefore employed a special agent to prosecute investigations upon grasses and forage plants.

No country in the world possesses such vast forage resources as ours, and in none are the plants which compose that forage more various. Our botanist informs us that there are over 3,500 different kinds of grasses in the world, of which over 700 are known to grow within our territory. There are, besides, many useful forage plants—not grasses—such as the clovers and alfalfa. The annual hay crop of the country has an estimated value of $600,000,000 and more than 14,000,000 head of cattle are supported upon our grazing lands. The maintenance and improvement of these resources is a matter of importance to every citizen of the United States, and of direct and vital interest to every American family. Upon it depend the vast meat and dairy interests, and to a great extent the more important methods of maintaining the fertility of our agricultural lands.

In our great territory, including lands of many different elevations and climates, much exploratory work yet remains to be done upon our native grasses, and by continued examinations it can not be doubted that useful species new to agriculture will from time to time be found. In the arid regions of the West and Southwest are nutritious grasses and other native forage plants whose introduction into culture, if carefully undertaken, could not fail to greatly benefit these sections. The importation of the native or improved forage plants of other countries has in some cases resulted in much benefit to our agriculture, and doubtless many other plants can be found and tested with regard to their adaptability to our climate and soils. The study of grasses for special purposes, as for example, for binding the drifting sands along our ocean and lake shores; for holding the embankments of our great rivers, which frequently overflow and sweep away farms, while they cover others with destructive débris, materially broadens the interest in grasses and makes this work of practical importance to many other classes of citizens.

Considerations like these have induced the Secretary of Agriculture to recommend to Congress the establishment of a separate Division of Agrostology for investigating grasses and forage plants, with special reference to their use in those sections of our country where they are at present little known. The establishment of such a division would demonstrate to the citizens of this and other countries that our National Government fully recognizes the primary importance of the grasses in the rural economy of the nation. It will be the function of the new division to instruct our people in the habits and uses of these plants; to examine their natural history and adaptability to our different soils and conditions; to import, test, and introduce foreign kinds into cultivation; to identify the plants sent in by correspondents; and to prepare circulars, bulletins, and manuals for distribution. I am pleased to be able to tell you that we have reason to believe that Congress will give us the authority and the means with which to carry on this work.

The Division of Botany, which has been so prolific in giving birth to new divisions—the Division of Forestry and the Division of Vegetable Pathology, as well as Agrostology, are its children—has recently developed several other new lines of work. It has, for example, devoted a great deal of attention recently to a more systematic study of weeds. Among others, that czar of weeds, the Russian thistle, which some of our Congressmen think to be worth its million, has received much careful attention. The Department has done all that it could do in investigating the natural history and methods of distribution of this weed, and in publishing circulars and bulletins relative thereto. There are other weeds which are almost if not quite as dangerous as this, and they will all be studied as rapidly as the means available will permit.

A special expert has been engaged and a laboratory fitted up for the systematic study of seeds with reference to their purity, germinating power, etc. This is an important matter, especially in connection with our studies of grasses, forage plants, and weeds, since our grass seed and seed grain are always liable to be contaminated with the seed of weeds. It is our desire to establish standards of purity and of germinating power for all the chief American seeds, and in this way promote the trade in these seeds and especially the demand for them abroad. Our exports of clover seed are already very considerable, and many seeds of commerce demand the oversight of this Department.

I speak this morning to many agricultural chemists, so that I need not take time to explain the disappointments that we have all felt with regard to the results of the chemical analyses of soils. We must acknowledge now that we can not tell the practical farmer all that he wants to know by a single analysis of his soil; that it often requires many analyses to learn, even approximately, the chemical nature of the soil of a given section and that, even when we have made these, we are unable to explain why one soil is productive while another fails entirely. We all know cases where soils having almost identically the same chemical composition yet differ greatly in the uses to which they can be put. In short, the chemical analysis of the soil does not tell us the whole story. A great deal more is to be learned about it before we can tell the farmer how to make it productive or why he should put one particular crop upon it and not another. Our Department has decided, therefore, to attack this old problem from two different sides; first, from the physical side, by studying its relation to heat, moisture, etc.; and second, from the biological side, by studying its nitrifying organisms, etc. This we hope to do without neglecting the old lines of chemical investigation.

A new division has been created in the Department to be known as the "Division of Agricultural Soils," whose duty it will be to study the rainfall and temperature after they have entered the soil and to keep a continuous record of them in the most important types of soil in our country. Our Weather Bureau keeps a record of the temperature and of the moisture in the air and of the rainfall until it reaches the surface of the soil. It is proposed in this new division to continue the study of the rainfall after it enters the soil. The actual conditions of air, moisture, and temperature which soils are able to maintain largely determine what classes of plants are adapted to them. These things depend in turn upon the texture of the soil. Even with the same rainfall and exposure to heat it is well known that different soils maintain very different conditions. This difference in the meteorological conditions under the surface has an important bearing upon the adaptability of soils to crops, because of the influence on their development, yield, texture, quality, vitality, and time of ripening.

Soils adapted to early truck and small fruits, for example, are sandy, open, and warm, allowing the rain to pass through them very readily and maintaining only a small amount of moisture. This dry condition gives them their peculiar value for forcing vegetation to an early maturity. The tobacco soils of Pennsylvania owe their peculiar value to their close texture and to the fact that they maintain an abundance of moisture for the crop. This produces a large, heavy type of wrapper which competes with the Cuban tobacco. The tobacco of the Connecticut Valley, on the other hand, is grown on a very light textured, sandy loam, and the soil being much drier the crop is much lighter in color and finer in texture. It competes with the Sumatra wrapper.

The work of this new division is to be confined to the study, principally, of the texture of the soils adapted to these different interests. It will be one of the purposes of this division to develop the methods of these investigations and to encourage an extensive study of the soils of the country by State stations and colleges. There is a pioneer work to be done here which you can scarcely be expected to do. This work is based upon geological formations which may cover a number of States and may be found in widely separated parts of the country. Samples from the same formation or the same class of agricultural soils must be collected from all over the country and carefully examined and compared. In many cases it will doubtless be necessary to get samples of soils from foreign countries for the purpose of comparing them with our own.

Congress has also been asked to provide, in connection with our Chemical Division, for the investigation of the chemical characteristics of the various typical soils of the United States, especially in relation to the nature of the nitrifying organisms contained therein and the best condition for the growth of the same. This work has already been begun and promises to be most interesting.

I am in danger, however, of using too much of your time, and must hasten to a conclusion. You will be interested to know that the Department of Agriculture, which is, in part, a great experiment station itself, is pushing its scientific work ahead of everything else. We have made a little table showing the actual expenditures of the Department during the years 1892, 1893, and 1894 for all of its different purposes, and have classified these expenditures so as to throw all money used in the strictly scientific work in one column and all that expended for administrative purposes, for publishing and distributing documents, for distributing seeds, for purely business or strictly educational work, in another column. I will not burden your proceedings with this table, but merely give you the results.

The Department of Agriculture expended for the fiscal year 1892 $2,271,312.72, and 46.2 per cent of that sum was expended in scientific research. For the fiscal year 1893 the expenditures were $2,354,809.56, and out of it 45.6 per cent was expended in the application of science to agriculture. For the year ending June 30, 1894, out of a total expenditure of $1,990,530.70, the Department applied 51.8 to scientific work and investigation. While economy has been practiced in the administration of the Department, this economy has not impaired its scientific work. Comparing the expenditures for the fiscal years 1893 and 1894, respectively, I note that the total expenditures for 1894 are, roughly, $364,000 less than the total for 1893; but the per cent of the total amount paid out for scientific work, as distinguished from the administrative and general business, is 5.6 per cent more, in proportion to the total expenditures during the year 1894, than it was in 1892, and 6.2 per cent more than it was in 1893. It was during this same time that we commenced the new work in agricultural soils, agrostology, and seed investigations, and still further developed that in weeds and many other older scientific lines.

E.

A MATURE RESEARCH ESTABLISHMENT FOR AGRICULTURE

¶By the time of the outbreak of the First World War, the Department of Agriculture had won a secure place in the government. The unique combination of the Department, the state experiment stations, and the land-grant colleges gave the American farmer superb research support. Yet this generally fortunate state of affairs opened up new challenges and problems for those concerned with the application of science to agriculture. What some of them were is suggested by the following selections.

1. *A Scientist's View.* One of the scientists who worked in the elaborate system of government supported agricultural services comments on the difficulties of guarding the interests of true scientific research in the environment of a political organization beholden to a strong and self-conscious economic group. (Eugene Davenport, "The Outlook for Agricultural Science," *Science*, N.S. XLV [1917], 149–60.)]

Without wasting time in discussing the question whether there is such a thing as agricultural science, I desire to proceed at once to a brief review of the conditions both favorable and unfavorable to the progress of those scientific activities necessary to the improvement of American agriculture and the welfare of country people upon whom we all depend for our food supply, for the proper employment and treatment of our lands, and for certain human qualities best propagated and preserved in the life of the open country.

No thinking man can fail to be deeply impressed with the magnitude and the far-reaching consequences of what might be called the American program for agricultural advancement.

This program took definite form in 1862 in the establishment of a national Department of Agriculture, and in the passage of the Land Grant Act, whereby a college of agriculture was established in every state of the union. It was characterized and vitalized a quarter of a century later by subsequent acts providing for an experiment station in connection with every agricultural college; and mightily advanced by state appropriations, in some instances multiplying many times the federal subsidy. So generous indeed were these appropriations that the $30,000 of federal funds have been supplemented until the total revenues of certain institutions for agricultural research amount to no less than $200,000 annually.

This combined federal and state program aims directly at an adequate and a permanent food-supply, and with equal directness it proposes to retain upon the land, if possible, a fair share of the intelligence, the learning, and the culture of the American people. This latter purpose may be called Utopian, but a little reflection will convince even the most skeptical that in no other way can our lands be properly handled, for farming is after all and in the last analysis an individual affair.

The incidental effect upon citizenship of such a systematic effort, especially in a democracy, is an interesting sociological and economic question, but it is quite aside from the present purpose, which is to analyze the agencies that have been awakened in the name of agricultural science and to distinguish as clearly as possible between those that are really helpful and others that by accident or otherwise have become attached like barnacles to the ship and whose load is even less serious than their resistance.

The sudden establishment of a national system of fifty institutions under combined federal and state support, and the engaging upon this extensive scale in both education and research in a hitherto neglected, if not despised, field was certain to be followed by results both desirable and undesirable. The combination is still further complicated by the fact that the new field has suddenly become popular, drawing into its vortex amounts of money never before equaled, and engaging the attention of all sorts and conditions of men, some seeking opportunity for real service, others attracted by the loaves and fishes, even by the crumbs.

It was as inevitable that certain results should follow the agencies here invoked as that other effects should follow causes.

For example, it is impossible to launch so pretentious a program without a vast amount of good resulting, and in this respect the most sanguine enthusiasts have not been disappointed. It is impossible to accomplish a public service of this character and magnitude without developing a body of earnest, capable and devoted scientists who work, not for reward, but for the good that they can do, and it is my desire here and now to pay tribute of respect to the hundreds, yes thousands of men and women who labor both day and night, who expose and often destroy their health in carrying forward this great work. They shall have their reward.

But it is also impossible to suddenly engage upon an extensive scale in a new and undeveloped field without drawing into the service both inadequately trained and mediocre men. It is impossible that a field should be popular without attracting the sensationally minded, and it is equally unlikely that so large an amount of public money could be expended without the creation of a vast and complicated administrative machinery. . . .

A heavy weight of responsibility rests upon the young man now preparing for a career in agricultural research. It is not enough that he have some special knowledge and skill in a narrow field such as soil analysis, genetics or vegetable pathology. He must have scholarship, breadth of knowledge and vision enough to know the relation of his specialty to other branches of science, and the bearing of it all upon the business and the practise of food production, that is, farming.

For the purposes of the investigator a real knowledge of and sympathy with the actual operation of the farm and the problems of the farmer is not only desirable, but essential. Farming is a productive, not a speculative industry, and the problems of agriculture are those of production and distribution, not those of special opportunity.

Moreover, farming is a private business upon which the welfare of families depends—not a few scattered people, but a full third at least of all the population and constituting entire communities. This fraction of the race must not be disregarded or the earth will avenge herself not only upon the unsuccessful farmer, but upon the people as a whole, whose heritage, after all, the land is.

The agricultural scientist, therefore, must not make mistakes, or he will lead a whole people to disaster. Our philosophies may be wrong; they can be readjusted. Our conceptions of the solar system may be incomplete or wholly erroneous; but everyday life will go on about the same. However, if we entertain wrong conceptions about the serious business of food production, the consequences are swift and merciless.

If we get too little out of the earth, population is unduly restricted or unutterably miserable; and if we win our sustenance by methods destructive rather than permanent, then our successors, if not we ourselves, will pay the penalty of our error or of our piracy. Science is our only reliance, but the agricultural engineer must make no mistakes. He must be no blind leader of the blind. Therefore he must know the business of farming.

Now this is easier said than realized. The college student has lived all his life in school. Learning has been his occupation. Moreover, we shall tell him that if he expects to be really valuable, he must not stop with the bachelor's degree, but he must do so much in addition and do it so well that he will inevitably and in good time achieve the doctorate.

How then can this young man know by experience the business of farming? He can not know it as the farmer knows it after fifty years of earning a living and of clothing and educating the family he has raised. This prospective scientist will work for a salary, which means an assured living while he studies and attempts to solve the problems of those who live by production. . . .

The experiment stations are new, and fortunately whatever else may be said they have now the confidence of the farmers, who have come generally to feel that a new force is in affairs and that a new help to farming has appeared in that indefinite thing we call service.

Now there is always a temptation to put sacred things to ungodly uses, and the experiment stations have not escaped the operation of the general law. Science has shown that a certain disease or pest can be controlled, and it has pointed out the method of doing it. What more natural than that the public should take the stations at their word, and say "Very well, here is an appropriation; go ahead, make your serums and your rules to put the thing into practise; hale citizens into court; fine or imprison them if necessary, but make it work"?

Now this is hasty logic and bad practise. The experiment stations are organized for research, not for administration. Again, it is unseemly that a creature of the public like a scientific institution should appear against citizens in the courts and fine or commit them to jail. Besides, the experiment stations have no militia with which to suppress resistance, which in such cases as foot and mouth disease is as ever present as time and as explosive as a volcano.

Besides, the object of the scientist is research, and how shall the experiment station carry on further investigation after new truth if it must stop short and enforce the accumulating mass of revised practise. It will soon be so cluttered up under such a policy that new work is impossible and most of its funds and laboratory space will be used for the purpose of "regulatory work," when further progress is practically impossible, a condition that has already overtaken certain of the experiment stations and is all too rapidly threatening others.

The only safety either to the research worker, the station or the public is for the investigator to verify his discoveries, point out the method of their practical use, and go on after other truths, leaving the public to make such use of the new knowledge as it deems wise and relying upon the usual police power of the state for its enforcement, if enforcement is necessary. In no other way can research be protected; in no other way can the stations discharge the public service for which they were organized; and in no other way can the confidence of the public be indefinitely enjoyed.

The rate and the intensity with which administration under one pretext or another is coming to dominate research in this country, especially along agricultural lines, is little short of appalling to any candid observer who takes stock of the situation and who has the courage of his convictions. . . .

All this is done in the name of one or the other of two agencies—the administration of public funds, or the demands of efficiency.

Officers connected with federal and state administration seem to be unable to distinguish between the business of auditing and that of supervision. They reason that if they are in any way to certify funds they must also approve the work. In this way has ordinary auditing developed within twenty-five years into what was at first inspection of work and at last a kind of "cooperation" in which the one to be held responsible for results is under the dominance of authority entirely outside the institution which he serves. In this way an outside individual, even a minor officer, is able to overrule a university and its entire administrative machinery.

Efficiency is more insidious, for it works under the guise of service and proves by figures that scientists, teachers and others in the public service must be standardized in order to be made efficient. . . .

Modern efficiency standards are developed from the manufacture of shoes, clothes-pins, overalls, etc., and are expressed in motions per hour. These standards are not applicable to research. Money put into research is bread cast upon the waters. In the serious business of searching after new truth, no man knows in advance the road that shall be traveled before he may stand upon the heights. He may be held down, but he can not be pushed up. No power on earth is so impelling as his own initiative and determination to achieve.

Under what project did Darwin work? Did Faraday report regularly upon the progress of his mental wanderings after firm resting places? Could the searchers after the principle of radioactivity report progress from time to time? How shall we, even in the interest of efficiency, record the Sermon on the Mount or the Gettysburg address in terms of laboratory hours? Go to, we are dealing with strange gods at this point. Let us be forgiven and return to the worship of the true Deity which is ready to recognize the individual as the source of all real discovery and which is willing to accredit him with as much of honesty of purpose, and of faithfulness to the public as the political appointee, also an hireling. Above all let us not set up to rule over us machinery that is manned by those individuals who could not themselves do the work they attempt to supervise. And above all I protest against the present temper of the public mind which has been tampered with by professional exploiters until it is unwilling to trust its business in the hands of boards or other deliberative bodies even when composed of reputable citizens busy for the most part about their own affairs, but overrules their judgment by exalting individuals who have no occupation of their own but whose profession it is to multiply and to fill administrative positions, that render no service but that hinder mightily the progress of the true scientist whose one occupation is research.

Here have come together the working scientist and the professional officeholder. They face in opposite directions. At present the office man has the upper hand. He assumes the rôle of critic and the public has accorded him all he asks. The time will come, however, and may it not be long delayed, when the scientist will again come into his own and the institution to which he belongs will recognize no overlord, except the auditor, who will be an auditor, not an autocrat in technical science.

So thoroughly has chemistry taken the lead as a science fundamental to all improvement in agriculture that the terms are sometimes used synonymously. However, the outlook for the development of other sciences in their relation to agriculture is extremely suggestive. Physics, for example, has never consciously served farming. I know of but two graduate students in agriculture who have specialized in physics, and it was the experience of both that physicists were somewhat surprised to learn that their science could be of the slightest use in agriculture, whereas the facts are, it is of fundamental importance at many points.

Both botany and zoology possess undeveloped opportunities little dreamed of. They have in the past served agriculture mainly in the field of genetics or of animal and plant diseases. We are only beginning to study crop production from the standpoint of the physiology of the plant, its sensitive periods and the conditions essential to successful growth.

As a whole we have only scratched the surface of science in its relation to the practise of farming. The outlook is nothing short of a panorama to him who has an adequate vision of the future and the ability to work in any one of the great fields of science, distinguishing clearly between science *per se* and its application to the arts of man.

[2. *A Politician's View.* Even as the Department of Agriculture proved itself as a research organization, it ran up against two major problems which were insoluble in the chemical laboratory. The first problem, which was reaching crisis proportions by 1915, was how to get the results of research into the hands of dirt farmers and convince them that science was superior to inherited lore. The second problem was how to convert the increased productivity brought on by science into economic gains for the individual farmer. To the extent that the average farmer could see science bettering his lot, research could substitute for the Populist crusade. Carl Vrooman, Assistant Secretary of Agriculture under Woodrow Wilson, addressed himself to these problems rather than to the details of how to administer a research establishment. What was the essential difference between industry and agriculture in this period when an individual tried to introduce the results of science into the stream of technological practice? (Carl Vrooman, "The Agricultural Revolution," *Century Magazine*, XCIII [1916], 111–23.)]

Agriculture, though one of the oldest of the arts, is the youngest of the sciences. Less than two years ago, for the first time, the American Academy for the Advancement of Science admitted agriculture into the family circle by giving it a place on its program and in its organization. Thus agriculture has become a sort of modern Cinderella. For thousands of years the servant and drudge of civilization, at last she has found the magic slipper and is making her début as a veritable and acknowledged princess, a royal dispenser of bounty and happiness. . . .

It is indeed highly important that the farmer learn the agronomic lesson of how to increase his yields and the economic and business lesson of how to buy and sell to advantage, but in a larger sense these matters are important only as stepping-stones to a realization of the higher possibilities of life. A scientific success has little importance to the farmer unless it can be made the basis for a business success, and a business success in turn has little real significance unless it can be translated into terms of life. I know farmers who have broad fields, great herds, huge barns, and large bank-accounts, but whose successes end right there; who live narrow, dull, purposeless lives—lives devoid of aspiration, happiness, or public spirit. The wealth of such men is like much of the fertility in our soil: it is not available. These men need instruction in the art of living as much as their less-prosperous neighbors need instruction in the art of growing and marketing crops. For, after all, it is only the wealth that we dominate and dedicate to some useful or noble purpose that we can be said actually to possess. All other wealth that stands to our credit is either inert or actively sinister, and in the latter event it often gains the upper hand and finally comes actually to possess us.

The agricultural possibilities that open out before the American farmer in bewildering profusion are for the most part yet unrealized. The lot of the up-to-date, scientific, and businesslike farmer has improved greatly during the last few years, but the lot of the average farmer still leaves much to be desired, still lacks much that has been chronically lacking to the tiller of the soil for thousands of years. On a western Iowa farm there was a young boy who plowed corn and did diverse other things from dawn to dusk. When asked what he got for all his hard work, a momentary fire of revolt flared up in his brain, and he said: "Get? Get? Nothin' if I do, and hell if I don't."

That boy summed up in one terse phrase the annals of husbandry for all the centuries before the advent of the science of agriculture. He is Millet's "Man with the Hoe" before he grew up. From time immemorial civilization has rested on the broad shoulders of the agricultural workers of the world, but before their eyes has opened up no vista of opportunity or of hope for them or for their children. Theirs has been the bitter choice between a life of unending drudgery on the one hand and the hell of starvation on the other.

In the last half-century the Department of Agriculture has spent some two hundred and fifty million dollars largely in research and experiment, to the end that American agriculture might be put on a high plane of efficiency. The results of this research and experiment have been agronomy and animal industry, a vast, but largely undigested and uncoördinated, mass of information about how to grow crops and "critters." During this entire period the department has been accumulating and hoarding a vast store of facts about how to increase production.

Thus during the first fifty years of its existence the department was chiefly a bureau of scientific research that gave the farmer from time to time an assortment of miscellaneous scientific information that he might or might not be able to utilize to his financial advantage. Unfortunately, a world of practical problems that destroy the farmer's peace of mind and involve the success or failure of his business—namely, his business and economic problems—were virtually ignored. In other words, for the first fifty years of its life the department hopped along on one leg, the scientific leg. Happily, during the last three years a miraculous thing has happened: the department has grown another leg, the leg of business and economic efficiency. Now it begins to walk, and we confidently expect in the near future to see it going forward with giant strides.

During the last three years, for the first time in its history, the Department of Agriculture has had at its head an economist. Under the direction of Secretary Houston it has achieved a new point of view and a new conception of its mission. For half a century the department has used its utmost endeavors to show the farmer how to fight the chinch-bug and the army-worm, the cattle tick and the Hessian fly and other insect pests, but had not even so much as attempted to show him how to protect himself from the yearly toll levied upon the fruits of his toil by such human pests as the usurer, commercial pirates posing as legitimate middlemen, and the other business parasites of the agricultural world.

The farmer who makes two blades of grass grow where only one grew before may be a good agronomist, but if he cannot sell his second blades at a profit, he is a poor farmer. In other words, farming is primarily a business. Very few practical farmers till the soil to demonstrate principles of agronomy. They produce crops to live rather than live to produce crops. Even more than large production they want *profitable* production. Upon the realization of this fundamental fact is founded the agricultural renaissance which recently has been begun. . . .

[A] recent achievement of prime importance has been the working out of a system of direct retail distribution to the farmer of the accumulated results of the scientific research of the last half-century. While each of the older bureaus of the department has many years of honest and invaluable research work to its credit, in the main little has been done until recently toward putting the results of the work of the department's scientific men before the farmer properly condensed, correlated, and couched in terms easily understood. Fewer than a dozen years ago the Department of Agriculture was almost as far removed from actual contact with the masses of our farmers as the State Department or the Coast and Geodetic Survey. No wide-spread, continuous, and systematic effort has yet been made to carry agricultural education to the farmer by word of mouth or by demonstration; the Office of Farm Management was a minor appendage of one of the older bureaus; the publications of the department were lucky if they escaped being still-born, so little was the effort made to popularize them and to interest the farmers in them by means of the press. It is difficult to realize that a major government department, established for the specific purpose of informing the people, spending millions of dollars of the people's money every year for research work, could ever have been so indifferent to the practical application of the results of its research as the Department of Agriculture seemed to be until a few years ago. Yet one has only to glance over the current list of farmers' bulletins to find evidence of that seeming indifference.

Many of the so-called farmers' bulletins are really technical papers. Much of the information published on vitally important practical problems is scattered about in so many bulletins as to be entirely un-get-at-able by the average farmer. The teachings of the department with regard to a number of the most vital farm problems have not been properly differentiated regionally and special bulletins prepared for the different important agricultural regions in the United States. Some of the most fundamental features of everyday farming have been almost entirely ignored. . . .

It is obvious that in the near future the farmers are going to do coöperatively a number of things which to-day are done for them by the business men of the towns. The movement in this direction is inevitable and irresistible. It is every day gaining in momentum. The wise business man will recognize this fact and trim his sails accordingly. If he is engaged in an elevator business or a creamery business, and it becomes apparent that the farmers of the neighborhood are about to assume that function of the community, he will do well to say frankly to them: "If you think you can handle this business better and more economically than I can, I will sell it to you in a friendly way. There are plenty of other places where I can utilize my capital and trained business ability advantageously." That will be good business, for it is folly to fight the inevitable.

If the business men will take this attitude, they and the farmers will prosper in the future as neither of them has prospered in the past, and the entire nation will prosper with them. I have spoken to bodies of business men in a number of our States, and I find that more and more this reasonable and sympathetic spirit is gaining headway among them. They recognize that if the American people pull together, there will be prosperity enough to go around; but that if we squabble and squirm, each one striving for a mean personal advantage at the expense of his fellows and the community in general, there will be very little real and abiding prosperity for anybody.

There has been circulated a deal of eloquent misinformation as to the supposed *identity* of interest between various commercial and industrial groups—between the farmer and the railroads, for example, or the farmer and the banks, the stockyards and various other corporate interests with which of necessity he must do business. That there is a *community* of interest between the farmer and these interests does not admit of a doubt, but that there is an *identity* of interest does not follow. After the farmer, the railroad, the bank, the commission man, the storekeeper, have worked together for their common advantage as far as they know how in the light of the old ideals, there is still left a twilight zone of opportunity where some men by stealth or craft can still profit at the expense of others. It is this commercial war zone that the spirit of coöperation is gradually encroaching upon.

The supposition that natural economic law will prevent all illegitimate profits is one of the strangest delusions ever harbored in the minds of intelligent men. Despite economic laws, reinforced by man-made laws, the cunning and unscrupulous sometimes gain larger profits than do men who conduct their business in a strictly legitimate way. If a man's controlling ambition in life is to pile up unearned millions regardless alike of private rights and public welfare, one could not truthfully tell him that the quickest way to the realization of this sordid dream always lies along the paths of legitimate business enterprise. We may as well recognize frankly and fully the wide gulf that yawns between men who are trying to earn money and men who are trying by hook or crook to possess themselves of money that other men have earned.

The paramount issue before the American people to-day is not the tariff or corporation control or any of those other political or economic problems which newspapers and politicians discuss glibly; the real issue is not political or even economic. It is moral.

Is the individual citizen willing to produce all the wealth he acquires and to work and vote to render it impossible henceforth for any one, by any financial hocus-pocus, to acquire wealth that others have produced? That's the issue. . . .

Regulated competition is unquestionably better than irresponsible and uncontrolled competition. Moreover, by the slow, sure means of experience, Federal and state control of business is becoming at once more elastic and more effective. But no perfecting of the mechanism of such control can ever overcome the inherent limitations of this method of promoting social and economic justice. To realize the higher possibilities of civilization fuller recourse must be had to the principle of coöperation.

As far back as history goes we find civilization developing as fast as and no faster than men have developed the capacity to work together with their fellow-men to a common end. The day of hybrid, involuntary coöperation by means of slavery, serfdom, or economic exploitation is past. As President Wilson has indicated, the time is ripe for a coöperation that is not exclusive or oppressive, but rather inclusive and beneficent, founded on the principle of the open door, and dispensing its profits among all who participate in its activities according to the measure of such participation.

Manifestly, one of the best ways to develop this spirit of coöperation during our present transition period is for the business man and the farmer to get together in spirit and in purpose, to forget old antagonisms, and, as far as possible, to infuse into the present era something of the creative, beneficent spirit of the future. Thus the business man who is on the square and anxious for better things should not only refuse to make common cause with business men who stand for the ethics of the jungle, but should line up actively with like-minded men among all classes of his fellow-citizens in an endeavor to bring about a general realization of the fact that our maximum of national efficiency and prosperity can come only when every citizen, business man as well as farmer or wage-earner, is able to feel that his success will be in proportion not to his craft and Machiavellian ability to outwit and spoil his fellow-men, but rather in proportion to the intelligence, determination, and industry that he puts into productive work.

IV

CLIMAX: SUNNY PROGRESSIVISM AND THE SHADOW OF WAR

Doubtless the rise of science put much of the concept of "progress" into the progressive faith. Theodore Roosevelt was the first president after John Quincy Adams to show overt personal enthusiasm for science. The conservationists of the early 1900's saw science as a substitute for power politics, a means of determining the public interest in a truer sense than the balancing of rival interests. Yet if science meant progress, it also meant national power. The application of science to industry and agriculture meant that it was becoming an essential factor in the strength of the nation. Germany, which had led the way in the application of science to industry and had been the admiration and model of scientifically ambitious Americans for half a century, now emerged as a threat to the balance of power among nations partly because of her industrial pre-eminence. When the British blockade cut off supplies of German optical glass and German dyes, the products which depended on German industrial research, Americans awakened to the importance of their research establishment with a sense of shock. When Germany became the enemy in 1917, Americans found themselves in a war of science as well as a war of industry. The thoughtful statesman of 1918 could share with the progressive of 1900 a feeling for the importance of science, but he could less easily share the innocent belief in progress.

Had the application of science to practical life revolutionized American life by 1918 or had the United States retained its colonial backwardness in organizing its scientific brainpower? Had Americans mastered the art of organized innovation which could break the conservative hold of tradition in technology which had reigned through most of history? Had American democracy provided in its own fashion the institutions necessary to couple science and technology? Or was democracy at a fatal disadvantage when pitted against an autocracy which could pour resources into science without consulting an electorate ignorant of the practical potentialities in the life of the mind? Clearly, two lines of answers can be developed for each of these questions depending on your point of view. Americans in 1918 were puzzling over these issues as had the generation of John Quincy Adams a century before or as men now do.

A.

THE PROGRESSIVE'S CREDO—W J McGEE

[W J McGee shared with Gifford Pinchot a prominent place in the conservation movement during the administration of Theodore Roosevelt. In addition, he was for many years head of the Bureau of American Ethnology in the Smithsonian Institution. In the selection that follows he engages in a favorite end-of-the-century sport: measuring fifty years of scientific progress and incidentally revealing his faith in the all-pervading beneficent influence of science. Remember the distinction between science and technology and see if McGee is able to gain an advantage in his argument by ignoring it. (W J McGee, "Fifty Years of American Science," *Atlantic Monthly*, LXXXII [1898], 307–20.)]

Scientific progress, especially in a land of free institutions, is so closely interwoven with industrial and social progress that the advance of one cannot be traced without constant reference to the other. Indeed, the statement of our national progress during the past half-century is little more than a summary of results and practical applications of scientific research. Fifty years ago our population was hardly more than twenty millions, now it is seventy millions; then our wealth was less than seven billion dollars, now it is eighty billions. At the beginning of the year 1848 there were fifty-two hundred and five miles of railway in the United States, now there are two hundred thousand,—far more than any other country has, more than all Europe; nearly as many miles, indeed, as all the rest of the world put together. Some of those who attended the first meeting of the [American] Association [for the Advancement of Science] made their journey, or part of it, by stagecoach or in the saddle. They met many a boy riding to the neighborhood mill with a bag of corn as grist and saddle, and the itinerant doctor or minister on horseback, with his wife on a pillion behind; they passed by farmers swinging the back-breaking cradle or wielding the tedious hoe, while lusty horses grew fat in idleness; they caught glimpses of housewives spinning and dyeing and weaving with infinite pains the fabrics required to clothe their families; they followed trails so rough that the transportation of produce to market multiplied its cost, and carrying back family supplies was a burden: everywhere they saw hard human toil, enlivened only by the cheer of political freedom, and they did not even dream of devices whereby nature should be made to furnish the means for her own subjugation. Most of the mails were carried slowly by coaches and postboys; the telegraph was little more than a toy; the telephone, the trolley-car, and the typewriter had not begun to shorten time and lengthen life; and steel was regularly imported from Sheffield, and iron from Norway. The slow and uncertain commerce of interior navigation was the pride of publicists, and Chicago boasted a population of twenty-five thousand; a shallow wave of settlement was flowing over the vast interior to break against the bluffs of the Missouri, though the pioneers still feared to pitch tents on the broad prairielands, and chose rather the rugged and rocky woodlands skirting the waterways as sites for homesteads; the fertile subhumid plains, with ten million buffalo feeding on their nutritious grasses, were still mapped as "the great American desert;" the Rocky Mountain region beyond was a mystical land, yielding the wildest and weirdest of travelers' tales; California was an Ultima Thule more remote in thought and interest than are Hawaii or even the Philippines to-day. . . .

The progress of the nation during the half-century is beyond parallel. By normal growth and peaceful absorption without foreign conquest the population has trebled, and the national wealth has increased tenfold. The subjugation of natural forces has proceeded at a higher rate, and the extension of knowledge and the diffusion of intelligence have gone forward more rapidly still. This advance, so great as to be grasped by few minds, is the marvel of human history. The world has moved forward as it never did before. Yet fully half of the progress of the world, during the last fifty years, has been wrought through the unprecedented energy of American enterprise and genius, guided by American science. . . .

The genius of American astronomers has brought appreciation from laymen as well as investigators, and their labors have been rewarded by increased facilities; America is better endowed today with observatories and apparatus than any other country,—nearly as well as all the rest of the world. Most of our rapidly growing universities have their own observatories. A dozen years ago the installation of Lick Observatory was an event in the scientific world, and attracted such public attention as to leave little for the two observatories installed within the year,—Flower Observatory in Pennsylvania, and Yerkes Observatory, an adjunct of the University of Chicago. Fifty years ago astronomy was a sober and sluggish science, far removed from practical every-day interests, cultivated respectably in Europe and beginning to attract serious attention in this country. To-day its data are doubled and its activity is tripled; it touches industry and the public welfare at many points, and advances more rapidly than ever before; and a full share of this progress is due to American genius and industry. . . .

The formula of physical science came to America as a mariner's compass to a crew of maroons. Already a nation of inventors inspired by intellectual freedom, Americans were still blind leaders of the blind; for invention is impossible without at least intuitive recognition of the uniformity of nature, while without conscious recognition of this law the inventor drifts in a sea of uncertainties, making port only by chance. The newly formulated doctrine was seized and assimilated with such avidity that within a decade it was more generally understood and adopted in this country than in all Europe. Under its stimulus invention throve and manufacturing grew apace: the crude reaper was made a self-raker, next a harvester or header, then a self-binder or field-thresher, according to local needs; the hoe gave way to the horse-cultivator, and the flail to the horse-power thresher, the neighborhood water-mill to the steam-driven roller-mill grinding for all the people of a whole state; and the farmer learned to live by the strength of his beasts and the craft of his machines merely guided by his own intelligence. The mechanic arts were regenerated; steam was harnessed more effectively than before, and our railway-making and locomotive-building became and remains a revelation to the world; for within this year, 1898, European engineers have been compelled to swallow incredulity as to the rapidity of American bridge-building, while British promoters hastening to supply Egypt with locomotives have saved half the time required for delivery, despite the doubling of distance, by ordering from American builders. The tide of foreign importation was soon stayed, and then turned, and now American steel tools are sold in Sheffield and fine American hardware in Norway, while products of American machines in the form of foodstuffs and fabrics are carried into every quarter of the globe. The characteristic of American inventiveness is its diffusion. Invention is as free as the franchise, and open competition gives life to genius no less than to trade. American devices (temporarily protected by patents) are so diffused that every citizen is in contact with the products of physical science and mechanical skill: everybody may have a machine-made watch better than the average hand-made product of Geneva, nearly equal to the tested Swiss chronometer; every family may have its sewing-machine and telephone; and every man, woman, and child wears machine-made buttons, pins, hats, and textile fabrics.

A typical American device is the bicycle. Invented in France, it long remained a toy or a vain luxury. Redevised in this country, it inspired inventors and captivated manufacturers, and native genius made it a practical machine for the multitude; now its users number millions, and it is sold in every country. Typical, too, is the bicycle in its effect on national character. It first aroused invention, next stimulated commerce, and then developed individuality, judgment, and prompt decision on the part of its users more rapidly and completely than any other device; for although association with machines of any kind (absolutely straightforward and honest as they are all) develops character, the bicycle is the easy leader of other machines in shaping the mind of its rider, and transforming itself and its rider into a single thing. Better than other results is this: that the bicycle has broken the barrier of pernicious differentiation of the sexes and rent the bonds of fashion, and is daily impressing Spartan strength and grace, and more than Spartan intelligence, on the mothers of coming generations. So, weighed by its effect on body and mind as well as on material progress, this device must be classed as one of the world's great inventions.

With the advance of the half-century in simply applied mechanics, there have been still greater advances in the knowledge of the more obscure powers of nature, manifested in electricity and magnetism, in sun and wind and storm, even in vitality and mental action. Some of these have been made in Europe, but more in America. Fifty years ago Morse and Henry were doing the final work required to transform the electric telegraph from a physical experiment to a commercial agency, and soon nerves of steel and copper, throbbing with intelligence, were following the pioneer into the remotest recesses and pushing beneath the ocean; Faraday, the Siemens brothers, Helmholtz, and later Sir William Thomson (Lord Kelvin) freely gave genius and toil; then came Edison with an eruption of brilliant inventions; and to-day time and space are as if they were not, and from sea to sea our subjects of thought are as one. It was but yesterday that half our world knew not how the other half lived; now both halves read the same items at breakfast.

Themselves harvesters after the experimentalists in physics, the early telegraphers were planters for Graham Bell, and the telephone came to carry the word of man afar, and the graphophone to perpetuate it forever, and thus to complete the annihilation of space and time as obstacles to the diffusion and unification of intelligence. Inspired by success in conveying thought, inventors sought to convey grosser powers, and dynamos were invented to furnish light better and cheaper than the world had known before; devices for warming and even for cooking, and for lowering temperature by fans and refrigerant pipes, quickly followed; and now the lightning is harnessed in our houses as the thunder is subdued in telephone and graphophone. Meantime, motors and transmitters were perfected, and electric transportation came into successful competition with steam locomotion, while the power derived from waterfalls and central plants was made divisible, so that units of power are now sold as freely as pounds of tea or sugar were fifty years ago: and a way has been found to counteract the concentration of artisans in factories located by waterfall or engine. The conquest of nature by electric power, gained through controlling an infinitesimal part of the vibrant atomic energy of our corner of the cosmos, has come rapidly, and so steadily as almost to escape notice; yet it is a marvel beside which the magical lamp of Aladdin and all other figments of Oriental fancy are as nothing. . . .

Such have been a few of the advances in science of the half-century; the discovery of the persistence of motion, the invention of spectroscopy, the control of electricity, the discovery of the periodic law, the recognition of evolution, and the culture classification of mankind may be considered the first half-dozen. If summed in a single term, the half-century's advance in science may be expressed as recognition of the uniformity and potentiality of nature; while the applications are invention on the practical side, and kinetic interpretation (or interpretation in terms of motion and sequence) on the philosophic side. Most of the advances began in Europe, to be hastened in America, and a full half of the progress must be credited to cisatlantic genius and enterprise.

In truth, America has become a nation of science. There is no industry, from agriculture to architecture, that is not shaped by research and its results; there is not one of our fifteen millions of families that does not enjoy the benefits of scientific advancement; there is no law in our statutes, no motive in our conduct, that has not been made juster by the straightforward and unselfish habit of thought fostered by scientific methods. A nation of free minds will not be selfish or cruel; and the sense of uniformity in nature finds expression in national character,—in commercial honesty, in personal probity, in unparalleled patriotism, as well as in the unequaled workmanship which is the simplest expression of straight thinking. Every step in our national progress has been guided by the steadfast knowledge born of assimilated experience. The trebling of population in a half-century, raising the republic from an experiment in state-making to a leading place among the nations, is the wonder of history; the thrice-trebled wealth and educational facilities gained through application of new knowledge are a marvel, before which most men stand dazzled at home, and wholly blinded abroad; the three times thrice-trebled knowledge itself, hitting the nation high in enlightenment and making way for still more rapid progress, is a modern miracle wrought by scientific work; but greatest of all in present potency and future promise is the elevation of moral character attained by that sense of right thinking which flows only from consciously assimilated experience,—and this is the essence of science now diffused among our people.

B.

A STATESMAN'S FOREBODING—ELIHU ROOT

[Elihu Root had served under Theodore Roosevelt as Secretary of State and Secretary of War. Better than most Americans he knew the ingredients of national power, and better than most politicians and diplomats he had an awareness of the nature of science. Root delivered this statement on May 29, 1918, just as the war effort was reaching its climax. Does he view Germany's use of science in the same way as Whitehead did in the first selection? (Elihu Root, "Industrial Research and National Welfare," *Science*, N.S. XLVIII [1918], 532–34.)]

I HAVE no justification for expressing views about scientific and industrial research except the sympathetic interest of an observer for many years at rather close range. One looking on comes to realize two things. One is the conquest of practical life by science; there seems to be no department of human activity in which the rule of thumb man has not come to realize that science which he formerly despised is useful beyond the scope of his own individual experience. The other is that science like charity should begin at home, and has done so very imperfectly. Science has been arranging, classifying, methodizing, simplifying everything except itself. It has made possible the tremendous modern development of the power of organization which has so multiplied the effective power of human effort so as to make the differences from the past seem to be of kind rather than of degree. It has organized itself very imperfectly. Scientific men are only recently realizing that the principles which apply to success on a large scale in transportation and manufacture and general staff work apply to them; that the difference between a mob and an army does not depend upon occupation or purpose but upon human nature; that the effective power of a great number of scientific men may be increased by organization just as the effective power of a great number of laborers may be increased by military discipline.

This attitude follows naturally from the demand of true scientific work for individual concentration and isolation. The sequence, however, is not necessary or laudable. Your isolated and concentrated scientist must know what has gone before, or he will waste his life in doing what has already been done, or in repeating past failures. He must know something about what his contemporaries are trying to do, or he will waste his life in duplicating effort. The history of science is so vast and contemporary effort is so active that if he undertakes to acquire this knowledge by himself alone his life is largely wasted in doing that his initiative and creative power are gone before he is ready to use them. Occasionally a man appears who has the instinct to reject the negligible. A very great mind goes directly to the decisive fact, the determining symptom, and can afford not to burden itself with a great mass of unimportant facts; but there are few such minds even among those capable of real scientific work. All other minds need to be guided away from the useless and towards the useful. That can be done only by the application of scientific method to science itself through the purely scientific process of organizing effort. It is a wearisome thing to think of the millions of facts that are being laboriously collected to no purpose whatever, and the thousands of tons of printed matter stored in basements never to be read—all the product of unorganized and undirected scientific spirit. . . . The solitary scientist . . . needs chart and compass, suggestion, direction, and the external stimulus which comes from a consciousness that his work is part of great things that are being done.

This relation of the scientific worker to scientific work as a whole can be furnished only by organization. It is a very interesting circumstance that while the long history of science exhibits a continual protest against limitations upon individual freedom, the impulse which has called in the power of organization to multiply the effectiveness of scientific and industrial research to the highest degree is the German desire for military world dominion, supported by a system of education strictly controlled by government. All the world realizes now the immense value in preparing for the present war, of the German system of research applied at Charlottenburg and Grosslichterfelde. That realization is plainly giving a tremendous impetus to movements for effective organization of scientific power both in England and in the United States,—countries whose whole development has rested upon individual enterprise. It remains to be seen whether peoples thoroughly imbued with the ideas and accustomed to the traditions of separate private initiative are capable of organizing scientific research for practical ends as effectively as an autocratic government giving direction to a docile and submissive people. I have no doubt about it myself, and I think the process has been well begun in England under the Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research, and in the United States under the National Research Council. I venture to say two things about it. One is that the work can not be done by men who make it an incident to other occupations. It can be encouraged of course by men who are doing other things, but the real work of organization and research must be done by men who make it the whole business of their lives. It can not be successful if parcelled out among a lot of universities and colleges to be done by teachers however eminent and students however zealous in their leisure hours. The other thing is that while the solution of specific industrial problems and the attainment of specific industrial objects will be of immense value, the whole system will dry up and fail unless research in pure science be included with its scope. That is the source and the chief source of the vision which incidentally solves the practical problems.

We are thinking now mainly of science as applied to war; but practically the entire industrial force of mankind is being applied to war, so that our special point of view takes in the whole field. It is quite certain that if the nations on either side in this war had been without a great fund of scientific knowledge which they could direct towards the accomplishment of specific things in the way of attack and defense, transportation and supply of armies, that side in the war would long since have been defeated. Germany had the advantage at the start, because she had long been consciously making this kind of preparation with a settled purpose to bring on the war when she was ready. It would be the height of folly for the peaceable law-abiding nations of the earth ever to permit themselves to be left again at a disadvantage in that kind of preparation. Competency for defense against military aggression requires highly developed organized scientific preparation. Without it, the most civilized nation will be as helpless as the Aztecs were against Cortez.

We are not limited, however, to a military objective, for when the war is over the international competitions of peace will be resumed. No treaties or leagues will prevent that, and it is not desirable that they should, for no nation can afford to be without the stimulus of competition.

In that race the same power of science which has so amazingly increased the productive capacity of mankind during the past century will be applied again, and the prizes of industrial and commercial leadership will fall to the nation which organizes its scientific forces most effectively.

FOR FURTHER READING

A history of industrial research in the United States is nonexistent. The only account worth consulting which deals directly with it is the relatively brief Howard R. Bartlett, "The Development of Industrial Research in the United States," *Research—A National Resource: II—Industrial Research*, Report of the National Research Council to the National Resources Planning Board (Washington: Government Printing Office, 1941), pp. 19–77. A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge: Harvard Univ. Press, 1957) gives a connected analysis of those phases which touch the Federal government. Three volumes of economic history—Fred A. Shannon, *The Farmer's Last Frontier: 1860–1897* (New York: Farrar, 1945); E. C. Kirkland, *Industry Comes of Age: Business, Labor* *and Public Policy, 1860–1897* (New York: Holt, 1961); and H. U. Faulkner, *The Decline of Laissez Faire, 1879–1917* (New York: Rinehart, 1951)—pay some passing attention to research and provide copious general background.

Special studies of high quality exist only for the electrical industry. Harold C. Passer, *The Electrical Manufacturers 1875–1900: A Study in Competition, Entrepreneurship, Technical Change, and Economic Growth* (Cambridge: Harvard Univ. Press, 1953) is a model study. Kendall Birr, *Pioneering in Industrial Research: The Story of the General Electric Research Laboratory* (Washington: Public Affairs Press, 1957) is a good study of an important laboratory. Matthew Josephson, *Edison* (New York: McGraw, 1959) stands by itself as a biography, not only of Edison, but of any figure in the history of technology of the period.

The Berkeley Series in American History

Sigmund Diamond, THE CREATION OF SOCIETY IN THE NEW WORLD

Robert Middlekauff, BACON'S REBELLION

Wilbur R. Jacobs, THE PAXTON RIOTS AND THE FRONTIER THEORY

Jackson T. Main, REBEL VERSUS TORY: THE CRISES OF THE REVOLUTION, 1773–1776

David Levin, THE PURITAN IN THE ENLIGHTENMENT: FRANKLIN AND EDWARDS

Adrienne Koch, ADAMS AND JEFFERSON: "POSTERITY MUST JUDGE"

Alfred Young, THE DEBATE OVER THE CONSTITUTION, 1787–1789

Charles Sellers, ANDREW JACKSON, NULLIFICATION, AND THE STATE-RIGHTS TRADITION

Frank O. Gatell, THE JACKSONIANS AND THE MONEY POWER, 1829-1840

Bernard A. Weisberger, ABOLITIONISM: DISRUPTER OF THE DEMOCRATIC SYSTEM OR AGENT OF PROGRESS?

Armin Rappaport, THE WAR WITH MEXICO: WHY DID IT HAPPEN?

P. J. Staudenraus, THE SECESSION CRISIS, 1860–1861

Grady McWhiney, RECONSTRUCTION AND THE FREEDMEN

Ari Hoogenboom, SPOILSMEN AND REFORMERS

A. Hunter Dupree, SCIENCE AND THE EMERGENCE OF MODERN AMERICA, 1865–1916

Irwin Unger, POPULISM: NOSTALGIC OR PROGRESSIVE?

Richard Abrams, THE ISSUE OF FEDERAL REGULATION IN THE PROGRESSIVE ERA

Ernest R. May, THE COMING OF WAR, 1917

Henry May, THE DISCONTENT OF THE INTELLECTUALS: A PROBLEM OF THE TWENTIES

E. David Cronon, LABOR AND THE NEW DEAL

Paul Sothe Holbo, ISOLATIONISM AND INTERVENTIONISM, 1932–1941

Cushing Strout, CONSCIENCE, SCIENCE, AND SECURITY: THE CASE OF DR. J. ROBERT OPPENHEIMER

Richard Lowitt, THE TRUMAN-MACARTHUR CONTROVERSY

Hugh Ross, THE COLD WAR: CONTAINMENT AND ITS CRITICS

Charles Sellers and Henry May, A SYNOPSIS OF AMERICAN HISTORY

The Berkeley Series in American History