



Energy and Man

A Symposium

Contributions by

Allan Nevins · Robert G. Dunlop
Edward Teller · Edward S. Mason
Herbert Hoover, Jr.

with an Introduction by
Courtney C. Brown

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ILLUSTRATIONS

Front Endpapers

Allan Nevins (*top left*); Edward Teller (*bottom left*); Herbert Hoover, Jr., and Courtney C. Brown (*top right*); Robert Dunlop (*bottom right*).

Back Endpapers

Herbert Hoover, Jr., Edward S. Mason, and Robert Dunlop (standing), Grayson Kirk, President of Columbia University, Frank M. Porter, President of the American Petroleum Institute, Courtney C. Brown, and Allan Nevins (sitting) (*top left*); Herbert Hoover, Jr. (*bottom left*); Edward S. Mason (*top right*); Courtney C. Brown speaking, Frank M. Porter, Edward Teller, Edward S. Mason, and Herbert Hoover, Jr., listening (*bottom right*).





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INTRODUCTION

THROUGH THE AGES, LEARNING HAS LOOKED TO THE WORLD of practical affairs for the major subjects of its interest. It is very appropriate that a great university, Columbia, through its Graduate School of Business, should share with a great industry, through its representative, the American Petroleum Institute, an inquiry into the role of energy, past, present, and future, in the lives of each of us.

Another name for energy is prime mover. The world most certainly is on the move, not just physically, but culturally, politically, and in other ways. The availability of an abundant and inexpensive supply of energy should condition the direction of these moves perhaps more than any other factor. Just as the successive harnessing of prime movers in the past in the form of animal power, wind power, water power, and now mineral power has changed the cultural, political, and physical scene in which life occurs, so will the forms and abundance of the energy supplies of tomorrow condition the milieu in which we live.

So, when early in 1959 the American Petroleum Institute asked the Graduate School of Business if it would collabo-

rate in the preparation and presentation of a comprehensive symposium worthy to serve as a part of the commemoration of the centennial of the oil business in the United States, we were delighted to accept. It was decided that it would be appropriate to consider energy in its several forms and to discuss circumstances that will best assure its continued availability in abundance. Thus, on November 4, 1959, a group of over three hundred government officials, economists, historians, scientists, and executives from a broad range of industry gathered in the rotunda of Columbia's Low Memorial Library to hear delivered and to discuss the papers which are reprinted in this volume.

In introducing this inquiry into energy and its impact on our lives, a brief word should be said about the program's "grand" design, as well as about each of the speakers. The presentations start with an account of the role of energy in the history of Western man by Dr. Allan Nevins. It would be redundant to plunge into an extended introduction of Dr. Nevins. Suffice it to say he is one of the country's leading historians, a man whose insights, particularly into the past of the American scene, have provided us all with stimulation and enlightenment. Dr. Nevins is on familiar ground when he speaks from a Columbia platform. The recipient of two Pulitzer Prizes for work in history and biography, he has presented a number of classic interpretations of the early history of the petroleum business.

Building on this background, the program moves to a discussion by Mr. Robert Dunlop of petroleum's impact over

the last century as a major source of energy, or prime mover. The only representative of the petroleum industry on the program, Mr. Dunlop has been President of the Sun Oil Company for the last twelve years. He is regarded as one of the best informed authorities in the oil business on the economics of the industry and has been active in seeking effective presentations of public affairs issues affecting it. He is a director of the American Petroleum Institute and serves as a trustee of the University of Pennsylvania.

Mr. Dunlop's paper is followed by a survey of the future—of those energy sources that are now in the laboratory or pilot plants, but promise to have profound influence in the years to come. The speaker, Dr. Edward Teller, is Professor of Physics at the University of California and Director of the Radiation Laboratory at Livermore, California. Born in Budapest, Hungary, and educated in Germany, Dr. Teller came to this country in 1935 to teach at George Washington University. Shortly after the start of World War II, he was assigned to the Manhattan Project and during the next few years he rendered outstanding service to his adopted country. Dr. Teller has made important contributions in the fields of electric and nuclear physics, and in quantum theory. In recent years he has been noted for his work on the practical applications of thermonuclear principles and the development of thermonuclear weapons.

Next in sequence comes an analysis of some of the conditions—political, physical, and economic—that will be necessary to assure an abundant supply of low-cost energy, presented by Dr. Edward S. Mason. A member of the Har-

vard faculty since 1923, Dr. Mason was Dean of the Harvard Graduate School of Public Administration from 1947 to 1958, when he chose to become Frank W. Taussig Professor of Economics and to devote his full time to teaching and research. During World War II, he served as Chief Economist for the Office of Strategic Services and was Deputy to the Assistant Secretary of State. He was Chief Economic Advisor to the United States at the Moscow Conference in 1947, and in 1954-55 he directed the team which assisted in drawing up a plan for the economic development of Pakistan.

The program concludes with a paper by Mr. Herbert Hoover, Jr., on energy and public affairs which provides a broad view of the energy story against a world-wide background. A consulting engineer by profession, Mr. Hoover has worked with a number of firms in the United States and abroad, besides acting as a consultant to the governments of Venezuela, Iran, Brazil, Peru, and other nations. In 1953 he was a special advisor on world-wide petroleum matters to the Secretary of State, and he served as Under Secretary of State from 1954 to 1957.

It was a particularly great privilege for the Graduate School of Business of Columbia University to share in this occasion. The proceedings were tape-recorded by the Voice of America, and the publication of these distinguished lectures will constitute, I believe, a fitting document to commemorate this important birthday of a great and dynamic industry.

Thanks are due to Mr. Frank M. Porter, President of the

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American Petroleum Institute, who presided over the afternoon session, and to the staff of that organization for their efficient help in preparing for the occasion. I would like also to acknowledge the assistance of Professor William A. Owens of Columbia University, the author of *Fever in the Earth*, a recent novel about petroleum, who was responsible for preparing the lectures for publication.

COURTNEY C. BROWN

Dean, Graduate School of Business
Columbia University

**III. ENERGY PATTERNS OF
THE FUTURE**

by Edward Teller

LADIES AND GENTLEMEN, I AM TO TALK TO YOU ABOUT ENERGY in the future. I will start by telling you why I believe that the energy resources of the past must be supplemented. First of all, these energy resources will run short as we use more and more of the fossil fuels.

We find that more and more such fuel is being discovered and I am quite sure that within the present century there need not be an acute shortage of any of the fuels to which we are accustomed. But the demand for fuel is rising—and rising substantially—and new fuel deposits are usually discovered in locations which are a little less accessible than those which we have already used, and so the price of the fuel will go up.

In fact, this process, as you all know, has already started. The price of fuel has been creeping up steadily, and the price of energy has been kept relatively low and steady, only because while the price of fuel is rising, the utilization of the fuel has been increasing.

In our modern energy-producing machinery, we utilize approximately one-third of the energy of the fuel and while

there are possibilities of increasing this utilization to one-half or two-thirds, we certainly won't utilize it 100 per cent, and even the further increase which is now in prospect begins to come a little hard. Therefore, it begins to be of real interest to see what else we can do and what we can use for fuel.

Furthermore, fuel, in some places of the world, is cheap. In other places, where there are no close-by coal or, particularly, oil deposits, fuel is much more expensive, and therefore large regions of our globe are, at least to some extent, retarded on account of absence of usable fuel.

There are all kinds of alternative possibilities which have been considered, and which I will discuss later. But I would first like to mention another reason why we probably have to look for additional fuel supplies. And this, strangely, is the question of contaminating the atmosphere. Now, all of us are familiar with smoke and smog and all of us know about it as a nuisance. Perhaps it is also a hazard, but certainly it is a nuisance, with which we are all familiar.

I would like to talk to you about a more hypothetical difficulty which I think is quite probably going to turn out to be real. Whenever you burn conventional fuel, you create carbon dioxide. It has been calculated that the carbon dioxide which has been put into the atmosphere since the beginning of the industrial revolution equals approximately 10 per cent of the amount of carbon dioxide that our atmosphere contained originally.

There are modern methods by which we can find out reasonably accurately how much of this additional carbon

dioxide the atmosphere actually contains today. They are the result of some excellent work at the Scripps Institute in California, and through these methods it was found that actually the carbon dioxide content of the atmosphere has increased by only 2 per cent.

It will interest you, perhaps, to hear how this was found out, and I can tell you in a very short time. A certain fraction of the carbon that is in the carbon dioxide is very weakly radioactive, and this activity can be traced back to the effect of cosmic rays which produce carbon in the atmosphere. The carbon dioxide which is now in the atmosphere is a little bit less radioactive than the carbon dioxide that was in the atmosphere thirty, forty, fifty, one hundred years ago. You can still sample that old carbon dioxide by investigating wood that grew thirty or forty or one hundred years ago, and this slightly aged wood is more active. What has happened? In the intervening years we have burned a lot of the material which had been deposited in the carboniferous era and at other times, times so long ago that in the meantime the carbon in the coal or the carbon in the petroleum has lost its radioactivity. So part of the carbon in our atmosphere is not radioactive carbon, but ancient inactive carbon.

Ten per cent has been added, 2 per cent is found present. The rest is in the ocean, mostly on the bottom of the ocean, precipitated as calcium carbonate. We now know that most of the carbon has gone this way, and that the atmosphere contains only that much additional carbon as has

been burned in the last ten or fifteen years. That is the residence time of the carbon dioxide in the atmosphere.

If now, the rate of burning conventional fuels continues to increase by a factor of 2 each ten years, the result will be that by the end of the century there will be an increase of carbon dioxide in the atmosphere by more than 10 per cent. The carbon dioxide is invisible, it is transparent, you can't smell it, it is not dangerous to health, so why should one worry about it?

Carbon dioxide has a strange property. It transmits visible light but it absorbs the infrared radiation which is emitted from the earth. Its presence in the atmosphere causes a greenhouse effect in that it will allow the solar rays to enter, but it will to some extent impede the radiation from the earth into outer space.

The result is that the earth will continue to heat up until a balance is re-established. Then the earth will be at a higher temperature and will radiate more. It has been calculated that a temperature rise corresponding to a 10 per cent increase in carbon dioxide will be sufficient to melt the icecap and submerge New York. All the coastal cities would be covered, and since a considerable percentage of the human race lives in coastal regions, I think that this chemical contamination is more serious than most people tend to believe.

For this then, and for many other reasons, I will say that any new fuels we find will be welcome. I believe that of the new fuels, nuclear energy is the most promising and I will talk about nuclear energy from here on.

Nuclear fuel has, of course, been saved—its energy content has not been released, because atomic nuclei repel each other so violently that except under extraordinary circumstances they cannot come into contact. And only when they come into contact do they release the energies which reside in them, energies that are a million times greater than chemical energy.

In the last couple of decades, we have learned how to release these nuclear energies. All of you are familiar with nuclear fission, how a uranium atom may split into two parts, releasing a lot of energy and some neutrons, how these neutrons can approach further nuclei, how this process then can repeat and multiply, creating what is known as a chain reaction and giving rise to fabulous amounts of energy connected with small amounts of material.

In the early years of the Second World War we learned how to tame this energy, how to build nuclear reactors which would release such energy. The first nuclear reactor went into operation a little less than eighteen years ago. Nuclear reactors are still not economically competitive. Why not? What is holding us up?

There are two answers that I could give, a wrong answer and a right answer. I will give you the wrong answer first. The wrong answer is that we first must solve the question of raw materials. Uranium, as we dig it out of the ground, is usable for reactors only in a somewhat clumsy manner. One has to do one of two things, either to separate isotopes, or to achieve what is known as breeding. All these prob-

lems are extremely interesting and I will spend a very few minutes to discuss them with you.

Uranium contains 99.3 per cent of a sluggish, relatively less useful isotope and .7 per cent of a red-hot isotope, Uranium 235. The straightforward method is to separate these isotopes and use the active part. Once you have that active part, it is easy to make a good reactor. We used to believe that the separation was too expensive. Many people still believe it. We are producing today this isotope at an announced price, and if you compare this cost with that of gasoline or coal, BTU for BTU and dollar for dollar, you find that the modern nuclear fuels already prepared and separated cost only 70 per cent of what you pay for a conventional fuel.

Therefore, the price of the nuclear fuel is not an excuse. This is the wrong answer. Still, I will pursue this question of price because there is a further possible development in store and a very interesting one, too. While a nuclear reactor works, it not only produces energy, it also can produce some additional nuclear species, in particular, Plutonium, and this process is known as breeding.

One uses up the active material, but at the same time, one activates inactive material. The result is that when this process is fully worked out (and it is not worked out yet) you can expect a great additional drop in the fuel price.

This breeding or activation, which I have described to you, won't work unless you have some fertile material available, and there are only two fertile materials—Uranium and Thorium. What about their supply?

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They are cheap today, but won't they run short? Well, they won't for a hundred years. And furthermore, they won't for millions of years, if we find reasonably cheap methods to separate Uranium and Thorium from materials in which these substances are contained only in small percentages. We are making progress in using ores in which only one-tenth of a per cent is Uranium or Thorium and I think in the course of time, we may find methods by which we can extract the few parts per million of Uranium that are contained in very common substances, like granite.

You should realize that once this procedure is worked out, we can extract from a ton of granite, in the end, more heat than from a ton of coal. But first you must separate out the Uranium and then you must do something with this Uranium to use all of it, to breed it. If you can accomplish all of this—and it won't be easy—then we will literally be able to burn rocks, and the fuel problem will have been solved once and for all.

Now, in view of this, in view of this great future and in view of the present cheap price of Uranium 235, why aren't the light bulbs in this hall actuated by nuclear reactors, which they are not, to the best of my information? The reason is that in the course of fission, radioactivities are produced, the reactor is hot, dangerous to approach, and must be handled by distant control equipment.

All this is not only expensive in itself, it also slows down research directed toward better methods, cheaper methods, of producing energy. Even today in conventional fuels, half

the expense of producing energy is in capital equipment and operation, and only half of it in raw materials.

Operation and capital investment is much greater in the case of nuclear fuel, and the main question is how to find ways and means to improve nuclear technology so that operation and capital investment will drop. I am quite sure that this can be accomplished, although in order to accomplish it, we will need many talented nuclear engineers and so far there is no overabundance.

I would like to pursue an associated thought for a moment. What about this dangerous material which makes it so difficult to approach a nuclear reactor? What kind of consequences does it have otherwise? Are nuclear reactors dangerous? Well, I dare say yes, it is dangerous if a nuclear reactor malfunctions. It can release the radioactive poisons contained in it and it can contaminate many, many square miles in the down-wind direction.

Now, at this point, I should like to draw a sharp distinction between this kind of contamination and the so-called fallout about which there has been so much popular agitation. The fallout coming from tests is so negligible that it is certainly and demonstrably smaller than that from a great number of natural effects to which we don't give any thought. The danger of fallout from nuclear activity has been exaggerated to such an extent that I feel that the only real medical hazard has become the hazard of stomach ulcers.

I should particularly point out that a very serious scientific question exists on whether these exceedingly low-

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level activities coming from world-wide fallout have or have not any harmful effect. Nobody knows, but it is clearly demonstrated that they have no more harmful effects, in fact, less harmful effects, than the effect from cosmic rays on those who live at some elevated position, say, Denver, Colorado. At the same time, concentrated fallout is bad. What a nuclear reactor can do if it malfunctions and spreads its radioactivity over the countryside is most serious. This should be guarded against extremely carefully, and indeed very great precautions have been taken to avoid nuclear accidents. With good luck and very conscientious work, the Atomic Energy Commission and everybody else connected with the undertaking have so far avoided such accidents.

It is essential that we maintain this good record, and we must find methods at the same time to lower the price of all procedures connected with nuclear energy. This is a big and important and detailed and nasty engineering job, but one which I am sure will be solved in the course of time.

One last word about reactors. Since it is such a big and difficult job, it is extremely important to concentrate on the most hopeful and most easy aspects of it. I am much more interested in stationary nuclear reactors than in any nuclear reactor which moves. I am talking about civilian application. Wherever there is motion, there is greater hazard.

To be quite specific, I think that we are going to need our gasoline for many decades, perhaps for centuries, in order to drive our cars, or fly our planes. I think the neat, handy,

chemical energy package of gasoline is something which we shall not be able to replace for a long time.

Therefore, I advocate that we replace our stationary energy generators as soon as it is economic by the more abundant nuclear power, and save our petroleum for mobile equipment and for petrochemicals. I think that is a reasonable, long-range view.

But it is not necessarily the end of our mission. There are other things in the offing. In 1951 and 1952, when thermonuclear power produced the first hydrogen bomb, we were asked: "It is clear that fusion can be used in war. What about using fusion in peace? It is the same reaction, isn't it?"

Well, it is the same reaction, but that's not what counts. It is easy to blow up something; it is much more difficult to make it react at a slow and controllable rate. Greek fire saved Constantinople from the Moslems more than a thousand years ago, and a millennium had to elapse before this chemical energy became usable in a controlled fashion. Well, we are not going to take a thousand years to control nuclear energy. But we are going to take some time, and I will tell you why.

In order to make thermonuclear fuel work slowly we must use the material in great dilution. We use as few atoms, or rather positive and negative ions, as would correspond ordinarily to a high vacuum. But it is a high pressure vacuum because of the high temperature, so that few particles produce many atmospheres.

Under these conditions, the reaction would be comfort-

able and slow, but these hot particles will bump into the wall and lose their energy. What to do about that?

We have to invent a medium which contains the ions without depriving them of their heat content, and that can be done. There is such a medium—magnetism, magnetic lines of force which induce the ionized particles to spiral around them and which keep the particles away from cool walls.

In principle, all of this is very simple. It is the same kind of problem as to try and confine a high pressure gas in a bottle made out of rubber bands. The magnetic lines of force have certain properties similar to rubber bands. They can be pushed aside and the hot gas can leak out in between. Then we lose it and lose its energy.

Well, we found that indeed—excuse me for the horrible word—this magneto-hydro-dynamic-instability does actually take place. Nor is it the only kind of instability that occurs. This gas, which consists of positive and negative ions, insists when you try to work with it, on starting to oscillate. The positive and negative ions beat against each other and the oscillation, in turn, induces phenomena like turbulence, which give rise to a loss of the valuable gas.

The situation is a little bit similar to that in the art of flying a hundred years ago. Then, people were worried about turbulence in aerodynamics and there were gentlemen who proved that to fly is impossible. We had at least one encouragement in those days, those of us who were around: we could see the birds fly. Today, we have only one kind of model for natural thermonuclear energy release, and that

is the model furnished by the sun and the stars. This model we cannot copy so easily because the sun and the stars do it by the brute force method, or perhaps what is even worse, by sheer inertia.

We have to do it more cleverly. If we do it, we will have a cleaner fuel, we will have an abundant fuel, and by having worked out the appropriate method of confinement by magnetic lines of force, we shall automatically be able to generate electricity without moving parts, without moving anything, except the magnetic lines of force.

Can we do it? Almost ten years ago, I was asked the same question about hydrogen bombs, and I couldn't do anything but enumerate some doubts and difficulties, such as those I am putting before you now. And when one in the audience said, "Well, Edward, we saw such difficulties four years ago. Do you know whether you can do the thing now?" I said, "No." When they asked, "So what is the progress as compared to what you told us in 1945?" I was forced to say, "Today we don't know the answer on the basis of much better evidence."

We have done a lot in the last seven years in exploring the properties, all the possible instabilities, of exceedingly hot ionized gases. We begin to understand them. We begin to know how to avoid them. Perhaps we may even get an inkling of how to use them.

Today, we don't know the answer on the basis of much better evidence, and I believe it is extremely important that work on controlled fusion continue because the end result is valuable and its eventual achievement is probable. Maybe

it will be the year 2000, maybe it will be even later. In the meantime, we will have learned a lot about electric discharges, about how to use a hot gas in a bottle, and there are all kinds of amusing uses of that.

I still have one other, more fantastic and, I believe, more feasible project to cover. And this is Project Plowshare, the peaceful use, not merely of nuclear energy, but of nuclear explosions.

A nuclear explosion is cheap and big, and it can be used for earth-moving jobs. You could dig harbors, you could dig water-level canals. You can break up rock formation, impermeable rock formation underground, and you could regulate water seepage and water flow below the surface. You can use it in mining. You can use it in a strange way in energy production, because you might make a big explosion very deep down in the ground and then mine the heat as today volcanic heat is mined in both Italy and New Zealand, converted into live steam and used to turn turbines.

All this can be done in principle. The easiest of these undertakings, the digging of canals and harbors, what I would like to call geographical engineering, is not only feasible, it is demonstrably possible.

We, furthermore, can undertake a beautiful exercise. I like to call it the exercise of putting the cart before the horse: using nuclear energy to get more oil.

How do we do it? With the help of nuclear explosives, you can blow up several hundred feet of overburden from a shale deposit, and you may strip-mine these shales.

There are other methods. We know, at least to some ex-

tent, how to break up underground formations. We might make the material more porous, pump out the oil more easily, and furthermore, open up for exploitation gooey or solid substances like tar sands or shales. If once they are broken up, they might be accessible to a heat-carrying fluid which will allow a release of more of the oil.

All these are dreams, but dreams which to some extent will come true, if only we are permitted to experiment with the effect of nuclear explosions. Furthermore, there is one great surprise in store for us if the development is not stopped. We are on the track of making completely clean nuclear explosions, explosions which will leave no radioactive fallout, which will not have any of the dangers of reactors and not even the slight dangers of the present world-wide fallout associated with them. If we have that, our blasting of canals and harbors, and carrying out of other plans, can proceed with great ease and great safety and great flexibility.

If people will not be too nervous, if progress is not stopped, this can be done. I would like to close on this one idea. When I read the novels of Jules Verne (and I'm sorry I haven't read them for a few years, because my children have outgrown them) I am struck by one thing more than by anything else: I'm struck by his optimistic attitude. When a new big possibility comes up fraught with uncertainty and with danger, he says: "Let's try it." In contrast, today's science fiction doesn't tell us anything, except how terrible, how dreadful the consequences of science will be.

The Russians in the last two or three years have per-

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formed eight explosions at or above one kiloton. They have announced their intention of blasting at the level of thirty kilotons. They have claimed, and we have not checked, that these explosions have not been nuclear. I think that the future will belong to those people who will look ahead in a positive and constructive way and who, after taking all the many and necessary safety precautions, will proceed confidently toward imaginative goals.

Thank you very much.

DEAN BROWN: We have taken a rather spectacular journey since ten o'clock this morning. We started with man, developing energy in the form of wind power and water power, and we have just been shown a vista of man's developing electric power without moving parts, as a result of our study of thermal gases.

I know that there are many questions that you will have of Dr. Teller. I would like to ask one question to start. It's a clarifying question, Dr. Teller. As I understood your comments, nuclear fuel, as fuel, BTU for BTU, is perhaps about 70 per cent as costly today as conventional fuel. The adaptation of nuclear fuel to useful purposes, however, involves a high security hazard, and it is this latter, as I understood your comments, that puts the additional costs on the end product of fuel produced from nuclear sources. Is that correct?

DR. TELLER: Yes, but I would also put a slightly different interpretation on it. The cost comes from the capital equipment and the handling. If, today, by magic, all the radio-

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active hazards would vanish, these costs of capital equipment and handling still would remain great, but because of greater flexibility, both in research and in actual application, they would start dropping, in my opinion, very fast.

Capital equipment and handling costs have remained high because radioactivity imposes all kinds of limitations, both on the actual execution of the job and on the research connected with the job.

DEAN BROWN: Here is another clarifying question. Would you please summarize briefly the danger from increased carbon dioxide content in the atmosphere in this century?

DR. TELLER: At present the carbon dioxide in the atmosphere has risen by 2 per cent over normal. By 1970, it will be perhaps 4 per cent, by 1980, 8 per cent, by 1990, 16 per cent, if we keep on with our exponential rise in the use of purely conventional fuels. By that time, there will be a serious additional impediment for the radiation leaving the earth. Our planet will get a little warmer. It is hard to say whether it will be 2 degrees Fahrenheit or only one or 5.

But when the temperature does rise by a few degrees over the whole globe, there is a possibility that the icecaps will start melting and the level of the oceans will begin to rise. Well, I don't know whether they will cover the Empire State Building or not, but anyone can calculate it by looking at the map and noting that the icecaps over Greenland and over Antarctica are perhaps five thousand feet thick.

DEAN BROWN: I am going to ask Dr. Teller two more questions before we turn to the next speaker. If a truly clean bomb is just over the horizon, can this clean process be

harnessed on a controlled basis, thus eliminating the need for elaborate safety precautions in stationary nuclear power plants?

DR. TELLER: The clean process is based on the thermonuclear process. Fusion reactions can be carried out cleanly. But as I have tried to explain to you, the fusion reaction has its own difficulties. Fission produces unavoidably a great variety of radioactive substances and some of these are really disagreeable.

Therefore, the fission process cannot be cleaned up.

DEAN BROWN: You have dealt, Dr. Teller, with combustion and nuclear energy. How do you view the future of fuel cells and other means of energy conversion currently being investigated?

DR. TELLER: The fuel cells, are, of course, a really wonderful idea and there have been signs recently that fuel cells will be highly successful. I would say that discussion of the fuel cells belongs primarily with the ways that the fuels are exploited, rather than in a discussion of the fuels themselves. Fuel cells will perhaps make it possible to use conventional fuel with better efficiency and also to use it much more conveniently.

Fuel cells could be run on solar energy and this, in turn, might be most useful for certain purposes like heating of isolated houses or like objects even farther away, such as satellites. Such conversion of solar energy directly into electricity would be a most wonderful invention. I believe that the direct conversion of heat into electricity is something that should be given the most serious consideration in con-

nection with nuclear reactors, too, because a nuclear reactor today works in the rather clumsy fashion of first giving the energy to a heat transfer liquid, creating problems of heat transfer, corrosion and everything else, and then letting this liquid, in turn, do the work outside the reactor.

There is a possibility that a future reactor will spew out electricity without any intermediate agency and under those conditions the cooling of the reactor could occur at much lower temperatures, with much less difficulty and with much less corrosion.

Therefore, this whole development of direct conversion into electricity is a very fertile and interesting field. I have not referred to it in my talk because it has not much to do with my topic but I am grateful to be given the opportunity to comment on it.

Thank you very much.