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U.S. Science and Technology in National Strategy

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U.S. SCIENCE AND TECHNOLOGY IN NATIONAL STRATEGY

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by

Mr. J. Carlton Ward, Jr.

May I say that I learned a new word last week at a high level conference at the Buffalo laboratories of Cornell University: 'frustraphy.' You will not find it in the dictionary. I came early this morning especially to hear your first lecture. The lecturer pulled the rug from right out under me on very important particulars, and I suddenly realized what 'frustraphy' really means. I have been assigned a very interesting subject here today and I would like to compliment the College this year on a new innovation for speakers, and that is to send to them the curriculum well in advance so that at least the speaker has some idea as to where he fits into the development of the subject. I want to assure you that to address a group of your high level of attainment is something not to be approached too easily or too idly. Therefore the better you can furnish your prospective speaker with the needs of the curriculum, I think the better the job he can do. So I want to pay this compliment to those who thought up this new approach.

As I have tried to do in the past, instead of offering mere opinions, or the conclusion from an opinion research, I would prefer to give you some so-called facts (notice I said 'so-called') from which you can form your own judgments and come to your own conclusions. Instead of accepting what may obviously leak between the lines as personal opinions (and let me point out that I shall probably fall into the trap of expressing them), I want you to come to your own opinions. Therefore, I have more charts than perhaps I have time to properly show. The Admiral has been exceedingly helpful in telling me that I may run over into the question period, so we are not going to start with a number of very amusing stories except to say that when I heard his introduction it made me think of a recent one in which the chairman said, 'This gentleman needs no introduction; he needs a conclusion.'

Now the assigned title requires that we examine 'the role of the United States scientific community in the formulation of national strategy and in the expansion of national power.' I would like to restate it in the reverse, because I think it is then more logical: 'to examine the role of the United States scientific community in the expansion of national power and in the formulation of national strategy' because it would appear that strategy is the first derivative of power, and not power that of strategy. However, the assignment also goes on to state: 'Include an analysis of the impact of the vastly expanded governmental research programs on the scope and quality of basic research and technological advances.'

And so we are going to try to show the interaction between science, technology, and economics. Often these are treated as separate disciplines, and separate subjects. I like to think of all knowledge as being very much like an electromagnetic wave spectrum. We talk about visible light; we talk about infrared and heat; we talk about ultraviolet; we talk about ultrahigh radio frequency; and we talk about supersonic and hypersonic frequencies; and we talk about x-rays and cosmic radiation. But actually, in nature, all these are one continuous spectrum; and similarly it would seem that knowledge is a continuous spectrum. So, whereas it may be pointed out that the so-called social sciences are not really sciences, nevertheless we must deal with them, and therefore we will deal with them in the context of their relation to the sciences. This involves us, of course, in the problem of 'What is a science?'

In listening to your speaker this morning, it appeared that he was well aware, and quite careful to point out, that science and technology are two different things. He didn't so state it, but you could infer this from the way he handled some of his subjects. As we must deal with them here, they are completely different things. 'Completely,' of course, may not be fair, but this was said to shock you so that you will view them separately. Now let us see why.

Science has been defined many times by many people. For us today, I want to merely put this sort of label on it--that science is 'that human occupation devoted to expanding our knowledge of the world, our universe (of which we are a part), its forces, its materials, its properties, and its dynamism.' In other words, science is dedicated to creating new knowledge. Let us not say for what purpose, because the true scientist is not primarily concerned with this. He's primarily interested in new knowledge. He would just as soon work on the most ridiculous sort of problem, from your and my point of view as practical people, as he would the most practical mundane thing. I like to think of the Bernoulli brothers. There were six of them, all mathematicians, and they each lived in hope that they would create a mathematical abstraction or principle that had no application. Five of them died bitterly disappointed because somebody subsequently put to good use everything they had produced. The sixth one, it is said, died happy. He produced a principle he thought was thoroughly useless—no one would ever find a use for it. What do you think it is? It's the theory of the solution of simultaneous equations, now the basis of so much of our advanced mathematics in daily use all over the world. Such as these are true scientists. They are interested in new knowledge.

Now, let's take the technologists; these will be the engineers. We also have in use a similar term, namely 'technician,' for a little lower order of professionalism, but let's talk now in terms of the engineers. The engineer is motivated completely differently than the scientist, and yet he is so often confused with him that you, who are in the great defense organization, frequently use them interchangeably and thus in the wrong roles. It should be pointed out that, to do so, can at times lead to disastrous results. The engineer has a task to perform that a scientist is not trained to deal with—to make intuitive judgments, judgments which cannot be verified by experiment but which involve a certain degree of intuition in forecasting. Let us take a simple example. An engineer must build a bridge. Now he may draw on the mathematics of stress and strain and the properties of material, all developed by scientific research. Well and good. But what does he build a bridge for? He builds it for the use of man, and furthermore he has to build it to a financing scheme that may have an amortization of, say, fifty years or so. This means that the bridge has got to be useful for fifty years, which then means that he's got to know who's going over it fifty years from now. What size vehicles? What axle loads? What traffic density? He needs to be a demographer; he needs to be a practitioner of all sorts of crafts that fall into the social studies category in order to apply his scientific knowledge of how the bridge should be built. No matter how precisely he figures his structural members, or how precisely he designs it, it still will be an unsatisfactory bridge if it doesn't fulfill a useful human function over a considerable period of time.

As soon as you bring man into any precise mathematical equation, you knock out its validity because there is no such thing as the average man, even though the social study people use such terms. How about a constant dollar? Never had one. An average man? I never met him. These are merely statistical concepts.

It was said by a great educator who served in Washington during the war that every office in Washington had its economist, and that they called themselves social scientists. Lord Kelvin said, 'It isn't scientific if you can't measure it.' So, of course, the economists try to measure. We have such fantasies as the Gross National Product expressed precisely! How many of you know that your wife's effort is in that figure at an assumed value in terms of dollars of production? I don't know how many cakes she bakes or how many diapers she changes or how many times she sweeps the rugs—that is exactly what this is intended to represent—or whether she is a social bridge type! But she's in there. And likewise, I want to warn you that the exhibits that I am going to show you today are statistical exhibits, so pardon me if I take a few liberties with my own exhibits by telling you that a statistician has been defined as a man who draws a straight line from an unwarranted assumption to a foregone conclusion.

You all know the famous story of the statistician who lived on one side of a river and wanted to cross it. He reviewed his data and he found out that the average depth of the river was 4.1 feet. There being no bridge, he decided to walk across, and drowned. Now, please, have these thoughts in mind when you see the following exhibits. And also have in mind that the engineer is a different breed of cat from the scientist. If only students knew this when they went to college they wouldn't make this frightful mistake that so many are making here in the United States because, very often, the secondary school advisors cannot tell them the difference. 'Oh,' they say; 'you want to be a scientist?' The boy actually may not know what a scientist is or does. He merely knows that he reads in the newspaper that the last satellite that went up was a great scientific development. Now if I may be slightly profane, I am going to say, 'Like hell it was!' As a structure and part of a system, it was an *engineering* development. The scientists, yes, did provide the knowledge necessary for its design and purpose. They did the work on the Van Allen belt; they did the work on the physics of space, mathematical models of trajectories, etc., etc. These are examples of *scientific* accomplishments. But the fellow who made the structure that was to be projected out there, and had to stand up under stress, and then make a reentry through the atmosphere, was not a scientist; he was an engineer. Let us not confuse these two. The poor guy who reads so much of the current literature, such as 'This is a great example of modern science,' goes to college to be a scientist, and what does he find? A curriculum that will cram math down his throat, physics down his throat, chemistry down his throat, maybe biology, too; and he is perhaps waiting to get to something that arouses his vital interest if he is an engineering-minded kind of a boy. He becomes frustrated. Similarly, perhaps a boy goes into engineering. He goes into it sometimes thinking it's like science, and finds it's not to his taste. This is where we have a lot of waste human products in our educational system, which was so deftly touched upon by the previous speaker. Enough, then, as to the difference between these two professions, except to say that I hope that throughout your military experience you do not rely upon one to do the job that the other is educated to do. Together they constitute an invaluable and inseparable team.

For brevity, we are not going to touch on the division between basic research, applied research, development, evaluation, and finally reduction to practice. These are five convenient labels to put on the separate steps of the overall process of, for example, weapon systems development. Before a weapon gets into the pipelines as a practical performing article for you gentlemen to nse, it has to go through those five stages. The scientists should not be responsible for all those stages, nor should the engineer. And likewise you shouldn't expect the engineer to have the training or the capability to develop the new knowledge of applied science on which this weapon system may have to be based.

I would now like to talk a little bit, as a point of departure, about the role of science and technology in history. It is very unfortunate, as I see it, that history has been taught by historians who were insensitive to their predominant roles. Often they have essentially been men educated in literature and political studies, and they have produced extraordinary histories about people who ruled countries and about social phenomena. What, in general, they didn't reveal was how those countries became great. It was often assumed that the king played almost the sole role in producing these historical developments.

So now, as a very quick and dirty piece of history by a nonhistorian, let us start with Greece and Rome. Some time ago, I was asked to give a talk in a leading prep school where the boys had become pessimistic about their future, largely because they had read and heard so much about the atomic bomb and its assumed power to destroy all mankind. They thought none of them had very long to live; therefore, what was the point of studying? The morale of the school was low, and bear in mind that this was one of the most famous schools in America. By way of preparation, I learned that the students had been taught to look upon ancient Greece as the Golden Age of man and, furthermore, were told that we had been retrogressing since then. So I went up to demolish ancient Greece in terms of mankind's present and future!

Let it be said, first of all, that every single civilization, in the modern sense of the term, is founded upon physical energy and its skilled employment for man's use. Your speaker this morning touched upon this to some extent. Energy, when employed, produces services and goods; services and goods are the measure of economic strength. Economic strength is, of course, the principal basis for national power. Now let's see what this did in our selected example from history. Greece produced the greatest literature of its time; some have said, of all time. Greece produced some tremendous statuary, built some rather handsome buildings, codified a lot of information. Euclid's geometry is a good example. He didn't originate it; he didn't invent it. He took it from the Egyptians, who had to devise it because they had to survey the land each time the Nile flood waters receded. If the Egyptians hadn't invented geometry and surveying--which they did because they had to--no one would have known who owned the lands when the waters receded. And so Euclid studied Abyssinian literature and Egyptian literature, etc., and from such sources he produced the geometry you and I studied. Now don't misunderstand me. This was a great work. Greece created a tremendous body of literature and art, and did some great things in philosophical thinking. Certainly we cannot shrug off Archimedes and his mechanical principles for the screw, the wedge, the lever, etc. Why, Democritus even conceived of the atom in the 4th century B.C.! But, gentlemen, why, if this nation had such a superior culture and high level of education, did Greece not become a great, lasting world power? Why did it go down the drain? As a point to keep in mind, it should be noted that its economy was based upon human slavery.

Now let's turn to Rome. Rome had a very plebeian group of writers, thinkers, sculptors, etc., in comparison with what Greek civilization had produced. Yet Rome lasted nearly one thousand years as the world's greatest power. At one time she claimed domination of the larger part of the so-called civilized world, although this was perhaps an exaggeration because the Chinese claimed to have been civilized when the Romans were barbarians, and I guess they perhaps were. We will come to China later. Now, the Romans learned how to build roads and to develop communications. The Romans invented the arch, and thus improved structures. No longer did they have to build their temples with flat stones like the Greeks. They were excellent engineers. They developed administration. Our law stems from Roman law. How many of you recall that the Roman aqueducts, which were a remarkable piece of engineering work, were in part responsible for the Romans solving urban living? No city in ancient times ever grew larger than about a quarter of a million people because it died off through plagues, epidemics, and inability to service it with food and utilities; but the Romans built an ancient Rome of over a million people. The Greeks could not. Two hundred and fifty thousand people was the maximum size of Athens in ancient times. Rome grew to over a million people and they did it by essentially the same good civil engineering which we use today. The Roman water system was outstanding. Water was brought over the hills and valleys, using a knowledge of hydraulics, then they distributed it around the city through lead pipes. They applied metallurgy to make the lead pipes. They learned where and how to mine the ore, and how to smelt the lead and manufacture the pipes. Every customer was billed monthly, just as you are for your electric light bill. He was billed on the basis of the hole in the lead pipe that led water into his particular household, and there was an inspector who went around looking at these every month to see that no one cheated. The Romans, furthermore, had all the protection, all the devices, of an orderly administration. They were practical economists and engineers, while the Greeks were not.

Let us turn again to Greece. You will remember that Greece's whole economy was based upon the use of the energy of slaves. Whenever Athens began to run downhill economically, perhaps partly because they were enlightened enough to allow slaves to become free men under certain conditions, they had to start a war to get more slaves, otherwise their whole economy continued to run downhill. Aristotle, perhaps their greatest philosopher, though a poor scientist, said with respect to science that it was a mental occupation. One shouldn't bother with experimental verification because that involved manual work, which was the work of slaves. His views have been said to have retarded science for fifteen hundred years. It was Galileo who had to break out of that philosophic straitjacket in the early 1500's.

To bring ourselves up to more modern times, let us look at England in the early 1700's when Newcomen, the engineer, developed the steam engine for pumping mine water from deep mines. This gave England ready access to coal; coal, in turn, gave them access to heat; heat gave them access to steam; engineering provided the engine, and then what happened? Out of that series of events, England went through an industrial revolution. This small country, which was said to be of approximately three million people at that time, built in a brief span of history an empire upon which the sun never set. They did it by producing more and better goods more cheaply than the rest of the world, and then exporting them. And, as you know, the flag and trade go hand in hand, and the first thing we knew we had 'Pax Britannia' for a hundred years throughout the civilized world.

If we think in terms of natural resources, did England have vast natural resources? She had some coal; she didn't have much iron, or large mineral deposits. In terms of the rest of the world, England was deficient in manpower. How then did she become so powerful?

In summary, it is reasonable to point out that the engineering and technological use of thermal energy, and the development of new machinery for its employment for the production of goods and services, under free enterprise incentives and proper civil laws, made England the great power that she became. In all fairness, it was not the kings, prime ministers, political theorists, or economists. They were the servants of these great forces created by natural science and harnessed by engineering and technology.

Now let us take another example from history of the role of science and technology--Germany. Here, as in England, was a country that saw clearly the role of science and technology. She, also, lacked great natural resources except coal, iron, and timber, and the German population represented only a small segment of the civilized world.

Germany, before World War I, moved into an existing vacuum, taking basic science from England and France in the field of chemistry, and constructing the great technology of synthetic chemistry. So, with a relative scarcity and paucity of resources, she was able to turn out vast quantities of goods on which the rest of the world relied. The Germans built up a strong economy; they built up a fantastically good chemical industry which is still good to this day; and they were able to threaten world peace.

They threatened the position of England; they threatened the whole world during World Wars I and II. Once more, applying the capability of their industries, and their scientific and technological competence, they devised weapon systems of such advanced character for their time that they threatened the whole civilized world, and precipitated what they thought would be a short war of victory creating for them the position of a leading world power.

On their own admission, they took advantage of our aviation developments. In the late 1930's, I remember a meeting in New York at which the NACA, then starved for funds, was having a kind of a celebration for the work that Dr. Lewis, the founder, had done. Germany was represented by the German director. At that time many of us thought that we were about to go to war with Germany and it seemed this was a very unusual thing for this man to come over and honor Dr. Lewis, his competitor. However, this great man said, with tears streaming, that nearly all that Germany had accomplished in aviation stemmed from the work of Dr. Lewis and his laboratory. The Germans took that knowledge, added tremendous research of their own, put it to work, and built up a strong aviation industry when ours was weak. And, in other fields of military science, you all know what they did with the Panzer divisions. There is no need to go into this further with a military audience. Science und technology, on which a strong economy had been built, enabled Germany to again threaten world peace. Yet, what were they in comparison with the rest of the world? Certainly a little bit of a country, in the terms which you heard this morning, an *insular country*. Even so, Germany came close to winning the war and attaining her objectives. She could also have had the atomic bomb if Hitler hadn't been the autocrat that he was. The Germans were the first to discover fission. They tried to build a bomb but Hitler turned the effort off and on as the German fortunes of war rose and fell. You can't do that with a scientific development.

Can we find some other examples? Yes, we can. Let us turn to the Orient. For example, there is China, an old civilization, a country which has hundreds of millions of people, with vast natural resources, while offshore lies a little island kingdom with only 15% of the land arable. Its population doesn't even approach a hundred million people, yet that little country of Japan, an island country like little England, became a major power and proceeded to threaten even the powerful United States and to dominate her whole hemisphere—China's six hundred million people, plus all the rest of the great Asiatic hemisphere. How? Was it due to the Mikado? Was it the Japanese Diet? No. Japan had embraced Western science and technology, which, coupled with a very industrious, hard-working people, enabled them to build up an economy with so much strength that it completely overpowered the giant slumbering China immersed in history, poetry, and philosophy.

These are the lessons of history. Leaders and governments can only exist and exert their independence in a competitive world when they can direct an economy made and kept strong by a progressive technology. The governments, as such, don't create power. Our Congress doesn't create our power; it *uses* it. No, countries do not become powerful through political sophistication, but through cleverly applied science and technology. The Russians discovered this in 1932 in the sense of doing something fundamental about it, and there will be some statistical exhibits for us to look at that should frighten us a bit.

We have talked about the difference between science and engineering. We have talked about the role of these factors in history, and now perhaps we should begin to study some of the statistical evidence.

Figure 1, following, is not a kindergarten exercise. It was taken from a DuPont publication and, in a fundamental sense, it represents much of what we are talking about. Let us look at the figure of the man in the picture. Look at the man in 1855, before the Civil War. He had to work very hard, his source of energy was his muscles, and he supplemented them with the power of the horse. There was also (the figures are all proportionate as to quantitative values) the New England water power mills, and the sign of the clock represents the time worked. This figure shows that the man had to work from sunrise to sundown, and he really worked! The symbol at the right represents the horn of plenty. We can take its size as representing the standard of living—the Gross National Product divided by the population of that time.

Now let us look at 1905, fifty years later. The automotive engine hadn't really come in yet in a general way. Dr. Diesel had just done his work, and there were a few very odd-looking vehicles running around on soft country roads, scaring chickens and horses, but not many. Man still had to do a lot of hard, manual work, and the horse was still the primary means of local

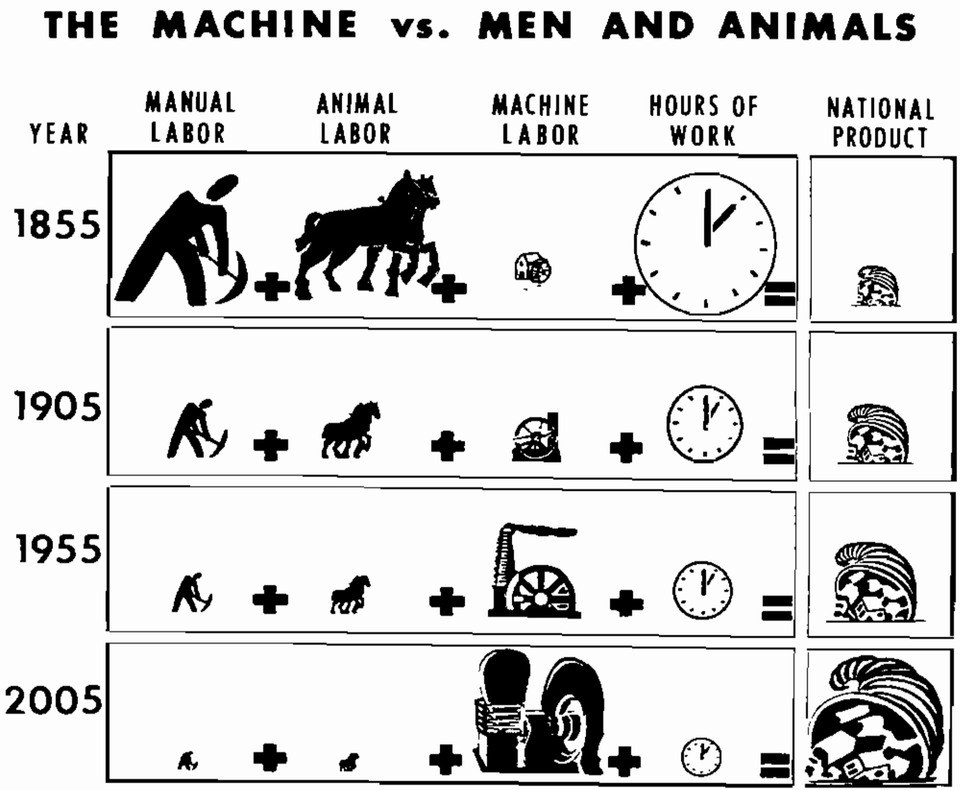

THE MACHINE vs. MEN AND ANIMALS
YEAR
MANUAL LABOR
ANIMAL LABOR
MACHINE LABOR
HOURS OF WORK
NATIONAL PRODUCT
1855
1905
1955
2005

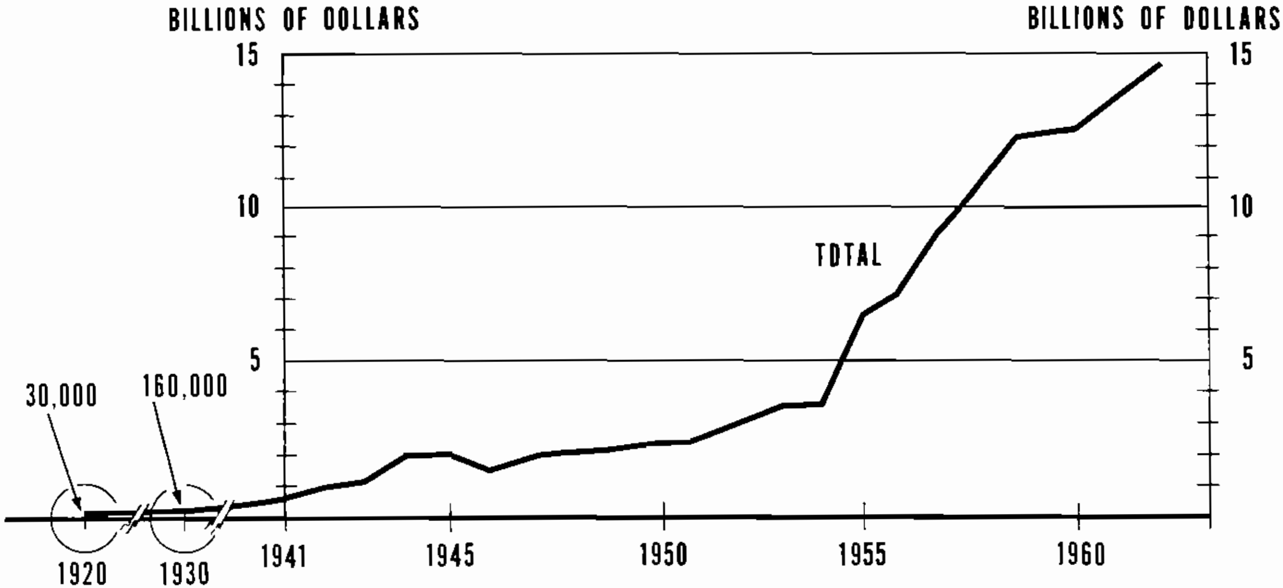
Figure 1

transportation, plowing, cultivation, running treadmills, and so forth. But we notice that the steam engine has come in. The steam engine supplanted the water wheel, and this additional source of energy is beginning to be important. The amount of energy available per man in 1905, as compared with 1855, is vastly enhanced. It follows, of course, that his workday has been shortened, and he only works twelve hours a day in that year. Notice what has happened to his standard of living. Now let us look at 1955; again fifty years have passed. Both man and the horse are getting to be only symbolic now, because the machine has taken over. Some very foolish writers, sociologists, and journalists, were writing books not too long ago proving that man was going to be the servant of machines. Hogwash! Because of the machine, the clock shows man's workday as averaging about eight hours. And look at the standard of living. Why man is doing wonderfully. Then DuPont polished up its crystal ball and looked at the year 2005. In that year, man is shaving with an electric razor; he's brushing his teeth with an electric toothbrush; he's shining his shoes with one of those new Christmas gadgets with an electric motor; he moves vertically and horizontally by automotive and electric power. He doesn't need to climb stairs; he goes up in an elevator; he does all kinds of things. But he doesn't use his muscles. The horse? You will find him only on the race tracks. The clock? Well, we all know about Walter Reuther and his six-hour day, not to mention labor's proposals for four-day weeks and mouthly vacations, plus 11 paid holidays. We don't know (I'm obviously not a sociologist) whether man can stand this prosperity. We could ask why does he still appear on the chart at all? Why hasn't he disappeared? This seems hard to figure out, but perhaps he still hasn't found out how to apply motor-driven zippers.

In Figure 2 we portray the growth of research in the United States, because research is the prime tool of science and engineering. Let us turn back to a period which I can remember clearly—World War I. We do uot find it on this chart. It has been said that the first true research laboratory in America was established in 1903. Before that we had the age of inventiou. After 1903, research ceased to be a oue-man effort aud became a team effort, brought about largely by the proliferation of science.

It isn't practical any longer to ask one man to invent a modern complex weapon system. We must put a team together, and this involves an added administration mechanism. This becomes an R&D team, from science to engineering.

GROWTH OF RESEARCH IN THE UNITED STATES



SOURCE: Industrial College of the Armed Forces

Figure 2

Prior to World War II, the chart doesn't look too impressive. But it was. When World War II was already beginning in Poland, the total research and development in the United States was approximately 300 million dollars, including all government bureaus (Agriculture, Bureau of Standards, NACA, etc.) and all of industry. In order to win the war, research increased to about a billion and seven or eight hundred million. While it doesn't look like much on this chart, it was a fantastic development, all in a period of four years. We survived because of it.

After the end of the war, it was 'Bring the boys home by Christmas,' and our winning team, including R&D, was largely demobilized. That's the way Congress and the public reacts. From roughly 1945 to 1952, there was no great increase, from the looks of the overall curve. During this period, nongovernment expenditures steadily increased, although the reverse was more nearly true for government expenditures. So the net was relatively a flat curve until the Korean War appeared. Then see what happened. We learned our need for continued R&D all over again. There are people who say that governments do not learn from their mistakes. I believe that they do, but they often learn the hard way. Let us observe the reaction to Korea. We suddenly and frantically begin to equip our troops with the things they need. We begin, again, to take research seriously, and to believe that Russia isn't a pal after all, and we might as well recognize it. R&D has never turned back since then. An interesting point is that, today, research totals over 15 billion per year, whereas at the beginning of World War II (which is not too long ago), it totaled 300 million.

This is a fantastic development, and more than merely a *symbol* of where we get our power in the world today. Research is the tool we must use to meet the rather dismal forecast for the future that you heard in this morning's early lecture.

In Figure 3 let us now observe the end result of R&D, in a specific instance over a period of time, and what its characteristics are. When Thomas Edison built his first electric station in 1882, in New York (the Edison Electric), it took nineteen pounds of coal to generate one unit of electricity, that is, a kilowatt hour. We see that by the year 1905, which was the year the Edison Electric Institute began to keep records, it was taking about six pounds. You can observe that this is a very orderly curve, and that by 1960 it was taking seven eighths of a pound of coal per kilowatt hour. It is startling to apply these figures in terms of our resources. Remember that if we had never learned anything beyond the initial technology

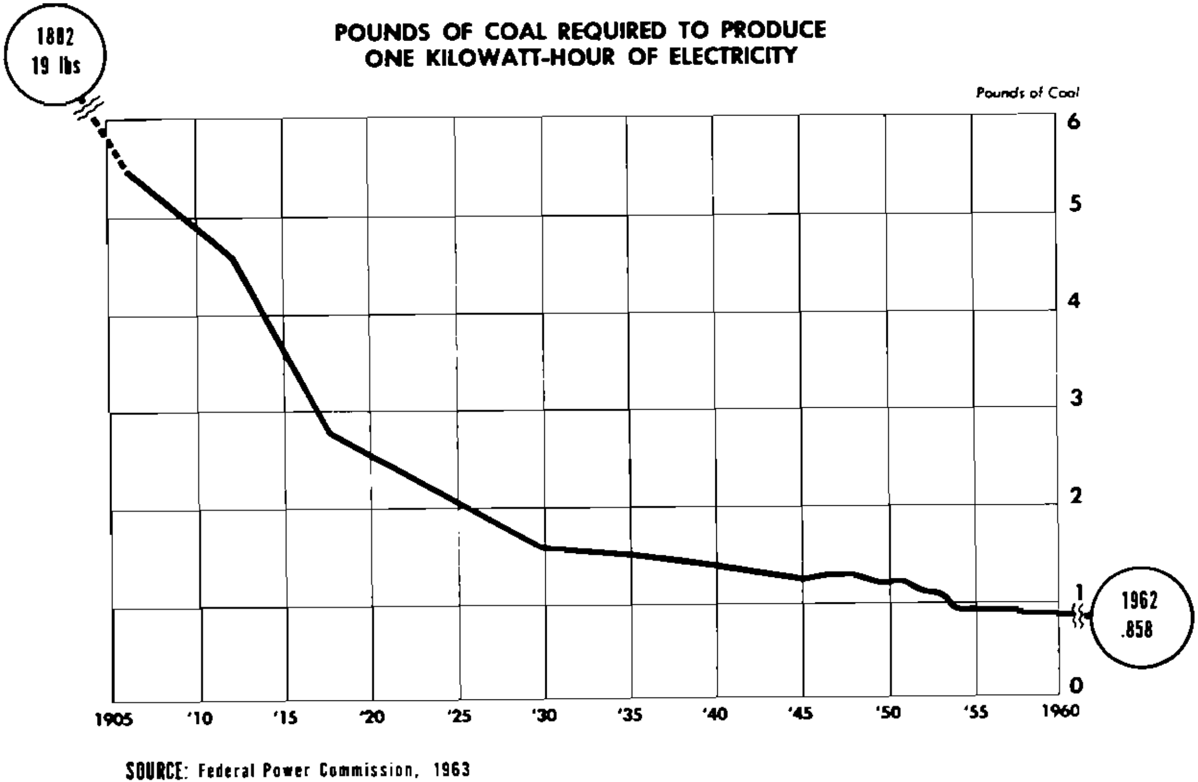

POUNDS OF COAL REQUIRED TO PRODUCE
ONE KILOWATT-HOUR OF ELECTRICITY
1882
19 lbs
Pounds of Coal
6
5
4
3
2
1
0
1962
.858
1905
'10
'15
'20
'25
'30
'35
'40
'45
'50
'55
1960
SOURCE: Federal Power Commission, 1963

Figure 3

of the first power station, which used nineteen pounds of coal per kilowatt hour, and we were *still* using nineteen pounds to generate a unit of power, our coal supply would look pretty sick in this country. Every time we increase efficiency, we multiply our resources accordingly. In 1963, steam power plants were being built that would only use two thirds of a pound of coal, and the drop from seven eights to two thirds is again tremendous, applied to our costs and our total fuel resources. The same thing applies to the world's oil, coal, and gas snpplies. We are observing the characteristics of continued research and development to show what would happen if we stop educating engineers and scientists. In this case, the particular emphasis is on engineers (this is an engineering curve), and if we fail to continue to advance, the conclusion is rather disastrous. Particularly, in this case since the world, including the United States, doubles its use of power every decade!

Figure 4 was done by a distinguished scientist. It has a very amusing aspect to it which we can later observe. In the 1830's, Faraday, working in his Cambridge laboratory, discovered the principle of electromagnetic reaction (today we would say the principles behind motors and dynamos). It wasn't until 1882, when Thomas Edison built his power station, that anybody employed it. In other words, it took nearly fifty years, from the time of the scientific discovery to the time of its commercial application.

Let's turn to radar. Nikola Tesla, a man of nnnsual capability, forecast radar in 1905. He didn't discover it, but the naval scientists down at Anacostia around 1922 discovered it; they measured it; then they asked for 15 thousand dollars from the Navy Department to exploit their discovery and were told there were no funds. Think of it—15 thonsand dollars! So, iu 1922, the knowledge appeared scientifically, but it wasn't applied until the British developed it for the Battle of Britain, for which Sir Watsou Watts was knighted.

If we want to have an example of how science and technology determine the course of empires, think what that one single development by Watts and his Australian colleagues did to turn back the forces overpowering Britain during that weak period of their war effort. Think what that one scientific discovery did in enabling the seven hundred fighters of the RAF to avoid destruction and, in turn, to destroy so large a portion of tbe 2500 bombers that the Luftwaffe was using. Germany was forced to give up the effort and England was never invaded, thank God for their sakes. Thank God

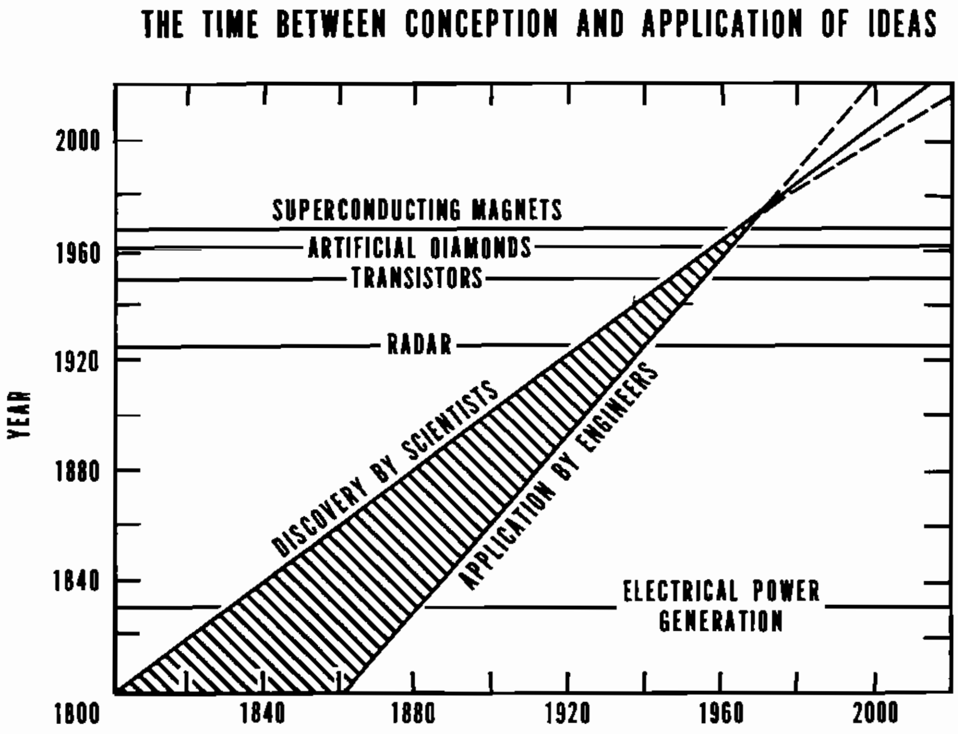

THE TIME BETWEEN CONCEPTION AND APPLICATION OF IDEAS
SUPERCONDUCTING MAGNETS
ARTIFICIAL DIAMONDS
TRANSISTORS
RADAR
DISCOVERY BY SCIENTISTS
APPLICATION BY ENGINEERS
ELECTRICAL POWER GENERATION
2000
1960
1920
1880
1840
1800
YEAR
1840
1880
1920
1960
2000
YEAR

Figure 4

for our sakes, too! Now observe that it took only eighteen years, from 1922 to the period of the beginning of World War II, to harness this new scientific discovery–against 40 years between Faraday's principle and its application by Thomas Edison.

Let us next look at transistors, discovered in the Bell Laboratories years later. It took a period of about six years before the transistor began to replace the vacuum tube and allow us to go to subminaturization and to greater reliability, including resistance to vibration and heat, and the many other advantages which are so important to our weapon systems. All this in six years!

Now we move on up the diagram, and we come to the artificial diamonds developed in the General Electric Laboratories. They reduced that concept to practice in about three years. Artificial diamonds, of course, are very important to industry because, among other uses, these are important cutting tools.

Let us look at the most recent example on the chart, superconducting magnets. These are basic in fusion phenomena, and here it was a matter of only a year and a half between discovery and use. This chart points out that we no longer have time for contemplation. This is a dynamic process; it has vital implications to our security.

The amusing thing is that, taken literally, the chart's artist left himself open to a rather wild interpretation. You see the curves cross about 1970, which can only be interpreted to mean that, by then, the engineers will have harnessed the latest discovery before the scientists have discovered it!

Figure 5 shows the areas where federal money obligations go. Particularly note the funds obligated to defense R&D. These increase from six billion six hundred million to seven billion three hundred million per year, in a three-year period. It should be noted, in comparison, that atomic energy increases from 850 to 1100 million dollars, whereas NASA jumps from 776 million to 2,821 million in the same period. NASA's increase is a ratio of almost 400% in three years, and Congress is questioning the coming budget request by NASA for well over 5000 million dollars, which approaches the total budget for all R&D in the Department of Defense.

Below, and plotted to a different scale, we see obligations for the Department of Health, Education, and Welfare. This has grown,

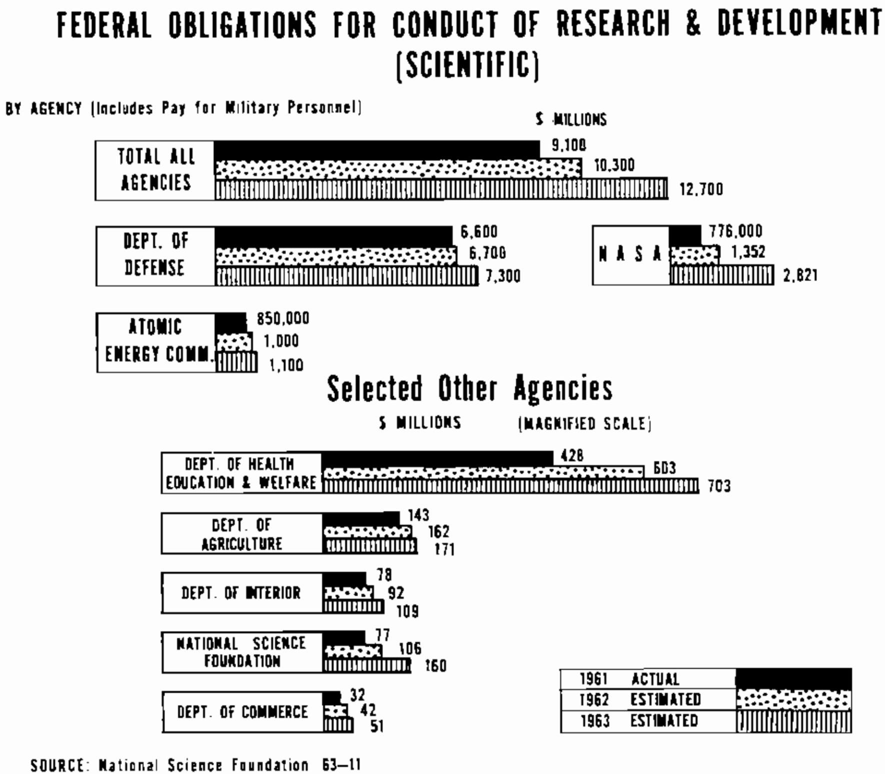

FEDERAL OBLIGATIONS FOR CONDUCT OF RESEARCH & DEVELOPMENT (SCIENTIFIC)
BY AGENCY (Includes Pay for Military Personnel)
$ MILLIONS
TOTAL ALL AGENCIES
9,100
10,300
12,700
DEPT. OF DEFENSE
6,600
6,700
7,300
N A S A
776,000
1,352
2,821
ATOMIC ENERGY COMM.
850,000
1,000
1,100
Selected Other Agencies
$ MILLIONS
(MAGNIFIED SCALE)
DEPT. OF HEALTH EDUCATION & WELFARE
428
603
703
DEPT. OF AGRICULTURE
143
162
171
DEPT. OF INTERIOR
78
92
109
NATIONAL SCIENCE FOUNDATION
77
106
160
DEPT. OF COMMERCE
32
42
51
1961 ACTUAL
1962 ESTIMATED
1963 ESTIMATED
SOURCE: National Science Foundation 63–11

Figure 5

in the same period, from 428 to 703 millions per year. Grave questions have been raised as to whether the availability of laboratories and suitable scientists exists to meet efficiently the objectives of the program. The appeal of social needs is great, but the question remains whether the possible shortcomings will not prove a danger to research needs in other areas.

Next, we have the Department of Agriculture—entomology, soil, crops, etc., then the Department of the Interior. They're all stepping up their R&D requests. Then we have the National Science Foundation. The National Science Foundation is somewhat different, because that money largely flows into basic research—largely into universities. Lastly, we have the Department of Commerce, which has just had some difficulty with Congress.

Figure 6 shows the Research and Development expenditures in percentages of the federal budget. It has often been said, by social scientists, that government tends to lag behind events; so, when we observe that the expenditures for research, as a percentage of the federal budget, have gone up since 1940 from 1% to 13% of a current 91 billion dollar budget, we are looking at one of the most dynamic economic parameters of this age. It reflects and responds to political forces, and results from the new understanding of the role of science and technology in everyday life.

Figure 7 is an interesting chart. In World War II, one pound of aerospace products cost approximately ten dollars; in the 1950's, one hundred dollars; today—one thousand dollars; tomorrow—your guess. Look at that trend; it's a nightmare, and reflects the cost of the built-in technological developments.

Figure 8 is a chart by Davis and Roddis, two engineers of the Atomic Energy Commission, and was drawn in 1955. Now please review the coal curve (see Figure 3). If you will follow the shape of that curve, you will see it duplicated here. It is fat and wide because it hasn't happened yet, and there are pluses and minuses to be taken into account. And what has happened? Davis and Roddis said that by 1965, in the high cost fuel areas of the United States, efficient atomic power plants will compete with conventional plants. Such plants are now under construction; they are off the drawing boards and being built. One such plant will be running in 1967 and the cost will be 6 mills. Davis and Roddis were a bit too conservative. This is perhaps a warning to

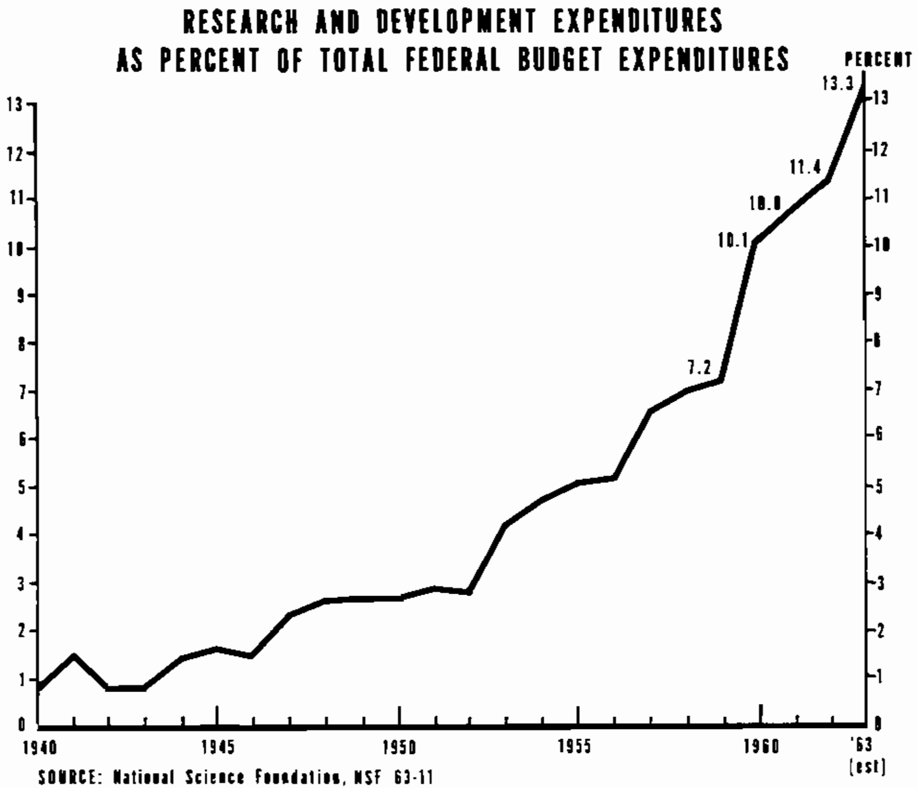
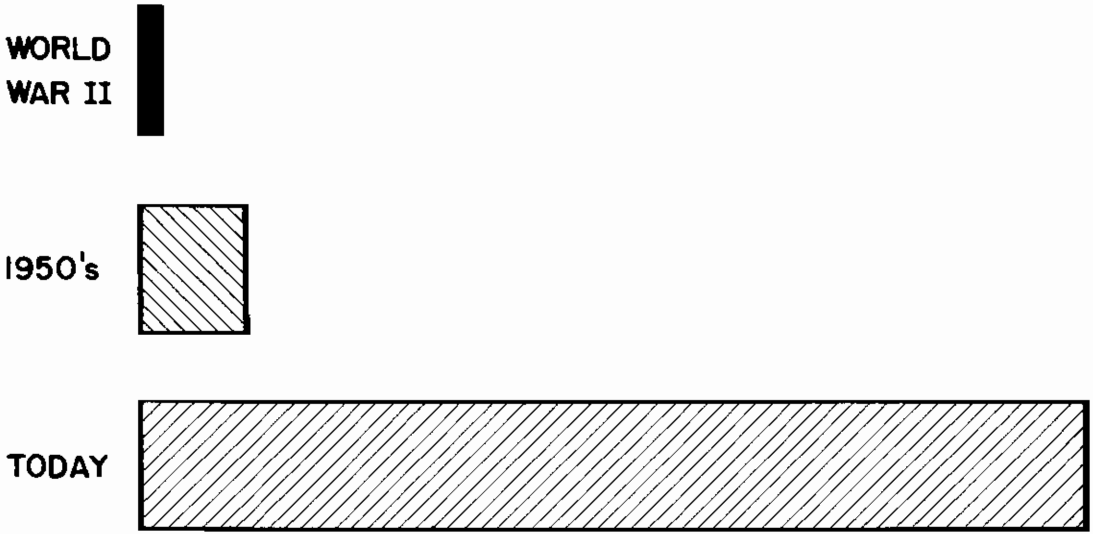

RESEARCH AND DEVELOPMENT EXPENDITURES
AS PERCENT OF TOTAL FEDERAL BUDGET EXPENDITURES
PERCENT
13.3
11.4
10.8
10.1
7.2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
1940
1945
1950
1955
1960
'63 (est)
SOURCE: National Science Foundation, NSF 63-11

Figure 6



COST PER POUND OF AEROSPACE PRODUCTS HAS INCREASED SHARPLY. IN WORLD WAR II, A PERIOD OF VERY HIGH PRODUCTION, COST WAS ABOUT $10 PER POUND; IN THE 1950's COST PER POUND SOARED TO $100. TODAY IT IS $1,000 PER POUND. TECHNOLOGICAL GAINS HAVE SHOWN AN EVEN GREATER INCREASE.

SOURCE: AEROSPACE ECONOMICS

Figure 7

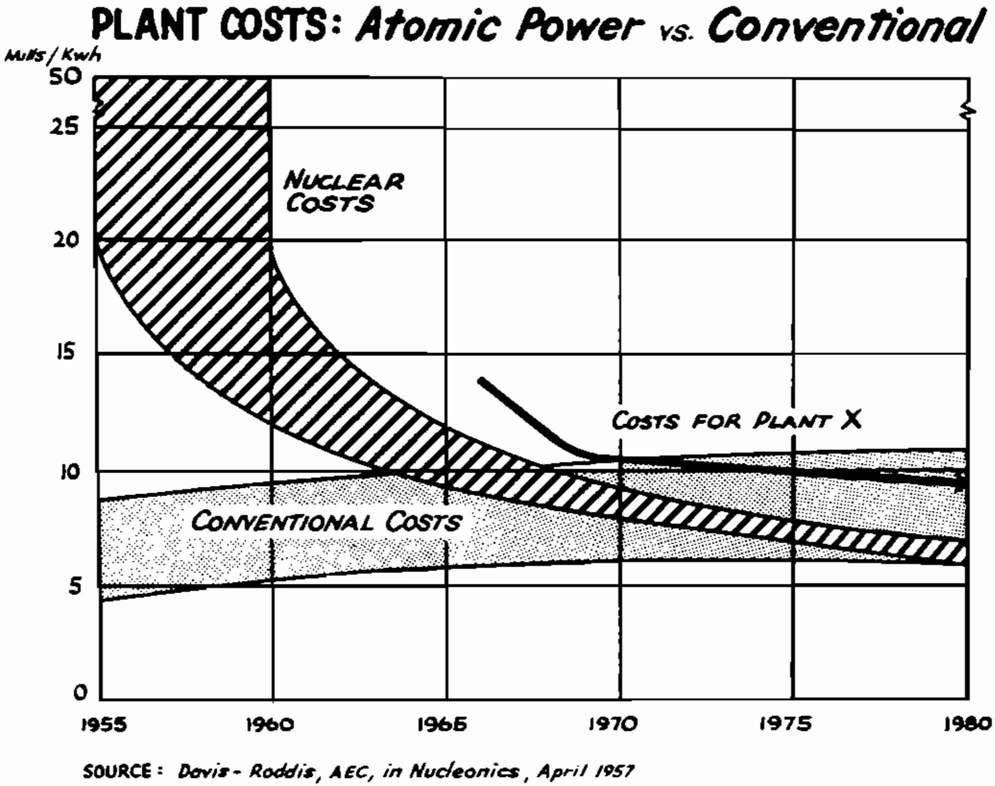

PLANT COSTS: Atomic Power vs. Conventional
Mills / Kwh
50
25
20
15
10
5
0
NUCLEAR COSTS
COSTS FOR PLANT X
CONVENTIONAL COSTS
1955
1960
1965
1970
1975
1980
SOURCE: Davis - Roddis, AEC, in Nucleonics, April 1957

Figure 8

those tempted to prophesy. If one wishes to pontificate, it is well to remember that there are certain fundamentals in applied technology, and these must be taken into account. Even then it is a perilous occupation. The role of technology is presently being read into the atomic power chart even as it is historically enshrined in the coal economy curve of Figure 3.

When your lecturer spoke this morning, he talked about vital natural resources. Obviously, we all think in terms of coal, oil, and gas, and when we're going to burn them all up, and then where will the world get its energy? Perhaps we can think of the people who have said, 'Oh, those guilty unthinking scientists who developed that atom bomb to destroy the whole world!' Such people are often not aware that the knowledge gained thereby may well be the savior of world civilization. Atomic energy will provide almost unlimited energy sources long after our carboniferous fuels are no longer readily available. Research cannot be viewed merely as expense, bnt rather as a fruitful asset, sometimes of the most vital value. Without advances in the technology of energy sources, it would be only a question of time before we go back to that gentleman with the pick, shovel, and horse that we saw on the first chart (Figure 1).

In Figure 9 we see something taken from your own profession. This chart refers first of all to the original core of the *Nautilus*. Actually, she steamed 63,000 miles before refueling. The same ship, the same plant, with a technically improved second core, steamed 95,000 miles, more than a 50% improvement. We now notice how this is typical of our Figures 4 and 8 in which there is a great improvement early in the development stage. The third core steamed 180,000 miles. The fourth core was originally designed for 200,000 miles, but now it has been predicted to last 400,000 miles.

Figure 10 is a chart made by the Standard Oil Company; it pictures a beaker of oil with the silhouette of a refinery at night on it. It shows that out of oil come many chemical products. The illustration shows the enormous impact of petroleum chemistry and technology. Let us look at some of the many end products—resius, antifreezes, rubber, plastics, paints, insecticides, fibers like dacron and orlon, etc. This poses the question, How much longer can we afford to burn energy fuels which are also our sole sources for carbon chemistry? These fuels were all laid down 300 million years ago during the Pennsylvanian geologic era and none are deposited any more. When we have used them up, there will be nothing of the same kind to replace them.

IMPROVEMENT IN NUCLEAR PROPULSION

U.S.S. NAUTILUS

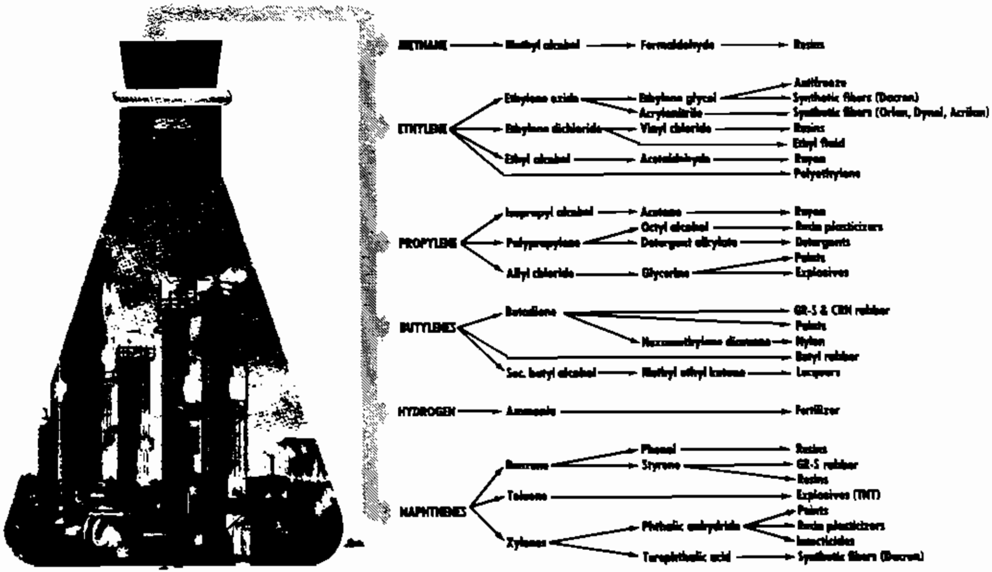
	1st Core	2nd Core	3rd Core	4th Core
NAUTICAL MILES STEAMED (APPROX.)	60,000	95,000	180,000*	200,000**
BARRELS FUEL OIL EQUIVALENT	57,000	88,000	161,000	171,000

*PREDICTED (PRESENTLY INSTALLED CORE)
**AVAILABLE FOR INSTALLATATION—FUTURE DESIGNS PREDICTED FOR 400,000

SOURCE: A.E.C. and Congressional Record

Figure 9

CHEMICALS FROM OIL



SOURCE: "The Lamp", Standard Oil Company (New Jersey)

Figure 10

Then there is the question of atomic fusion. If we were to develop the phenomena of fusion as a source of energy, then we would not have to be an insular country, or a seacoast country, or any other limited kind of a country. We would have power running out of our ears; and since power is the basis for economic strength, any country with efficient technology could aspire to world leadership. But no one has done it yet.

In Figure 11 we will look at the economics of the space program as a consequence of science and technology. Note the connection between the date of the Russian Sputniks and Luniks and our response to them. The effort is so tremendous, that it can't even be kept to scale on the chart. No wonder Russia seems to have called off the race after she used up her initial advantage. This new industry is a product of research, development, science, engineering, and technology. It is dynamic; and we can quickly be left at the stake if we are not capable of competing in the race. No one has yet fully demonstrated that putting a man on the moon is 'good' or 'bad'; we are only pointing this out as an example of scientific and technological capability. If we are going to remain a leading power in the world, it wouldn't take very many years of inattention to any given challenging horizon to make us as vulnerable and as exposed as a Navy armed only with sailing vessels and front-loading cannon.

In Figure 12 we have the relationship of science and engineering to economics in a very specific and spectacular area. It portrays the growth of the aerospace industry, and, of course, the first large peak in the curve is airplane production in World War II. Then came the 'bring the boys home by Christmas' reaction in 1945, which nearly ruined our industry. We, as industry representatives, testified to Congress why that wasn't a very wise thing to do with Russia as our enemy. This is a good example of politics and social attitudes lagging materially behind reality. But what happened in 1950? Korea. Now notice the line indicating the military production response. Next note post-Korea, and the usual lethargy that sets in after the shooting stops. But it didn't last long; the 'cold war' was still with us.

Perhaps we should conclude consideration of this chart by pointing out that science and technology have here created a vast industry, employing over a million skilled workers, which has provided the entire world with hitherto undreamed-of means of transport, and with social consequences of great import. The aerospace industry, finally, is peculiarly an important element of national power.

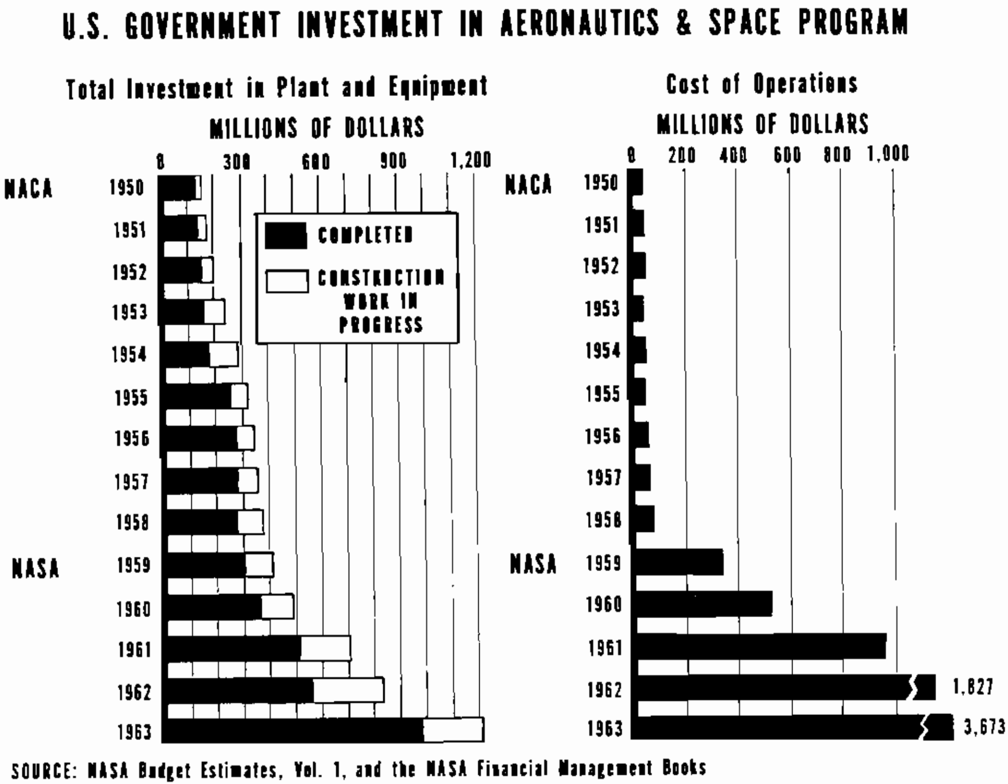

U.S. GOVERNMENT INVESTMENT IN AERONAUTICS & SPACE PROGRAM
Total Investment in Plant and Equipment
MILLIONS OF DOLLARS
0
300
600
900
1,200
NACA
NASA
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
COMPLETED
CONSTRUCTION WORK IN PROGRESS
Cost of Operations
MILLIONS OF DOLLARS
0
200
400
600
800
1,000
1,827
3,673
SOURCE: NASA Budget Estimates, Vol. 1, and the NASA Financial Management Books

Figure 11

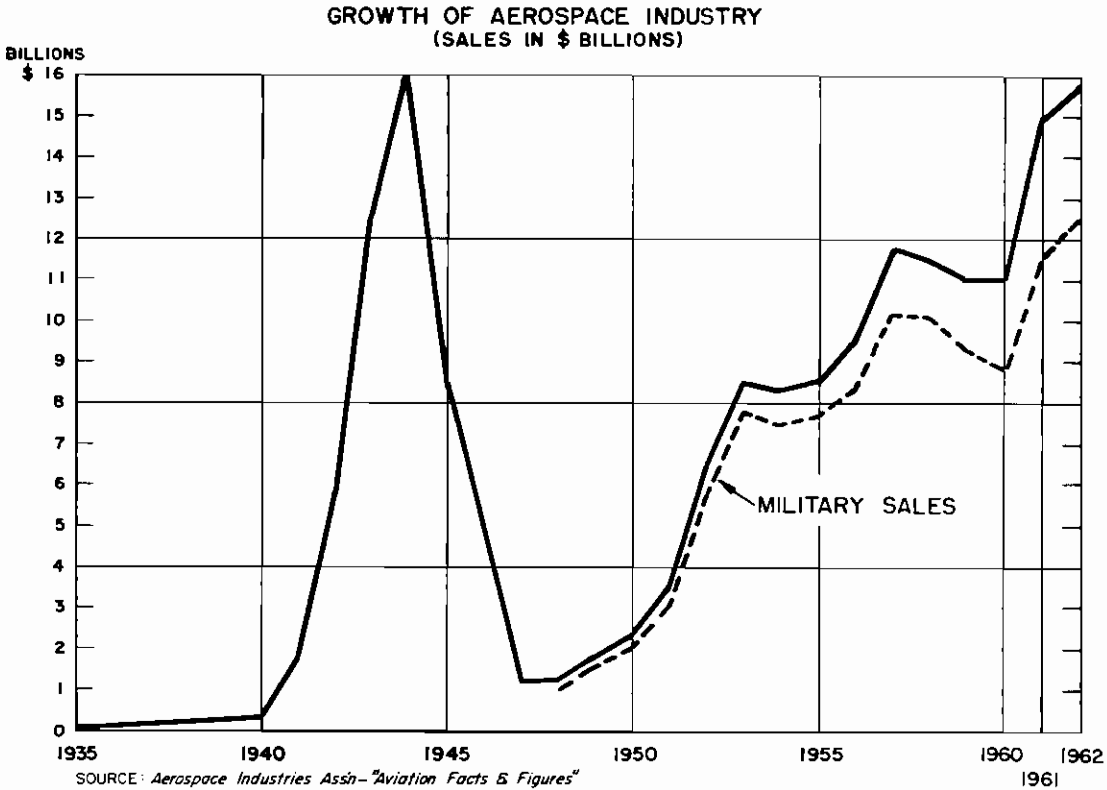

GROWTH OF AEROSPACE INDUSTRY
(SALES IN $ BILLIONS)
BILLIONS
$ 16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
MILITARY SALES
1935
1940
1945
1950
1955
1960
1961
1962
SOURCE: Aerospace Industries Ass'n–"Aviation Facts & Figures"

Figure 12

Figure 13 is another example. This chart reflects the growth of electronics industry. I was certainly one of those who failed to see the enormous future prospects for this industry in its early days. Just think back to the time when we were merely building home radios. Few thought it would develop into such a spectacular industry. The chart shows how, until World War II, electronics doesn't even register as a major industry. But, of course, during World War II, all of our technical and scientific capabilities were called upon to devise weapon systems such as bomb and gun sights, fire control gadgets, radar detection devices, special communication devices, and training aids. Then in 1945 came 'Bring the boys home.' All the stuff went back on the shelves and the pressure was off until along came the Korean War and we went to work again. In the meantime, there was TV and new commercial applications such as computers. Observe the military sales curve on this chart. Particularly note its relation to the Korean War and how it required two years to translate weapons needs into finished quantitative goods, due to the technical requirements for development and reduction to practice. Because of the necessities of the cold war and outer space, the graph shows we cannot, and have not, since relaxed.

In Figure 14 we see why the United States can be, and is, the most powerful nation in the world. With only one sixteenth of the world's population, we generate and consume one third of the world's electrical central station power. Electrical power means national power, because that electrical power flows into commerce, production, and services, making us the richest country in the world. This presupposes that we are continuing to develop the necessary technologies to employ all this power efficiently.

Figure 15 is an amateur attempt for an engineer to be an economist. Economics, by the way, has been defined as a 'dismal science.'

In this chart we find an attempt to enter this 'dismal science,' for which I have great respect, because I feel that, as a social study and not a social science, it is more difficult than engineering, which is also a form of so-called social science. In displaying this chart, we are deliberately using statistics to test the theory that it is only through the technological use of energy that we produce the goods and services which provide our standard of living. What do we find? Except during the war and the Great Depression of the 1930's, there is a close statistical relationship. I believe that all statistics should be questioned even though they

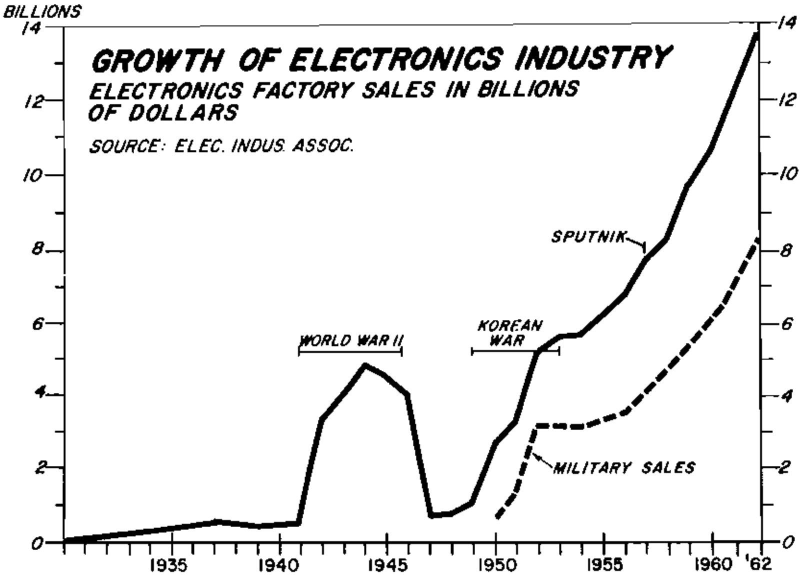
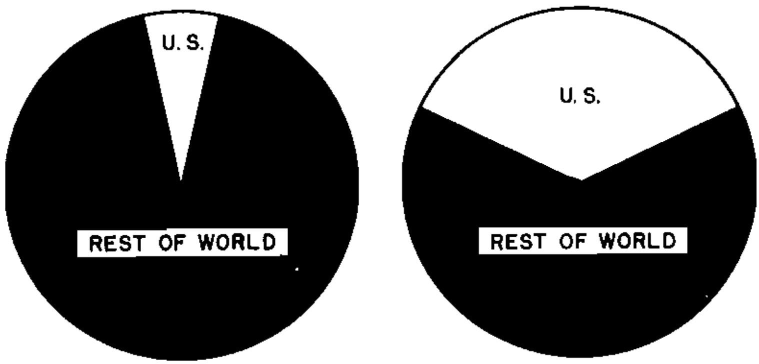


Figure 13

WITH 1/16 OF THE PEOPLE U.S. HAS OVER 1/3 OF THE POWER



POPULATION

United States	186,591,000 persons
Rest of World	2,963,409,000 persons
World Total	3,150,000,000 persons

ELECTRIC POWER CAPACITY

United States	198,927,000 kilowatts
Rest of World	382,775,000 kilowatts
World Total	581,702,000 kilowatts

SOURCE: *United Nations Statistical Office*
Bureau of Power, Federal Power Commission

Figure 14

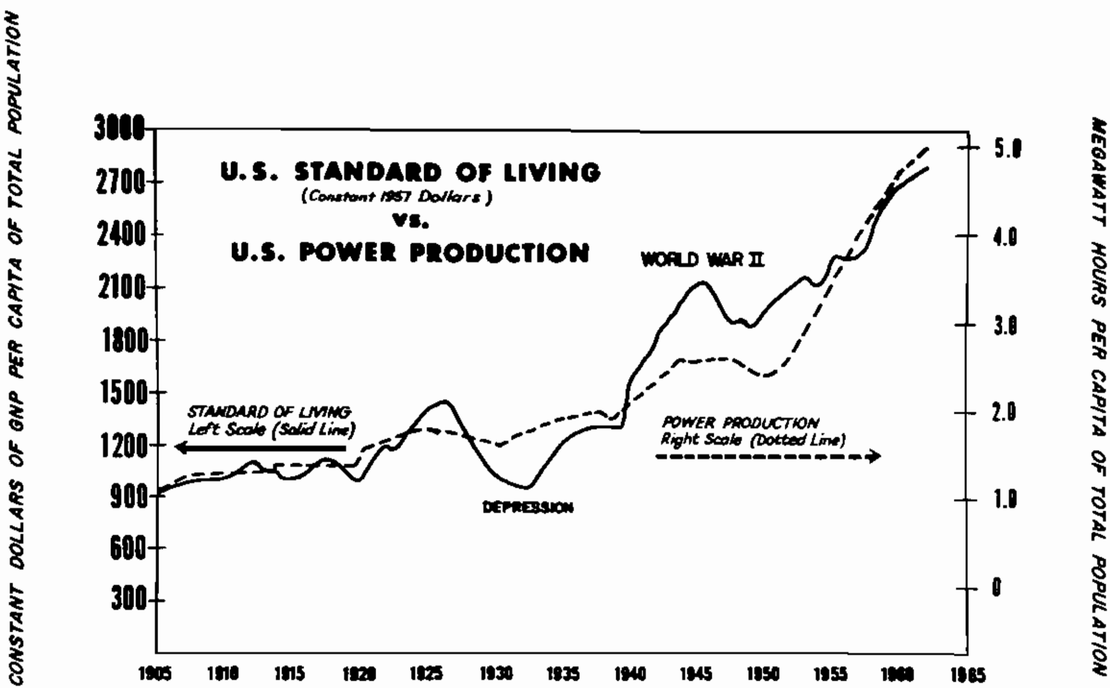

U.S. STANDARD OF LIVING
(Constant 1957 Dollars)
vs.
U.S. POWER PRODUCTION
CONSTANT DOLLARS OF GNP PER CAPITA OF TOTAL POPULATION
MEGAWATT HOURS PER CAPITA OF TOTAL POPULATION
STANDARD OF LIVING
Left Scale (Solid Line)
POWER PRODUCTION
Right Scale (Dotted Line)
WORLD WAR II
DEPRESSION
3000
2700
2400
2100
1800
1500
1200
900
600
300
5.0
4.0
3.0
2.0
1.0
0
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965

Figure 15

are the best tools we have to present to you. You should tear them apart at your leisure; you should question them. You should look within the respective Gross National Products of the United States and the Soviet Union to find out how the Russians really sell us down the river. They take a factory making tractors and put its output into their Gross National Product; then they take a factory making transmissions for the tractors, and put that into the Gross National Product, too, so that the transmissions are in twice. It has been said, 'Give me a set of statistics and enough time and I'll prove anything.'

Often when labor sits down with management at the bargaining table, each side will take a typical position. Labor will select a year during which their side can find the highest return that labor made, with lots of overtime and full schedules of work; they take this year and point out that they are getting a very little more than they did then, although the cost of living has gone up disadvantageously. For their purpose, they rely on the Department of Labor cost of living statistics to prove that they are not getting their proper share. The manufacturer sits down and finds an area where his industry was depressed, and he finds a year when labor was earning relatively much less than normal. Then he takes what he pays for labor currently, and shows that labor gets a highly increased take. Finally, he lays down the Labor Department's standard of living figures and argues that labor is already getting more than its share.

Figure 16 shows another statistical way of coming to the same conclusion. This chart reflects the production per man hour in the United States over 53 years. How does a man who works less today with his muscles than he did 50 years ago produce so much more per man hour? Surely it isn't our politics that did it; or our social studies that did it; or our slum clearance that did it; or our urbanization that did it; or our health and welfare that did it. No. Technology did it. Our engineers reduced to practice new theories of production, devised new tools, and created new facilities, so that a workman, with less and less effort, produced more and more goods. This is the great strength of America, and if it ever starts diminishing, we, as a nation, are done. This is the basis of the race with Russia and socialism right today, and of course, if we can't continue to do better than our competitors, we will take second place.

The data for this chart, Figure 17, appeared at Ohio State University at a logistics conference, essentially a military

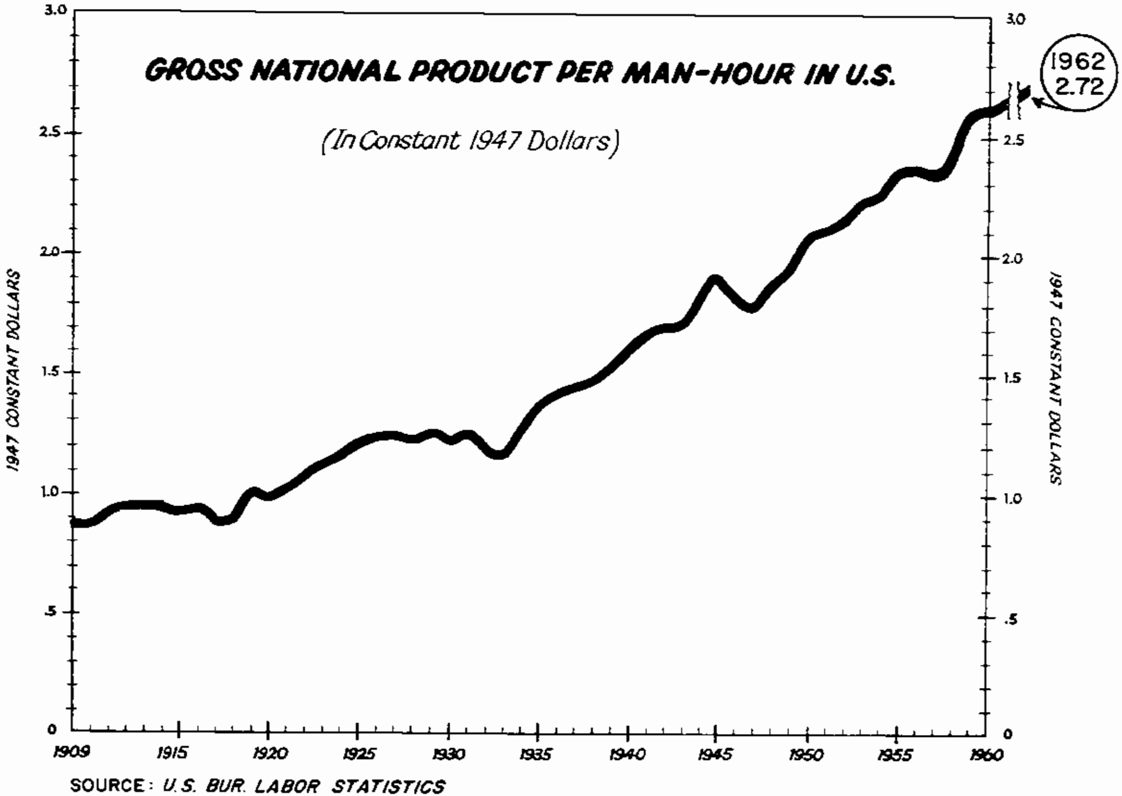

GROSS NATIONAL PRODUCT PER MAN-HOUR IN U.S.
(In Constant 1947 Dollars)
1962
2.72
1947 CONSTANT DOLLARS
1947 CONSTANT DOLLARS
3.0
2.5
2.0
1.5
1.0
.5
0
1909
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
SOURCE: U.S. BUR. LABOR STATISTICS

Figure 16

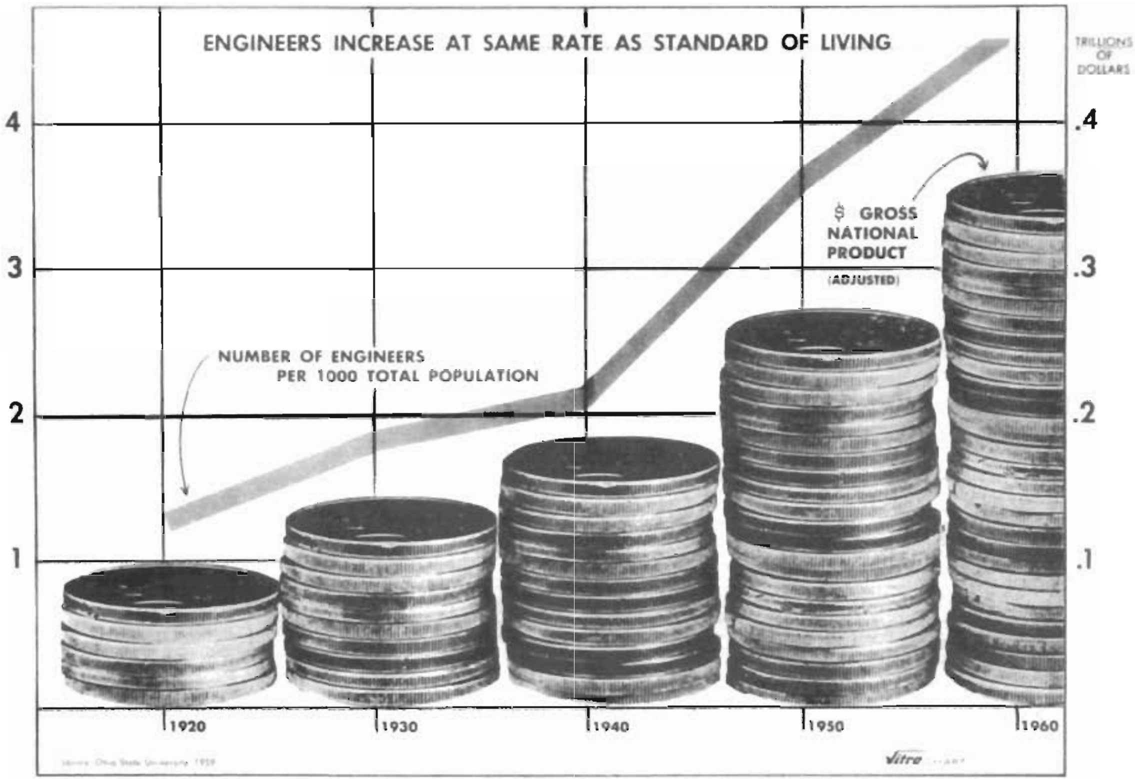

ENGINEERS INCREASE AT SAME RATE AS STANDARD OF LIVING
TRILLIONS OF DOLLARS
4
3
2
1
.4
.3
.2
.1
$ GROSS NATIONAL PRODUCT (ADJUSTED)
NUMBER OF ENGINEERS PER 1000 TOTAL POPULATION
1920
1930
1940
1950
1960
Vitro

Figure 17

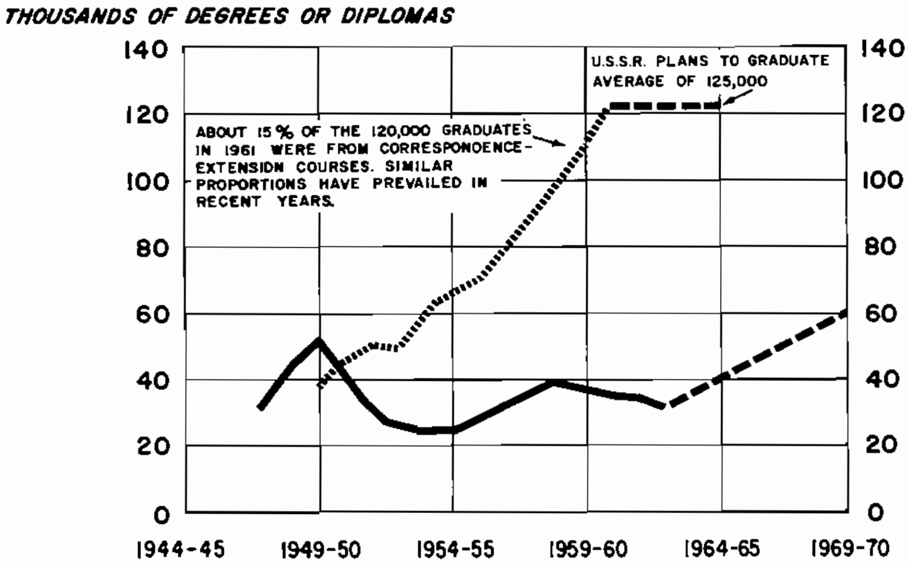
conference. The chart plots the number of practicing engineers in the United States during the period from 1920 to almost 1960, and then takes the standard of living in the United States for the same period and compares it to this number. The result is startling and bears out the thesis we have already presented.

In Figure 18 there is some bad news for us. This chart shows the production of engineers today in the United States from all accredited colleges with four-year degrees. The dotted portion as a forecast is not at all being realized. There is nothing on the horizon right now to indicate that the seriousness of this situation is being faced up to by the American people. Russia began many years ago to provide facilities and to institute measures to educate large numbers of engineers. She provided special incentives for students to enroll. According to our own educators, the Russian engineer is as well educated as his counterpart in the United States, although, in general, much more specialized. There is, from the evidence, a wider appreciation for the role of science and engineering than can be said to exist in the United States. That the enrollment of engineering freshmen continues to go down is one of our country's most critical unsolved problems. Fortunately, the problem of enrollment of students in basic science courses is not equally acute.

The Russian system reaches right into the secondary schools and there both boys and girls who distinguish themselves in mathematics and the natural sciences are approached. They are offered the opportunity to pick out the college of their choice and are offered full-paid tuition and a salary for living expenses, just so long as their performance meets the state-decreed standards of scholarship. In addition, the state guarantees employment upon graduation with special privileges and a superior salary, although the student must qualify to the preset standards. Lastly, the student can select any specialty in either science or engineering. Medicine has been set at a much lower level and approximately three quarters of all medical graduates are said to be women. This brings us to Khrushchev's statement, 'We will bury you.' When he said this, he apparently had no further notion of doing it with either thermo-bombs or force. He has in mind to do it by economic means. He has said so, over and over again. His peaceful co-existence, along with subversion and a few other varieties of mayhem, primarily means burying us economically. Apparently he is counting on technology to do it.

HIGHER EDUCATION GRADUATES IN ENGINEERING

NUMBER OF BACHELOR'S DEGREES AWARDED 1948 TO 1961 AND ESTIMATED TO 1970
U.S. AND U.S.S.R.



SOURCES: NSF., HEW., ENG. MANPOWER COMM.

Figure 18

There are curves for scientists as well as engineers, and also data on the nonscientific or nonengineering disciplines. These constitute a small percentage of graduates, especially when compared to those in the United States. They tend to show that, in America, students tend to select the easier college courses. If so, I fear we may be beginning to lean toward the course of inaction that led Rome to cease being a power after a thousand years of world leadership. Some of the signs may be here already. Perhaps we won't take the hard way, even if it is the most productive way. If so, this may be the *really* hard way for the nation, in the long run.

Now, gentlemen, we must conclude, since I don't wish to be labeled as a lecturer who didn't need an introduction, but instead needed a conclusion. Science and technology are moving and progressing in giant steps. Steam power, electric power, wire and micro-wave communications, aviation and aerospace, atomic science, are all in a sense both technical and economic developments, and hence have caused political and social revolutions. It is predicted that the next revolution, scientifically oriented, will be even more revolutionary and will lie in the field of molecular biology with its many startling possibilities. Let us take a moment to see, if we can, where this development may be leading. It tries to not only explain the mechanism of genetics, but it has begun to learn to 'read' the mechanism of genetics; it has, in a limited way, deciphered the genetic code. One may ask how can one microscopic cell contain all the potential necessary to create a complex man? Where does that potential reside? Think of it. It is a staggering thought. How did two little cell clusters determine everything about you--the color of your eyes, your bone structure, your muscle structure, your mental capabilities. In those little cell structures lie all of the instructions that bring this about. Bioscience has first found the mechanism, and now it has untangled some of it. We have a very, very long way to go yet, but, so far, it is like finding the Rosetta Stone. What will all this mean? It could mean just what it has already, as in the production of fruit flies, wherein fruit flies have been bred that have an extra set of wings, or no wings, or pink eyes, etc. All this has been done. Some of these strains are so valuable that they are kept in vaults. This was done largely by the pragmatic method that engineers use, the cut-and-try method. Now we are trying to determine the explanation, and this lies in the field of molecular biology. It is conceivable that man may some day design his grandchildren. Now, think. If your competitor first mastered such an art, what could he do with your future and with his? If the final speculation as presented by this morning's lecturer in his talk is a viable one, it behooves the United States to play the leading part in such scientific development, together with science generally, if we are to maintain our position as a world power.

I trust by now that the evidence presented, together with your own observations and experiences, has persuaded you that science and technology, from the earliest times to today, have been the determining forces of actual and potential power for any society or nation.

BIOGRAPHIC SKETCH

Mr. J. Carlton Ward, Jr.

Present Position:

Retired President, Vitro Corporation of America

Schools:

Cornell University, M.E.

Career Highlights:

1914	Development engineer for Int'l Paper Company
1915-17	Asst. to works manager, Niles Tool Works Div., Niles-Bement-Pond Company
1918	Production engineer, U.S. Ordnance Dept., Watervliet, N.Y. Arsenal
1915-25	Works manager, Pratt & Whitney Div., Niles-Bement-Pond Company
1925-29	Vice president, general manager and director of Hartford Machine Screw Company
1929-34	General works manager, General Cable Corp.
1934-35	Vice president, Rome Company, Inc.
1935-40	Vice president, general manager and director, Pratt & Whitney Aircraft Div., United Aircraft Corp.
1940-48	President, and later chairman of the board, Fairchild Engine & Airplane Corp.
1950-53	Chairman of the board, Thompson Industries, Inc.
1953-59	President and Director of Vitro Corp. of America
1959-61	Chairman, Vitro Minerals Corp.; President, Heavy Minerals Corp.; Director, Sheer-Korman Assoc., Inc.; Director, Cornell University Aeronautical Lab.; Chairman, Cornell University Engineering Council; Director, Flight Safety Foundation; Chairman of Board of Advisors, Industrial College of the Armed Forces.