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"Needed Social Innovations (Lecture 2)"

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JOHN RADER PLATT: I said I would talk this afternoon about needed social innovations. Well, TV can stay for a moment… Needed social innovations for long-run survival. We used to talk about for a steady state society—it was hard when *Limits to Growth* was being written to convince people to not talk about an equilibrium society. But an equilibrium can be a static equilibrium. Steady state has an idea of a flow system, where there is just as much water coming into the tank as there is flowing out, so it’s come to a steady state. So that was an achievement, to get them to talk about steady state. But then, these days, people say *Well, the state might not be steady, but what we need is a sustainable society.* We may have to put in lots of energy and capital investment, for example, in Third World countries for the next 30 years, but that does not mean we are going to always put capital investment in Third World countries. Or we might have a low birth rate for a while… while we are kind of leveling off population, and then it might go up again.

A sustainable society is one where we don’t destroy what our grandchildren will need, and we keep managing things in an intelligent way for the long-run future, even though it might not be exactly steady. Well, in order to discuss that, I think I want to discuss where we are in an evolutionary scale of things. And here I am going to go on from this morning's talk, where we were talking about the great inventions of the last forty years or so since World War II. We have these tremendous inventions which have… some of them have leveled off, 1978. Question is, that I'd like to raise, is how big are these inventions from the point of view of evolution, of human evolution and the evolution of life on this planet? Is television big compared to speech? Is it big compared to the coming ashore of the land animals?

As soon as you begin to ask questions of this sort, you don’t know how to make the comparison. In fact what we might do is draw a time scale starting from the origin of the planet, which is estimated to be 4.7 billion years ago, and coming up to the present, *p*, and what are some of the things that have happened, and make a list of some of these things. Well, one of the things that happened was the invention of cells. It’s not sure whether we could have talked about life before there were cells. Certainly, with cells life becomes fairly clear. Cells have been discovered in the ancient rocks about 3 billion years ago, 3.3 I think it is. Somewhere along here, the cells learned to do photosynthesis. They were little beasties called the blue-green algae, and these terrible nasty little one-celled animals go back to 2 billion years ago or thereabouts. And you know what they did? They polluted the place. With photosynthesis, they began to produce pollution called oxygen, and the sulfur bacteria and all those other bacteria that been around for millions, billions of years, said they are poisoning the place! And they held mass meetings and they said, *Down with the blue-green algae, they’ll kill all life*, and they did. The oxygen came, the atmosphere turned into a totally different kind of atmosphere, and those poor old sulfur bacteria and anaerobic bacteria were killed off. The only place where they live now is in oil seams and deep underwater and under dead, decaying things where you keep the oxygen out. There are still a few of them around, but they are dead; they are living on the fringes.

These polluters took over the earth and then somewhere along here, there came multicellular animals. That is supposed to be about 1 billion years ago. Then somewhere they developed nervous systems and eyes, and somewhere they came ashore, and we had the coming ashore of the land animals. Well, you know some of these stages, I'll jump over a few hundred million years in which there came mammals and birds and things like that. And about 2 million years ago, according to the present estimates, there came to be what we call human beings. And the things that made them human were tools, and fire, and speech. Now, we don’t have any record of speech, and the records on fire are very dubious, but tools are the identifying characteristics of the genus *Homo*. Of course they developed various sorts of things, like living in caves and painting pictures of bison on the walls.

But somewhere along here, about 10,000 years ago, (this was 2 million years ago), 10,000 years ago at the end of the glaciers, there came a new upsurge of organizational energy in human beings, it appears. They created first villages and then cities, wheels, writing, metal, and now you come on into the historical era. King Tut's tomb and after, so to speak. And now you have the science of the Greeks, the development of mathematics and astronomy. And then in our own times, the last few hundred years, we have the development of scientific technology. In the last 600 years or so, with printing, gunpowder, the mariner’s compass, suddenly the world becomes our oyster; we suddenly have methods of communicating rapidly to millions of people.

And then in the last 40 years or so, since World War II, we have had some of these developments that we talked about this morning, such as television, such as space travel, such as nuclear weapons, and so on and on. How do these inventions compare with the earlier ones? Obviously, it's very hard to make such a comparison because they are of different types. But if you will classify them according to types, now we can begin to make some guesses to how they might compare with the earlier ones. I've recently been working on an article called "Eight great evolutionary jumps today." I hope I will get *Science* to publish it. In it I've listed some of the evolutionary jumps, some of the big jumps of the last 40 years, that is since about World War II. And I've tried to find categories by which they could be compared with earlier things. For example, molecular biology, recombinant DNA, for example, which I guess everybody's heard about by now, is a form of genetic mixing. Recombinant DNA is a method of taking genes from one organism or one species and putting them in the chromosomes of another species, so that the other species gets them. At San Francisco State [University], they have taken the human insulin gene and put it into the *E. coli* bacterium, so the *E. coli* bacteria can turn out insulin by the kilogram, and it may be a very much cheaper source of insulin than sheep insulin that we get today from the slaughterhouses.

What have we had in the past in the way of genetic mixing, in the way of creation of new species or new possibilities? The answer is *sex*. Notice the lewd undertone in my voice. [laughter] You thought I was going to give a dirty lecture, didn't you? But what I'm going to tell you is that sex goes back to those bacteria. At least, if they are anything like the bacteria in the laboratory. Bacteria already have a male and female type, the F+ sends its DNA into the F- and produces mixing. This was a fine method of mixing, marvelous, it increases the evolutionary diversity and makes possible the faster growth of new species than by simple ordinary mutations. This got enormously speeded up about 10,000 years… oh, this goes back probably 3 billion years. It got speeded up 10,000 years ago with the domestication of plants and animals. So this is minus 10,000. The domesticated animals come about 8,000 years ago, as I remember the latest statistics. Domesticated plants and animals still use sexual crossing between male and female, but they make faster selection, human selection for desirable characteristics. So this is how we got cattle that would stay on the farm and weren't outrageously fierce bulls, and this is how we got domestic dogs and sheep and hogs and so on. So this speeds up the time to make species from a few million years to down to 50 or 100 years. Now suddenly, we have the possibility of making species, so to speak, in a single generation. In a single year, one can create a host of new modes of plants or animals. We can make a million times as many new species because we can cross genes from plants, from fungi, from bacteria, from animals, from yeasts;

we can cross all of these with each other in ways we didn’t dream were possible by the old sexual crossing methods.

The result is that this new technology goes as far beyond sex as the atom bomb goes beyond the chemical bomb. It is an evolutionary jump in terms of potentiality for the future, for the billion-year future or for the million-year future or maybe even for the hundred year future, with that insulin already coming out. Another example is our energy from sunlight. Solar electric. This is now used on satellites; there is a certain small amount of it used for amusement—you can charge your battery on your boat with a solar electric panel these days. A little expensive, but it’s convenient when you’re out at sea. Not much of it yet. On the other hand, the potential is enormous and there are many companies now trying to work on silicon cells, and they claim that the cost of silicon cells will come so low by 1982 that suddenly solar electric will be competitive with coal or even cheap oil in terms of electric power. You will cover your roof with solar cells not just for warming water, which you can do already, but for getting yourself 10 kilowatts of electricity to run all your machines in the house, and so on.

Other modes of energy that we now have recently are nuclear, and of course the possibility of fusion, although that hasn’t been done yet. I don’t think these are as important for the long-run future, perhaps, as the solar electric, and the reason is that we have troubles with nuclear power, with storage, with safety, as we all know, and there’s fears about it. Similarly, we have trouble in the long-run future with coal and oil, not just because of the cost or the scarcity; coal will last a several hundred years, probably, if we used it for all the world's energy, but it pollutes the atmosphere with carbon dioxide, and it looks like this could heat up the earth in a serious way. If we continue to burn fossil fuel in the next 30 years the way we have in the past, the amount of carbon dioxide in the atmosphere will double, and the estimates at present are that this will heat up the earth by 1 to 3 degrees, it would melt the polar caps in the course of a few years; it would shift the agricultural belt; it’ll be a major perturbation on the atmosphere and one that we may not want to get into, if we can go over to solar electric which is non-polluting by comparison.

What does this compare with in the form of energy in earlier times? The answer is photosynthesis. That, 2 billion years ago. And from the point of view of the long-run future, this may be as important—from the point of the view of the billion-year future or the million-year future—this may be as important as photosynthesis. Because, you see, this gives us direct electric energy. If we can get from satellites, which some people are talking about—Peter Glazer in particular—we can beam down the energy and we would have a non-polluting source on the earth and no thermal pollution either, other than the energy that we are using. It is more efficient; it’s 20 to 30% efficient, whereas photosynthesis is about 1% efficient, and it doesn't go through this chemical step of having to first make a product which then you have to take somewhere and burn. This gives you the energy directly. Now, there are advantages in these products. We will always use photosynthesis, probably, for chemicals of various sorts. Nevertheless, for the purposes of electrical power, clean power, it may be that the long-run future may belong to solar electric. It is the last 40 years that have given us this, and it may be, in the long run, far more important than photosynthesis is.

To take another example, rockets are a method of travel through the medium of space. In some ways this compares with the invention of ships, which were a method of travel over the oceans, over that non-resisting, easy medium of the oceans. They go back about several thousand years. The jump to space, space living in capsules, space factories, perhaps; the Russians are trying to do some factory experiments in space; space power stations, perhaps one of these days; perhaps even, one of these days, space settlements. If we build power stations, it'll take as many people up there as the Alaska pipeline, possibly thousands of people living and working in space. They'll have to have places to stay. They'll have to have little cities that'll hold thousands of people, with restaurants, and gravity, air and water and their own food growing in the sunlight, and recycling their sewage, and recycling their minerals, and it'll be a self-contained little planet. It'll be—some people have called the planet "Spaceship Earth"—this will be "Planet Space," so that the spaceship becomes a planet, instead of the planet becoming a spaceship. Turned it around, you see.

The result may be the first closed ecological system; it may be the first system of human beings that has an indefinite amount of energy. You see, on this planet, if we want more energy we have got to cut down more forests; we have got to expand against the demands of other nations and other people who want their part of the surface of the globe. In space, you just extend your mirrors another kilometer further, and you've doubled your solar power, and whenever you need more power, why, you run the mirrors out a little further. It is possible that this space jump may be like the coming ashore of land animals in terms of new habitats, and this is the theme, of course, of Gerard O'Neil's recent book *The High Frontier*, where he compares the frontier in space to the frontier of America from the European point of view after the discovery by Columbus. We still have only sent some dozen people to the moon, and some fifty or a hundred perhaps have already been in orbit, Russians and Americans and now a few other countries. It's like Columbus' first ship discovering the new world, but the implications for the long-run future, for the million-year future, for the billion-year future, may be as vast as the implications of the coming ashore of the ocean creatures coming into the land, with all the new ecological niches, all the diversity, all the energy they have on land that they don't have in the dark oceans. All the possibility of communication, of astronomy, of seeing other worlds which you can't see from the ocean. So our possibilities of space represent a new leap for us.

Let me list some other things, some baddies. How about nuclear weapons, how about ICBMs, intercontinental missiles? These are a form of weapons. Weapons can't be really distinguished from tools in the early days. The earliest tools were teeth and claws, and then when early man and woman made tools, back 2 million years ago, these tools were probably used for killing as well as for grinding food and chopping up plants. So tools and weapons remain overlapped for a long time, but the tools and weapons of early humanity 2 million years ago are comparable to our nuclear weapons and to our new modes of automation, which is our new method of making tools today, or our new method of using tools today. These go as far beyond our old weapons, the club, or even dynamite, or even the long range railroad gun of the 1930s, as those went beyond sticks and stones of 2 million years earlier. So this represents an enormous evolutionary jump.

I'll mention three more. One is the electromagnetic spectrum. I quoted this morning Teillard de Chardin saying that the discovery of the electromagnetic spectrum was a prodigious biological event. Electromagnetic spectrum means essentially TV, lasers, radar, all those new uses of these waves that we can send out. What are they in terms of this evolutionary classification? The answer is, they are a mode of detection and signalling, and if we look back at modes of detection and signalling, probably the greatest jump ever in evolutionary history was the jump from eyespots, photodetector spots, to image-forming eyes. We still see a number of creatures that just have single eyespots—the little blue-eyed scallop, if any of you have been around the coast where scallops are, you know there's a row of little blue dots around the opening of a scallop—and they can detect light and shadow, and when a shadow comes across, why, it closes and flips away. But when you go from a few eyespots like that to a cluster which are in an array with a lens that focuses on them, or which point in different directions, suddenly you have an image-forming eye. And now you can see at a distance. Now you can see predators, and prey. The blue-eyed scallop, if it had a magnificent brain, could still hardly imagine what it would be like, how different its world would be like, if it could suddenly *see* images of predators and prey some distance away. Image-forming eyes have been invented four different times in four different phyla: by the vertebrates like us, with our eyes; by the insects; by the octopuses, the mollusks; and recently it has been found that there is a little worm in the Mediterranean that has a tiny eye about a millimeter across which is an image-forming eye. So eyes are almost inevitable when you come to a certain stage of nervous organization, and as soon as you get them, suddenly you can see at a distance, you can make plans, you can avoid danger; you have to have sight before you can have foresight. (That's a joke.) [laughter]

Now we have gone from vision, which goes back about one billion years, to television, where we see around the world 10,000 miles or to the moon. We all walked on the moon together, we all stood beside Sadat in Jerusalem. Two billion people simultaneously having the same experiences. Radar that goes through nights and fog; darkness, can see the mountains of Venus and mountains of Mars. Lasers which we can use to cut holes, to send communications on, and so on. They go as far beyond vision as vision went beyond the eyespots of the creature before.

Then we need to mention data processing, electronic data processing and feedback. This is one of the great discoveries of the last 40 years, feedback control systems. If you look to what this can compare with, I call it problem solving, although it might be called by some other names. It is a method of putting in information, storing the information, and then using that information to control the environment. There have been… probably the thing it can be most compared with is brains. The invention of brains or complex integrated nervous systems, which goes back again, about 1 billion years. I like to say there are three methods of problem solving, which have been invented in the course of evolution.

The first method of problem solving is problem solving by survival. This is the method of the gray moth against the tree trunk. It discovers that the color of the tree trunk is gray because if it's too black, it gets picked off by birds; if it's too white it gets picked off by birds, but the gray moths survive, and so they have solved the problem of what color is the tree trunk. That’s a metaphorical way of putting it. But you see, the problems of food, of lifetime, of prey, of predators, of survival, are encoded in the chromosomes, in the DNA within each individual organism. So this is problem solving with storage in the DNA.

The second method of problem solving in evolution is problem solving by learning. The creature that now begins to have a nervous system that learns, it does not have to fall over the cliff to die for in order for the race to learn that there is a cliff there. It feels the ground slipping and it’s stumbled before and bumped its nose, and so its draws back before it gets to the cliff, or it sees another animal fall over the cliff, so it draws back because it has learned not to follow other animals that fall over cliffs. And the result is that we now have learning by the individual, not by the species, but by the individual. This will be encoded in the neurons and the brain.

The third form of problem solving is problem solving by anticipation. This is the method of science, where we know the laws of nature, or the laws of biology, or physics, or society, and we can solve problems because we work out these laws, and anticipate what’s going to happen correctly, we hope, before the thing has happened. A good example of these three modes is the first Sputnik that went up in 1957. Somebody had emphasized that this morning. The first Sputnik was not one of 10,000 Sputniks that were all shot up and some went too high or some went too low and only one found the right orbit. That would have been very wasteful; that would have been the DNA method, you see. It was not a learning Sputnik that tried one orbit and then another until it found the right one; that would not have been very efficient either. Instead, it was programmed by physics and the thermodynamics of rocket engines to steer, to turn on its motor and the turn it off at the right time, so that it went into the right orbit within one degree in angle and within 1% in velocity of what was intended to go around the earth.

The result is that the new mode we can use when we begin to have science. And that is the new mode which now gets encoded in our automatic machines, with data processing and feedback control. It represents a totally new mode of solving problems that we have never encountered before. We now have this capacity that we have never had. In that sense, it is a collective mode of brains, a collective mode of problem solving, which in some ways goes as far beyond brains as brains went beyond the ordinary old DNA.

I'll mention one last change in the last 40 years. That is systems design, systems analysis and design. By systems analysis and design, I mean the sort of thing that was done in creating the atom bomb, and then in creating the Apollo project, where people landed on the moon. This is a mode of creating change, fundamental change in our capacities as a species. There were a hundred thousand people, professionals, involved in the Manhattan Project that made the first atom bomb. It took about one-half percent of our GNP, it took about 2 billion dollars for four years, working to develop this new form of energy, this new form of weapon that we had never had before that you can just guess five years earlier that might be made. The same thing with the Apollo project: it took finally about 27 billion dollars, it was also in the range of a half-percent of our GNP; it took about a hundred thousand professionals, it took nine years, but at the end of the nine years, why, it had achieved its jump into space. These could be compared with the invention of systematic thought, where thought—I mean forethought, in the sense of being able to anticipate things ahead, being able to analyze them symbolically, and then being able to act on them as such a way as to control the environment or the future better. And so today we have a powerful method of shaping the future which we never had before.

Now, how does our old story of the evolutionary jumps look? Now it looks like these jumps of the last forty years are in no way inferior to some of the earlier jumps. They are as big or bigger in terms of their implications for the long-run future, a million-year future, maybe even a thousand-year future or hundred-year future, as some of the greatest jumps of the past. Nevertheless, there is not one, not two, not three, but a bunch—whether you agree with my eight, or whether you want to say it's three of them, or whether you want to say it's twenty or a hundred—there is a bunch of jumps occurring within our lifetime which are as big as the greatest jumps in all of evolution past.

In some ways—there are several things you could say about this—first is, many of these jumps are unpredictable but inevitable. I mentioned the case of eyes. The blue-eyed scallop cannot anticipate eyes, can't say when they're going to come. And yet when they come, they come in four different phyla at different times, because once you get to a certain stage of interacting with your environment with a nervous system, eyes become inevitable. If there are creatures on some other worlds, other planets far away, I feel sure they will develop image-forming eyes, and that these image-forming eyes will be quasi-spherical and point in all directions, and will have an array of detector cells of some sort. They might be made of something else from what ours are, but this is the nature of the physical world, that an image-forming eye can pick up light from all directions it can focus on it and make an image. You wouldn't have known that if you were a scallop. So, it is inevitable and yet at the same time it is unpredictable.

A very great man who died recently, a man named Conrad Waddington, compares evolutionary jumps to an evolutionary valley. Evolutionary landscape. What I've drawn here is the ridge around the valley, and you come over the ridge into the valley and you fall into the river and it goes down to the main stream, but if you come over the ridge somewhere else, there is another little river, and there is another little river that comes down into the main stream, and the result is: wherever you come over the ridge, you go down to that same equi-final solution at the end. All these eyes look like eyes. There are electric organs in various fish. They are created independently. All the electric organs under a microscope look like electric organs. Some come from nerves, some come from muscle. There are wings in three different phyla. Well, four. Insects and reptiles, the old flying pterodactyls. Birds, and of course bats among the mammals. All of their wings look like wings. They have long, thin bones; they have camber, they have strong breast muscles which pull them, flap them through the air. So, the result is that you converge on a similar outcome no matter where you come from.

Nevertheless, before you get over the ridge you don't know that the valley is there and you don't know what it is gonna look like; even after you get over it, you're not sure. So today with television, we couldn't have predicted it. Maxwell, a hundred years ago, probably could not have predicted television. He predicted that there were electric waves, that was as far as he got, and yet one sees the steady line from Maxwell, to Hertz who made the first waves, to Marconi with his wireless, to radio with Deforest and the tubes, to television. It's a steady stream, every one of the inventions along the series has been invented a dozen times over by different inventors. If one had died off, another comes along and takes his place.

The television was inevitable, even though it was unpredictable. And today, I think, its effects on our lives, on the lives of our children, on family, on education, on diplomacy, on world images, on our whole style of life, I think is almost unpredictable. We should do the best we can to predict it; we should anticipate the dangers. That's why I'm talking. Nevertheless, there will be surprises.

Second point is the increasing scale. Scale of the creatures that are bound together by these great evolutionary jumps. You start off with single-celled animals, but single-celled animals cannot invent vision; they cannot come ashore on the land, they'd be baked. It takes a multi-cellular animal before you can make some of these steps, before you can begin to have teeth and claws and legs and migration. As you move down this scale, you can't have cities until you have thousands of people. You can't have ships, or probably writing, until you have people to write to. You can't have railroads until you have cities of a million people or so who need the coal, or who can travel back and forth between one city to another. There is no point in having printing unless you have a society which has enough educated people who can read the printing. So you'd need millions of people there.

Today you see these new inventions; they require societies of 10 to 50 million people in order to create them. We could not have created rockets with a small country; we could have not jumped into space without having the resources and technology of an enormous continent either Russian or the American continent. An island society can't produce the first rockets to go into space. You come on down here, the same is more or less true of these others. The result is that as you move down these stages of evolutionary jumps and new inventions, it takes a bigger group to create them and at the same time it makes a bigger group more stable and builds still larger groups.

When you ask the question, *What next*? The only answer that I can see is that we must go to a global society. These inventions are already inconsistent with the nation state. Television, intercontinental rockets, the solar electric satellites are inconsistent with individual nation states warring against each other. Now, it may be that the nation states will win; that is to say, they will destroy themselves and so make this forever impossible. But if this continues to be possible, the nation states will have to amalgamate themselves into much larger units and much more peaceful than anything we have seen today.

The result is that I think the next 40 years are very hard to predict. I think the year 2000 is very hard to predict. Two of those developments in the last columns have come in the last nine years: the jump to the moon came in 1969, recombinant DNA came about 1973. What does the next nine years have in it for us? I don't think we can predict. Well, we might make some guesses, sure. I'm as glad to make guesses as anybody else. But I think we would all be prepared to be surprised by what may come out in the next nine years. By the year 2000, the situation, the society, the world, may be as different as ours—what is that, 22 years off? Go back 22 years, 1956. Before the women's movement, before the civil rights movement, the middle of the Cold War, hydrogen bombs. Our whole philosophy, our whole organization of the world, has turned around in those 22 years. And it may well be that it will turn around again by the year 2000.

One more point. A reason for all this coming at one time is because of World War II. These are all simultaneous because they reinforce each other, and because we put research and development teams on to making them. World War II delayed some development; it delayed television, which would have come by 1940 probably without the war, but it accelerated others. There in that last year, 1945, at the end of the war, one suddenly has radar atom bombs and long range rockets, the first jet planes, and the beginnings of the electronic technology of data processing, and electron microscopes which have made possible a new world of biology. These have all come together like a thunderclap in time, a thunderclap, like a lightning flash, to name something which might be even faster.

On this scale of evolutionary history, 2 million years since the first humans is the narrower than the narrowest line I can make with this particular crayon. 40 years of these last great developments is narrower than the narrowest line I can make with the blade of a knife. It is instantaneous on the scale of evolutionary history, and yet we see we have been building up to it in this way all along. From this point of view, it is like the moment of birth, where you've got this nine months' gestation, and by and by things begin happening, and it's hard to carry the load, you've got certain limits to growth—[laughter] I'm speaking with great empathy, you imagine, I haven't done this myself. And then by and by, everything begins to move. You've got contractions, and the baby's kicking inside, and it's saying *Hey! Wait a minute! I don't want this! Let's go back! I changed my mind!* You can't go back. Once you are at that point, it's gotta come out into the new world, and this is of course a moment of the greatest danger for the baby in its whole history. It suddenly, within a few seconds, has to learn to breathe, to cry, sweat, swallow, excrete, to do all those things that were done for it before, and if any one of these systems fails, it is dead. Now happily, in the case of babies, they've got the chromosomes inside that tell them how to do these new things. The chromosomes are the result of survival. They are the result of billions of babies who died along the way because they did not have some of these mechanisms. So the ones who survive today are the ones who have the mechanisms. I often think whenever I have some accident and recover from it, break the skin, clip myself on the eyebrow as I've done a couple of times, falling on rollerskates or something: That orbit is up there, that bone is up there because a billion animals died who did not have it. It's been paid for by life.

Well, I am emphasizing that because we don't have the billion animals this time for our system as a whole. This is the first one. How in the world shall we solve these terrible problems of managing these enormous new powers, these destructive powers, these creative powers? How can we manage them when we've never had them before? The answer is only by anticipation. We cannot solve the problems by survival. We cannot solve the problems by learning, except within limits; we learn within a year or two that that was a bad policy—quick, change it. We can only solve it by systems analysis and design. This is the meaning of new groups who are looking towards global systems analysis, like the Club of Rome group, the global modeling projects, the *Limits to Growth* projects, and now all over the world there are more and more economic systems, more and more technology assessment systems which are trying to look into the future deliberately, because that's the only way in which we can anticipate for this newborn infant… what's in it, ahead?

It's worth saying another word about this arrow. I don't think anything in our past is of much help to us, just as with a newborn baby. All that behavior of the fetus inside, all that dependence on the umbilical cord, yeah, it's some help, but it doesn't solve those new problems very well; you've got to solve them by a new mechanism. So, our sense of history, our study of what has happened to other societies, our study of archaeology, doesn't help us much here. We've got to do this by anticipation and by careful analysis. Nevertheless, I think we can see some directions which are important to go in, and one of these directions is space. I didn't believe in it until about three or four years ago, and now I've become a convert. Now I think that the ideas of Peter Glazer, on satellite solar power stations, and the ideas of Gerard O'Neill on space settlements—these may be the directions of the long-run future and possibly very important for the short-run future.

Glazer's idea of satellite solar power stations—maybe somebody has already talked to you about this—the idea is to put into space an array of silicon cells, possibly mirrors which focus sunlight onto a boiler. This array converts the sunlight into electrical energy; the electrical energy is beamed down by microwaves to the earth, and is picked up by an array of microwave antennas on the earth, which might be several kilometers in each direction. Then this is converted directly into electric power, into electric grid. At the present time on the earth we use 1/10000th of the total solar flux that's coming down. All of our fossil fuel energy is one ten-thousandth, 100th of 1%. We could collect sunlight and beam down several times this much energy. There is some fear that it might heat up the earth, and if we got up to 1% we could produce that 1-degree heating that we are now worried about with the carbon dioxide. But we don't have to heat up the earth. We can make reflecting roads and roofs which would reflect the sunlight energy back to space, and just balance the amount of electrical energy we are getting in. In fact, I think many of our industrial concentrations today, where the cities are heating up, they need to have reflecting roads and roofs in order to cool down Los Angeles, cool down Japan, and so on. But the result would be that we could possibly have 10 to 50 times as much power available on Earth for industrial expansion—those multinational corporations, yes indeed—but also for the Third World, for developing countries to come up to equality with the developed countries today.

This would take several decades. Glazer's time table is something like if we started research and development planning right now, we would be able to put up the first pilot station, maybe five thousand megawatts, in about thirteen years. The estimate is that within 20 years, they would bring back more energy than the Alaska reserves. Within 26 years, they would pay back their total investment with 10% interest, and then you would essentially have free power from there on. The basic point, regardless of these cost figures, which are going to change as people do things, the basic point is that the sun is our great mother. The sun is what we depend on. It's the one that pours out energy, like the great cow of the world whose nipples we milk. It is pouring out millions of times the energy we use on this earth. The earth is a beautiful place, but it is dark. It's dark half the time because of its rotation, it's dark in the depths of the ocean, it's dark under clouds. Out there is the new Jerusalem, with the light of 10,000 suns, where there should be no night. One can read Revelations with a totally different point of view when you begin to think about the potentiality of us as intelligent creatures, born on a planet, moving out to use the full energy and resources of the sun.

It is also true of other resources. We do not have to take resources up from the earth. It is 20 times cheaper to mine the moon than mine the earth. A small crater on the moon, a kilometer across or thereabouts, which is quite a small crater, has enough material to build hundreds of space settlements. The materials of the moon are oxygen, aluminum, silicon, and all the other metals. Oxygen one uses for making water, and maybe manufacturing. Aluminum you use for structural members, silicon you use for the solar cells. It is exactly the kind of material you want to make a viable space settlement. The asteroids also have enormous amounts of material; the asteroids may be a shattered planet, and instead of being limited to the surface of the planet, as we are here, the asteroids could essentially be mined and could provide enough materials for—listen to my figure: ten million space settlements of one million people apiece. The whole solar system could be filled with little planets with groups of people on them, in terms of the resources available out there.

There was a Russian dreamer and rocket enthusiast back in the early 1900s. His name was Tsiolkovsky. Konstantin Tsiolkovsky. And he was to Russian rocket development as Goddard was to the U.S. rocket development. Tsiolkovsky wrote a book back in 1905 called *Beyond the Planet Earth*. One of the memorable phrases in that book is, "Planets are a wonderful place for the evolution of intelligence; they are a wonderful cradle for intelligence. But who wants to stay in the cradle forever?” And so in a certain deep sense—regardless of our particular cost figures on solar energy, regardless of the particular capital investment in the first solar satellite power stations—in the long run, that is where the future lies. That is where the resources are; that is where the energy is; that is where the limits to growth cease to exist for us, for at least the next factor of one million. It’s very interesting. The U.S. Senate has just passed a resolution to NSF to start construction of a pilot satellite power station last month, sponsored by Harrison Williams of Rhode Island. I think probably the time has come. That is, this is within sight, in somewhat the same way that the Apollo project, landing on the moon, was in sight in 1959.

O’Neill’s ideas of space settlements are essentially, I’ve hinted at… he has the ideas of various forms, they might be big cylinders which would be rotating; they might be donuts or toroids which are going around, spinning around their centers. His idea is that these might have from 10,000 to 1 or 2 million people; it might be as big as Philadelphia. Some people say there would be a sense of confinement. But these would be 20 kilometers long, six kilometers in radius, and there is not very often today that you can see for 20 kilometers in this city, only when you get out and look at the mountains can you see that far. O’Neill even proposes that there should be mountains. If these spin around their axis, you see, there’d be six kilometers into the axis at the end, and he suggests that these could be contoured so it looks like the Grand Tetons. So you could spend your Saturday afternoons climbing up the mountain wall at the end of your cylinder. It’ll have waterfalls, it’ll have… you see, six kilometers is thicker than our atmosphere here; you’ll have blue sky, clouds, rain, and trees. He even has very fanciful diagrams showing San Francisco replotted inside a container of this sort and there is the Golden Gate Bridge and there are the ships sailing on the bay and so on.

A lot of this is fanciful; a lot of it is science-fictiony. The thing that O’Neill showed—two things that he showed, of greatest importance. The first is that these can be done with existing technology today. The bands around the outside that hold the cylinders together under their spin which gives everyone inside ordinary gravity, those bands can be the same size as the cables on the Golden Gate Bridge. It doesn’t take fantastic new inventions in titanium, or fantastic plastics. The windows can be the same sort of plastic that’s in the windows of airplanes. So it can be done with existing technology. His second point is that essentially they’ll have so much energy and so much resources that they can spend their time—first they’ll automate everything, you can imagine that—they’ll spend their time making another settlement. He imagines daughter settlements will be created like buds from yeast every six to ten years. So in ten years, there will be twice as many, in twenty years, four times. In a hundred years, says O’Neill, with his wild enthusiasm, you could have 10 billion people in space, you could leave the earth behind as a wild park, and revisit it from time to time, like for a vacation.

And perhaps what's more important, in terms of the long-run future, we would suddenly begin to have some life rafts for the human race. If we pollute or destroy this planet by any of a dozen mechanisms that might happen in the next few years, there would be some more people, our children and grandchildren out there, who could carry on, who could go on living, who could carry on the evolutionary development in new niches such as we have not imagined.

This is mind-blowing to me not because it is science fiction, because it isn't. That is, we are already probably within 10 to 15 years of some sort of satellite power station pilot project. There may be enormous difficulties. They may be fatal. It might not work. I mean, it wasn't sure that we would get people to land on the moon. So you don't know until you try it. But we are at the moment of trial. And similarly, these settlements: O'Neill talks about the possibility of the first one by 1996, and the first big one with a few hundred thousand people by 2002, and the first with two million people by 2010. There are those of you in this room who won't be as old as I am by that time, if I did it right.

The result is that this is the moment in evolutionary history, when, so to speak, a little seed pod on the planet pops open and flings the seed out in all directions, for new inventions, new discoveries, new potentialities, which we couldn't imagine here. It is possible, of course, that if these cost too much money and take too much energy—if we destroy ourselves with nuclear war in the next ten or fifteen years before they can get started—then the whole project will be aborted. If we haven't gotten started with the space pods by the year 2010, my guess is that it will be essentially impossible to do. The reason is that the demands of the world for using that capital for developing countries, for the poor; the hostility to technology will have risen by that time; we will have gone back into transcendental meditation perhaps, or all be contemplating our navels and playing the flute, which are marvelous ways of improving quality of life of a different sort, but they are not ways that lead us into space.

My guess is we are now facing a little time window of about 30 years, during which we will go into space or, if we fail to use that time, we will abort. It'll be just like squelching the moment of birth in the case of the baby: if it can't come out, it dies. We might not die, we might go on surviving for millions or billions of years on the earth, at a very much lower level of population and perhaps of resources than we would otherwise have had. Possibly a very good life, but the moment of possibility will have passed for us. I think this is the most exciting potentiality of the next ten to thirty years, and—as you can tell from my enthusiasm—I think some of us will live to see it. I think we should make political efforts to do the necessary studies and take the necessary steps to continue to make it possible, continue to evaluate it to see what its dangers are. Obviously, I hope that we are just at the moment of birth for the human race in its cosmic adventures. Thank you.

[applause; program ends]