

BIRGENEAU: It's a pleasure to-- by the way, my name is Bob Birgeneau, physicist and administrator here at MIT. It's a pleasure to welcome you all to the third lecture by Jack Gibbons in the Compton Lecture Series. Third, and he assures me, his last, that he fulfilled his commitments to check yes for this. A really fascinating subject which I know everybody in this auditorium is interested in. Sustainable Growth: Fantasy or Vision?

Most of you want to hear Jack, not me. But let me very quickly run through a bit of Jack's background. Obviously had a really illustrious career. Got his PhD in nuclear physics at Duke in the middle '50s. He there afterwards was a bona fide scientist doing I guess I'd say hardcore experimental nuclear physics at Oak Ridge National Lab.

Then in the '70s, in the middle of the energy crisis, decided to use his scientific talents which he'd demonstrated so excellently as an experimental physicist looking at the energy crisis and energy issues at Oak Ridge. He moved to become the first director of the Federal Office of Energy Conservation. That was in '73. He then went back to Oak Ridge to become director of the University of Tennessee's Energy, Environment and Resources Center. Back-- obviously he liked Washington because in '79 he went back to Washington where he was head of the Congressional Office of Technology Assessment.

Was in that job until '93. And then in February of '93, he managed to pass through this. But I think it was at that time a horrendous filter which Senate put in front of anybody that Clinton tried to appoint. And Jack got through this process marvelously and served as a Presidential Science Advisor. Of course, here at MIT we've had a long history of sending our faculty down to Washington to fulfill exactly that purpose where he served for five years.

Jack doesn't realize this but I, as Dean of Science at MIT, I have an incredibly special debt to him because I guess about four years ago I was ordered by my betters to produce five year planned budgets for every department in the School of Science that assumed a 25% decrease in research funding over that time period. And I then had a meeting with my department heads to discuss the strategy and how we would do this, and my department heads had the appropriate response which is they said, we won't do it. And that we're just going to boycott and we'll see what happens.

So I thought about this for a while. Then I decided that especially with Jack there in his job that it was a pretty safe boycott. Besides the worst thing they could have done to me is to have fired me as Dean and then I'd have to go back to doing research and teaching again. Which is not exactly a horrible life. Anyway Jack, through I think really heroic efforts in Washington, actually managed to keep science funding up at a level that we feel it ought to be.

And most especially in the life sciences, actually, we've seen there's been a tremendous growth and has both led to remarkable advances in the life sciences and also has had a huge impact on technology and on the economy as well. And so I think all of us actually at research intensive and science intensive universities like MIT really owe a tremendous debt of gratitude to Jack. Since he stepped down from the Science Advisor position, he's done a wide variety of things. And actually rather go through that long list-- and also received a wide variety of honors-- why don't I instead just hand it over to Jack because I'm sure you're much more interested in hearing what he has to say rather than myself. Jack?

GIBBONS:

Thanks, Bob, for that kind introduction. One thing that happens after you've been around for a while is it seems to take longer and longer to get through your checkered career. I remember someone my wife overheard on an airplane one day was about-- this woman talking about a friend of hers whose name was Happy so and so. And she said, poor Happy. Her husband just can't seem to keep a job.

It turned out that was Happy Richardson, the wife of Elliot Richardson, who had been fired a number of times from various key positions in the Nixon administration. I'm sort of wistful today as well as very pleased, first of all, that in this busy time and in this beautiful weather you have honored me by coming to this room to hear me go on about sustainable development. That's a real honor. The second thing I want to say is that my whole time here for this almost a year now has been one of great satisfaction and pleasure to me.

And I want to thank my hosts in the Political Science Department and in the University as a whole. For Chuck Vest's invitation for me to come and join you for this extraordinary year. For the various departments and programs that I've interacted with. For the students that I've met on both this campus and at Harvard. The whole thing has been a great refreshment.

A wonderful way to-- I don't guess I would call it decompress, but a change of pace and lifestyle from working in the White House. It has given me a little time for a reflection for the first time in a half a dozen years or so. And my reflection has more and more focused on the coming century. And incidentally, I think MIT is a kind of an institution that is going to be increasingly critical if we are going to negotiate the coming century. And I'll tell you why here in the coming minutes.

But I also want to say personally at the outset here that I have a kind of a time perspective that most of you can't enjoy yet. Namely living for 70% of a century. A century, as you get older, gets to be a shorter and shorter period of time. And it becomes more and more a part of the way you think about things. I never thought about a century when I was 20 years old.

My three daughters will probably survive to the middle of this coming century, and my grandchildren may well survive to the end of it. So it's a really short period of time. And I want to focus today on this, what I will claim to be a rather momentous and extraordinary century for humanity. Now to remind you of where we've been over this past year. I would presume a few of you maybe have braved all three of these lectures, but not all of you, for certain.

And I'll remind you, therefore, in brief review before we have our exam of what I said before. The first talk I gave was on the 21st century. Will science and technology contribute to society or scuttle it? And I want to thank Gene Skolnikoff, right there in the middle of the room. Right here, Gene, in front of God and everybody, that your suggestion of that title was very helpful and I appreciate it.

Will it contribute or will it scuttle it? And my answer, of course, was yes. But in order to look ahead, you have to look back. And I reviewed at that time the enormity and the pervasiveness of the fruits of research and technology. And of course, the human application of knowledge always is capable of both good and evil.

It provides, as one observer said during the 1950s, it provides the promises of heaven and also the perils of hell all at the same time. And we talked about the goods. Dependable food, drink, shelter. Deep inroads in health improvements. Transportation, communication, more jobs, amenities that were unimagined even two generations ago.

An extraordinary national security based on technological prowess. Waste management. It is inconceivable to think of any major city, including Boston, that could get along without a well engineered, technical infrastructure for its survival. As one slide I showed said, the sewage is unbelievable. And so you need energy and technology even to provide for the amenities of our cities. And you can go on and on.

And finally, and certainly not least of all, understanding the world and having the capability to enjoy, appreciate, and wonder at the creation that we are in the middle of. But it also has its bads. The invention and proliferation of weapons of mass destruction. The human population explosion, which certainly was in spades during the 20th century. You know, we're talking about the Y2K problem, and I think everyone now understands what Y2K means.

Someone said the other day, it really ought to be Y6B. What's that mean? The year 6 billion, thank you. Thank you, John. And that is an extraordinary number, a Y6B here as we turn the century.

Environmental losses, aided and abetted by advancing technologies and economic activities. Deforestation. The invasions of exotic species, the loss of ecosystems, the increase of carbon dioxide in the atmosphere, on and on and on as the negative ingredients of that 20th century growth. And the tension with some of the traditional ethical and cultural and religious values that came about in conflict with the way humanity is going with its activities.

Here's a quandary. Only about six months ago, Pope Paul described a concern he had about science and technology putting humanity at risk. It's kind of an anti-technology connotation, but that science and technology were putting humanity at risk. And at the same time, here's a person who has fought rather valiantly against effective family planning technologies, which are arguably humanity's greatest risk, namely population explosion.

So we have quandaries and dilemmas now coming to the fore as we exponentiate our way into the 21st century. So overall, the growing dependence on science and technology for our survival is a truism. However discomfiting, that Faustian bargain of Goethe's may be to us. The growing dependence on S and T for our very survival. Well then, in looking in the 21st century from looking back at the 20th, we reviewed the escalating global impacts of human activities, the combined multiplicative effects of population growth, and economic activity, and its staggering advance in both of those variables.

The biosphere limits that were being encountered, in terms of our atmospheric chemical composition, in terms of fisheries, of biodiversity, water supplies. Across the board around the globe, clear evidence of reaching limits. Social stresses and pressures as well. And finally, obviously, the weapons of mass destruction. So the imagery.

It's not surprising. The imagery that began to emerge about 50 years ago and has reiterated itself during this same period of time. Albert Schweitzer before he died said that mankind has lost its ability to foresee and to forestall. Man will end up destroying the earth. Rachel Carson noted the pervasive and extraordinary impacts of the use of persistent pesticides on the balance of survival in natural ecosystems.

Most recently, there has been a comparison between the notion of great impacts on the earth of asteroids or bolides as they crashed into the earth and eliminated species and sort of messed us up for a while. Of course, you recover within maybe five million years, so why worry? The modern comparison is that humanity itself is a bolide, is an asteroid. It's taking longer, it's taking hundreds of years rather than a moment in time, but nonetheless, can have and is having the same degree of impact on the so-called natural systems of the globe.

As I prepared my notes, I thought about that and I labeled it the hit that keeps on hitting. Is the effects of human population growth and economic activities. It's a slow motion asteroid, but it has the same net effect. So then that brought me to the notions of conflicts of time constants and of long recovery times that do operate on a lot of these systems. And the tragic human nature of not paying much attention to things that aren't happening very fast.

And I mentioned Adlai Stevenson Jr. who observed once that man would rather not see the handwriting on the wall until his back is up against it. And that notion of being in a short time-frame up against a wall is one that seems to be a part of our nature. And then we talked a bit about ways to focus on these long-term, high inertial issues, and the relevant science and technology options. In a sense, concluding that if we, as a Chinese philosopher once said, if we don't change our direction, we're liable to end up where we're headed.

My second lecture, before the holidays in December, talked about the governance of science and technology. I reviewed some of the historic interest and support of Americans in science and technology from the earliest work of Ben Franklin and the experiments of Thomas Jefferson and his sending Lewis and Clark on a discovery expedition to the west publicly supported. On the early support of inventions and the protection of intellectual property in the Constitution, and all the other things that happened during the intervening years between then and now.

Now some 200 years then of consistent public support of research and invention and dependence on technology for our future. It is a de facto national policy to support and nourish this activity with public resources, plus an active policy to encourage private investment and interest albeit with protection of the public interest along the way. It is a, I claimed then, a de facto industrial policy. And in fact, it has worked extraordinarily well in contrast to what some people would want to think.

The evolution, especially during the period since the end the World War II, has been also very important. The development of the National Science Foundation, of a Science Advisor to the President, of the National Institutes of Health, of the National Science and Technology Council, of the National Bioethics Advisory Committee-- all actions within the administrative branch to try to bring greater coherence to the notion of science and technology as a public investment. At the same time, the Congress has developed its own science committees and its capabilities of dealing with the same issues from the legislative side, including the invention and then the destruction of the Office of Technology Assessment, which I'd be happy to go into if you want to talk about that later.

But it's too early for me to cry this afternoon. And then most recently, a collision course between the administration and Congress in the 104th Congress in which the frustration over increasing deficits that mounted so rapidly during the '80s came to the fore. The 104th Congress in 1994-1995 was much less informed about the ways of the political process and also of the nature of research. And therefore there were some funny things that happened. At the same time, as Bob mentioned, this concern about cutting of our deficit gave some of these people the idea that we should just cut everything because any government expenditure however you might think about it merits just cutting to the bone.

And we literally were looking at possibilities of cuts of 30%, 35% in research over the coming five years. Along the way, one now very senior leader in the House of Representatives talked about wiping out the NOAA, the National Oceanographic and Atmospheric Administration at Commerce. As he said, we don't need that agency with its satellites and lights. After all, we've got the Weather Channel. Why do you need satellites?

And most recently I heard another true story. This one, unfortunately, even more recent-- namely within the last six months or so-- in which a member of Congress on an Appropriations Committee decided he would cut deeply into the National Science Foundation budget because, he said, the National Science Foundation has no reason to be messing around, doing research on automatic teller machines-- ATM-- and on gambling-- gaming theory. So fortunately, we had one PhD physicist in Congress at the time who reminded his colleague that ATM has to do with asynchronous transfer modes and gaming theory has to do very much with probabilistic calculations. But this man literally was going to cut NSF's budget because of the way those titles sounded to him.

And that, I think, was a sharp reminder of the need for all of us, especially in the wake of the demise of OTA, for all of us keeping an eye on what's being said and thought in the Congress, and staying very supportive of the few people we have in Congress that are technologically literate. Then came, course, the inexorable march of entitlements. And I mentioned that in my second talk. And I think most of you saw this that were here at that time. Those of you who were awake saw this representation.

It's a bar graph over time of our federal expenditures divided into four categories. And you will note at the bottom the changes between 1966 and 1996. The bottom line being the so-called entitlement programs. These are social welfare, Medicare, lot of other activities that drive the federal budget. And they're easy to vote for because the folks back home like them.

And then the national debt increased very rapidly, so it went way up. And yet, we had a budget balance amendment that said we have to balance even though we're funding these increasing programs. So what has to pay the penalty? Well, that turns out to be the so-called discretionary investments, which include education, research, and other vital activities which has now dropped in these 30 years from 22% of our budget down to 16% of our budget. We're headed for less than 1/7 of the entire budget dedicated and devoted to all of these kinds of activities.

That is a very disturbing thing, the notion of entitlements marching ever onward. And it tells you why even today, with a surplus in our budget, we have to pay such attention to the paucity of resources that are going to be available to be spent in the areas that we would like to spend our moneys on. Then I talked a bit about the other activities that have occurred. For instance, the work in the Congress led by Congressman Vernon Ehlers on the whole question of the revisiting Vannevar Bush's extraordinary exposition about public support of science and technology. Revisiting it here in the '90s.

And the bottom line being that there is a great necessity to link our science and technology investments, many of which are rather obscure to most people, but linking them more explicitly to the social purposes that are being served. That's easier to do in medicine and health than it is in some of the other areas, but it's absolutely essential for us to communicate, as I pointed out to our patrons, what we are doing and why it is important to them in their lives and the lives of their children. And that, of course, came along at the same time of the Government Results and Performance Act, which has been an important attempt to try to put a quantification, a measure progress, some milestones of advance that we can use as a way of gauging how well we are doing in our work.

And the notion of setting goals for research. In addition, simply to increasing the level of understanding of the universe. And one of the goals that we talked a little bit about was the notion of sustainability. How well are we moving along in terms of an activity for our nation and our world that is sustainable over the long-term, not just over the near term? Can we gain a better sense of the future and can we choose things that are sensible?

I quoted Max Born who said with frustration in the '50s, who said, intellect distinguishes between the possible and the impossible. Reason distinguishes between the sensible and the senseless. And it's that question of are our choices sensible as well as possible in the way we spend our public resources. And that sense of the future came more and more, and still will be with us, I think, as an essential underpinning to increase public understanding of research and also how we should be directing our investments.

You remember, I think I mentioned that C. P. Snow said that a sense of the future is behind all good politics. Without it, one can do nothing either wise nor decent for the future. And with that cheery note at the end, I ended Compton lecture number two. And now we are at Compton lecture number three and I'd like to turn again to the coming century and the notion of sustainable growth.

My view is that the 21st century is not just another century by any means. It's a prodigious moment of truth in human history. 200 years ago, you may recall-- I'm not that old-- but 200 years ago, Thomas Malthus, remember who he was? Dual degrees. Theology and economics.

That's a powerful, daunting combination of theologies. But Malthus grew quite concerned about the future because he saw population growing in geometric progression and resources growing in linear progression. And you know that's a divergent situation. And therefore his conclusion was that that would lead to stress and therefore war. To disease and also to starvation.

As it were, the horsemen of the apocalypse. But my perspective is that in the succeeding 200 years after Malthus, thanks to both science and technology on the one hand and migration on the other, we made Malthus look pretty silly. Or at least anachronistic. And we do have, I think, a real chance to prove that Schweitzer was wrong too when he said we've lost our ability to foresee and forestall, and that we will therefore end up destroying the earth. We do have that opportunity.

Certainly there's no guarantee that we can make it, but I believe it's possible. And what I'm going to try to point out now is why I believe the 21st century is that moment of truth in human history. Because we've reached a time of critical divergences in the 20th century and are going into the 21st century with a very, very large rate of change in some of these critical phenomena. It's the power of the exponential that is upon us, and cannot be escaped from its extraordinary force over time. And I would claim at least a couple of issues.

One is population growth. Now let me illustrate that with a-- one picture's worth 1,000 words, right? I will remind you of global population up to now looks like that, where the light blue is the so-called developing world and the orange is the industrial world. It's increasing, you can see, over the 20th century at an extraordinary rate. And that if you look at now at this point in time, about 90% of the growth from this point onward is in the developing world.

If you take the United Nations' median projections, which include a lot of assumptions about falling fertility rates, then you see that during the 21st century, we may well witness a rolling over of that growth in a direction of becoming a so-called levelized global population. Ranging somewhere in the range of perhaps 10 billion people. How we take care of 10 billion people is you have to be determined, but at least there's a sense that we are on the node. The second derivative has changed sign or is changing sign, and we're moving toward stabilization.

This indeed would be extraordinarily good news. On the other hand, it is very subject to certain assumptions. And let me illustrate that with this next chart, which I showed, I believe, during perhaps my first lecture. This is an assumption for Africa. Two different simple scenarios.

That population in Africa, measured here in billions, over time, and here's the 21st century right here, will move to a so-called saturation level if, in fact, birth rates fall to replacement level rates. Two different games are played here. One game is suppose by 2030, fertility rates are such that we reached replacement level birth and death rates in Africa by 2030. Just 30 years. In that case, we end up with about 1.5 billion people on the continent.

If, on the other hand, we postpone and delay, and we don't reach replacement level until 2065, some 35 years later, then there's the population will level out not at 1.5 billion people, but at 4.5 billion people. The consequence of a 35 year delay on the ultimate outcome of population gives you that sense of sensitivity to assumptions. And also the cost of delay in trying to achieve a change in such quantities as population growth. Now second area why I think the 21st century is so critical is that we have extraordinary stress on our resources around the planet.

And we, in fact, are overwhelming certain conditions of the Spaceship Earth itself. In stratospheric ozone, we know we're on the way-- another 30 to 40 years and we may even be there-- of stabilizing and cutting down on the destruction of stratospheric ozone which in turn causes a lot of problems of ultraviolet radiation at the surface of the earth. We caught that one in time due to some very interesting measurements and some very innovative chemistry. A great success story of international engagement in identifying a potential problem and catching it before it got too bad. There are other areas, such as the growth of greenhouse gases, which aren't as encouraging.

Here is a time plot over the last 150,000 years of carbon dioxide concentration and also average temperature, globally averaged. And you can see that while over this period of time of well over 150,000 years, we have now, in this century, moved beyond where we've ever been before. And the 21st century, even if we work on it hard, we will likely end up somewhere in this range of 500, 600 parts per million carbon dioxide in the atmosphere, which is a level of concentration of that greenhouse gas that we've simply not seen for millions and millions of years on the earth, if then. And the consequent impact on temperature, and not only temperature but generally the conditions of climate on the earth, are very problematic.

Now if you look into the 21st century, we see it's very fuzzy. It's a very fuzzy future out here because of uncertainties in the way we know how to calculate what's going to happen to global climate, or even what's going to happen to emissions of carbon dioxide, or even what happens to absorption of carbon dioxide in the natural systems around the globe. And that's why we have very large uncertainty bands around CO₂ and temperature changes during the coming century. An example of that is the fact that carbon is not only in the atmosphere, where we're really most worried about it, but also on the earth.

In terms of trees and roots and plants and other things, the terrestrial. And this enormous reservoir in our oceans, which is a great buffering. But also the great flywheel. Time constants of change for the oceans can be hundreds of years up to millennia. And then finally, some that is sequestered geologically in such things as coal.

So this gives you an idea of why it's so tricky to be very certain about the future of where the carbon is going to end up. But if you take your best guess and then take an educated guess about what kind of concentrations we can tolerate without getting into terra incognita of great proportion, then you get a feeling about the 21st century again. This is a business as usual curve going up here. That is if we do nothing but just continue what we're doing. This is amount of carbon in the atmosphere.

And here's time. Here's the end of the 21st century right here. And we play four games. Suppose we just let things go, and that's the top line that goes into very dangerous terra incognita. And then suppose we say, well, let's talk about either slightly above pre-industrial carbon dioxide concentrations versus doubling pre-industrial versus nearly tripling pre-industrial carbon dioxide.

What would it take to have an ultimate concentration under those three different scenarios? And that leads you to so-called well-behaved curves of changing our energy system and other things to enable us to end up out here at one or two or the third of the presumed level of concentration. Now the general consensus is that a doubling of pre-industrial carbon dioxide, first of all, is likely not to be catastrophic to the earth. It'll change. We don't know how much, but it'll change.

And therefore maybe that's what we should depend on in terms of our model. Let's let that be a sort of a reasonable person's approach. There's another point about it. Namely, I feel there's every bit of evidence to say that there's nothing we can do to stop it short of doubling that pre-industrial CO₂. We're much more likely to head toward a tripling.

But if you map this out and start at a goal down here and then work back to where the concentration would need to be limited over time in order to have technology developed and capital stock turned over, you find it follows a so-called least cost path over time. And that helps define the job, if you want to take it on. The job of slowing down our worsening of the greenhouse and making it more of an insurance investment in the future. And that in turn relates to-- I'll just mention two other impacts as evidence of the 21st century being this critical time.

One is, and I'll just put this as a floater. Look what's happened to fixed nitrogen in our earth, just this century. This only goes back to 1900. And you can see in this century that the human activities in nitrogen fixing have gone from almost negligible compared to natural fixing of nitrogen, by so-called natural processes, to where it now has crossed over in 1980 and now substantially exceeds all of the natural processes for nitrogen fixation. Now we don't quite know what this will do, but to a simple minded physicist, it kind of worries me that we are, in a short period of several decades, going from almost negligible to overwhelming in terms of how we affect that particular presence of nitrogen in the global system.

And then finally the last curve I want to show on this is looking again at the 21st century. Here's where the 21st century starts. And you'll note that we've been through these cycles of percent of energy developed. We've gone through a cycle of wood, and then of coal, and now of oil that we've pretty well probably have passed the peak of oil production in terms not of absolute quantities but in terms of the percent of total energy that we are providing. And we're moving rapidly into a time in which natural gas becomes more and more a main player in our global energy system.

But we also are pretty sure that natural gas supplies of a reasonable expectation is that perhaps they will run us out til near the middle of the coming century. Perhaps 2050. This particular best guess turns out to be more like 2030. And that meanwhile then we have to get ready for the next succession. What will that next succession be?

Will it be nuclear? Will it be other forms of long-term energy or so-called renewable supplies? We have to do something here, folks, before our kids become elderly and retired, like I'd like to become one of these days. In other words, it's a 21st century issue of enormous proportion and challenge to us. Now the fact is that if you take all of these anecdotal pieces of evidence, I would make the claim-- and I would hope you'd agree with me-- that in large measure, we're moving along an unsustainable path in terms of the way we are handling our resources and preparing to be able to be part of a world in which we could last for a very long time.

And that also includes this extraordinary growth in human population, multiplied by our economic activities and the way we create our economies. So there are two perspectives, and that's part of my topic. My title of my talk. Is it vision or is it fantasy, this idea of sustainable development? Well, fantasy, I would sort of equate to escapism.

There are several ways you can use escapism. One is the so-called supply side method. If you get into a problem, you just go make more. I don't know whether you can read that or not. It says, "gentlemen, the fact that all my horses and all my men couldn't put Humpty together again simply proves to me I must have more horses and more men."

And that is indeed a philosophy that is not rare, especially in Western civilization. Another approach that I think of as fantasy is, well, let's just not worry about the future. What's the future done for me after all, as someone told me one day. And I go back to Mr. Schultz early on when Lucy is philosophizing with Linus, and a very sensible approach. If we'd been stuck with the last generation's, then let's give it to the next generation.

We'll just pass it on. That's another, I think, fantasy in the long-term. And I've been around long enough to remember a wonderful guy named Harrison Brown and an extraordinary radio or television interview of an argument between Harrison Brown and a man whose name was C. Colin Clark, an economist.

And they were talking about population growth. And Clark ultimately took the position that technology would take care of population growth because at some point, we would be able simply to build spaceships and put our excess populations in them and send them off to other planets. And he was quite serious about his proposition. Mind you, this was only in the '50s, early '60s that this was going on. Well, this is the first time I've heard absolutely speechless on the part of Harrison Brown in making a response to that, because it was such a silly escapism approach.

I was reminded later of that same approach by a person, and this was a case of arguing about a fusion project, and someone described it as called Project Sherwood. And he said, what does that mean? And he says, sure would be nice if it would work. And so I think another form of escapism is simply to be ultra optimistic about where science and technology can take us. Another is that maybe just if we hope it won't happen, it won't happen.

And that's called Disney's Law, wishing will make it so. And that is a relatively common practice these days. In fact, there has been a serious effort in Congress in just this past year to disallow even a discussion of global climate change on the part of the employees of EPA. If you don't talk about it, maybe it'll go away. And I remind you what Mr. Jefferson said about-- if you're from Virginia, you have to have one Jefferson quote whenever you give a talk.

Mr. Jefferson was so unhappy with Congress in 1798 that he wrote the following. He said, "a little patience and we shall see the time of witches pass over, their spells dissolve, and the people, recovering their true sight, restore their government to its true principles." But I think a true principle is not that we should use escapism as a means of trying to solve our problems. Then, of course, there are some who would call on divine providence to bail us out. I have philosophical problems with that.

And then others that would simply say, *que sera, sera*. Let's just go with the flow and, I would say, sink into the ooze. So to me, that's my best shot at so-called fantasy about dealing with these issues.

And the other, on the other hand, is what I would call vision. And in vision, I would say let's accept Albert Schweitzer's implicit challenge, that we can foresee and we can forestall and we can end up not destroying but rather being good stewards of the earth. Let's stay anchored in reality. There are opportunities for innovation, albeit under the constraints of laws of nature. And also important time constraints that must be taken into account any time we think about moving from one condition to another.

Speaking of the laws of nature, there was a member of the Pennsylvania legislature about a half a century ago who wanted to make the value of pi exactly 3.14. And someone said, well, you know, that's silly. It's an irrational number. And the response of the legislature was, well, that's your opinion. Pat Moynihan once said that we may all have our own opinions, but we cannot all have our own facts.

So I'd say in establishing a vision, we should try to stick with the facts. Well then, what do we have to offer in a vision of a sustainable growth future? Well, again, I think three things. One is that we must avoid the use of weapons of mass destruction. And that has very real connotations.

It means that we have to really work hard and complete, start two, and start three in our nuclear weapons negotiations. We need to complete the ratification of the Comprehensive Test Ban Treaty. We need to work hard and complete the work on weapons plutonium sequestration and disposition. We need to be concerned, secondly, about what I fear are more than minor rumblings about the projection of military force into space, which is a revival of Star Wars and space-based weapons, which I think are a very bad mistake and could take us off in a very expensive and wrong direction. At the same time, Congress and even the administration is walking away from what should be strong support of the long-term research programs in the Department of Defense.

So I think that's a big concern. We have chemical and biological weapons that have global consequences. Just this past week, we've gotten very discouraged and are backing away from our attempts to finally complete the eradication of the smallpox virus because of some suspicion that it was held back in the destruction in other countries and that therefore some of it might still be around. A great and sad day for all of us.

And finally, in the area of avoiding mass destruction, I would recall for you John Kennedy's statement made a long time ago, 1963. He said, "if we cannot end now our differences, at least we can help make the world safe for diversity." And that has a lot of important technological connotations in it. He said, "I realize that the pursuit of peace is not as dramatic as the pursuit of war, and frequently the words of the pursuit fall on deaf ears. But we have no more urgent task."

So avoiding the use of weapons of mass destruction and controlling them is an extraordinary imperative, I think, for sustainable growth. A second is the establishment of a new economic era for providing goods and services in new ways. There is very encouraging progress, but much to be done, in the area of thinking in terms of closed systems. Of extraordinarily high efficiency of the use of resources, and of very low emissions from industrial processes. And very carefully designed materials, design in materials flow.

So enormous challenges in the engineering community and manufacturing in chemical engineering, mechanical engineering, and chemical processing. Great challenges. Lots of fun there, and a lot of progress in recent years in that regard. A number, especially of the multinational companies, are now making not only good progress in this direction, but also good money at the same time, which is a very encouraging development. Even cities are moving in this direction.

The city, for instance, of Chattanooga, and several other American cities are trying to tackle the notion of sustainability in a city context. What can they do in the way they use their land and build their resources and operate their system that is truly sustainable over the long-term? That's been particularly poignant to me since I live in northern Virginia, which is exploding with unbridled development and all the farmland is now filling up with row houses. And that, in turn, is raising land values, and people can no longer afford to stay there. And the debt rises and more schools have to be built, and it's a vicious cycle with seemingly no exit.

So thinking even in sustainable cities is a way, I think, to bring to home the notion of sustainability. Even at the home level is an interesting thought. How can one-- and that's the notion of recycle and all the other things-- but trying to get some reality to this very fuzzy notion of sustainability, I think, is an important issue for us. And along with that is the treating of so-called free goods. Air, water, the oceans.

Treating these so-called free goods more rationally via pricing policies, regulations, other rules of the road. The government, perhaps, is the worst of all actors in handling its so-called free goods. When you think of the extraordinary subsidies placed on water in the west, on grazing fees, and the sales of our publicly-owned timber lands. These are just extraordinary bad management practices, and yet we're going about it as though the world would never show the consequence.

In the oceans, very disturbing, there are now depletion of fisheries that are really extraordinary. 190 stocks of fishes in the US show greater than 80% either fully exploited or over-fished right now. And in the marine ecosystem disturbances, very disturbing because of these, again, modern technology with these 30 mile long nets and the like that simply destroy the marine ecosystems on the bottom. And put us in peril in terms of that supply of protein for our future as well as a stable ecosystem in the marine areas. So disciplined equilibrium management is a notion that we are going to have to undertake and work on as a global society in the coming years, or else we're going to destroy one of the most important protein resources for humanity.

And I would only mention that are national forests, which we treat more like tree farms, but were supposedly set aside for sustained use, but simply aren't being used that way. Recently someone raised the notion of having our national forests operated on a sustainable basis. And there were howls of protests from people who think of the national forests as a tree farm. So the question is just because they're out in the west, does that matter to you all in the east? I don't know.

But it matters to me to think that we would treat our own resources that way. And I think, ultimately, in terms of the new economic era, not only are there challenges in the way we think about designing to provide goods and services but also the need to develop more public-private partnerships where public interest, including intergenerational interest, are merged and integrated with private interest in new ways of approaching things where both the public and the private good stand to gain as a consequence. We've experimented with this, and I mentioned it in an earlier lecture, with our work on the partnership for a new generation of vehicles.

A decade long effort to develop a production prototype of an automobile that would achieve mileage and emissions capabilities that were well beyond the present state of the art. The chance to make an energy transition to a no net carbon emission energy system within about a half a century or more. The chance to build houses and buildings that have less than half of the amount of energy requirements that the present ones do and are as comfortable and as safe as the present houses. Even our notion of merging public and private interest and planting a long riparian rights of way so that the water quality, water that moves off of our farms and the likes, is dramatically improved. And that has public gain as well as private.

So there's another example of public-private merging for success. So the new economic era in providing goods and services is indeed the challenge for the 21st century. And finally, I go back to population and its stabilization. It is a century of reckoning for us. A time to get past the so-called pronatalists' policies and move toward a time in which we can realistically think about leveling off in the number of people on the planet, in Spaceship Earth, in order to be able to provide a bright future for the future people.

Bertram Russell once said that man would rather commit suicide than learn arithmetic. And I think that's a thing we need to have to learn about in terms of the growth of people on the planet. That means we have to worry about the economic status of our people because the better economic status, the lower the population growth rates, to a degree. Of course, that's a chicken and an egg problem because sometimes lower birth rate and smaller families means better economic status. It also means education of women.

It means provision of family planning services that are more available and more effective. The unmet need for family planning services today in the world is staggering, and yet we are being blocked from even contributing to the UN Family Planning Association activities in the world. That's just an extraordinary move on the part of Congress. The right wing religious groups have been blocking or attempting to block research on fertility as well as attacking our clinics. I think there's a desperate need for a dialogue in this area.

There is another element here which is also important in terms of analysis, and that is not only the number of people, but the rate of change of the number of people. There are recent articles by Bongaarts in *Science Magazine* and by Pete Peterson in *Foreign Affairs* in January, February of this year that bring out the extraordinary importance of thinking about time rate of change of a demographic transition between an expanding population and a stabilized population. And if you read that and think about the challenge to China, to Mexico, to other countries that presently have a very rapidly expanding population and a so-called youth-dominated population profile, you will understand the imperative of pacing and dynamics in change of population itself.

Well, what's required ultimately then to enable such options to be developed and acted upon? I think it's a paradigm shift. It means that end to dualism-- dualism being that humans are here to enjoy the rest of the world. We're sort of set apart from the rest of the world rather than being a part of it. And I think we need to rapidly move away from that notion toward a reaffirmation of humanity as caretaker or steward or co-creator, however you want to describe it, of the planet Earth.

That means, therefore, dynamic equilibrium and not exponentiation must be seen as a fundamental goal for survival. And I think that also means that growth must be sought and measured in new ways. Julian Simon was quite confident that we could just keep on growing numbers of people on the planet as though that in itself were a noble goal. That's in sharp contrast to Kierkegaard who once wondered whether or not a better measure of progress than numbers of people would be the increase in individuality in people. Rene Dubos fretted about this and he said, in terms of physical amenities, "just as important are the social amenities that make it possible to satisfy the longing for quiet, empty spaces, privacy, independence, and other conditions essential for preserving and enlarging the peculiarly human qualities of life. These are already in short supply."

And that's I think an important counter to some of Simon's arguments. And then Robert Kennedy 30 years ago said, "the gross national product measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country. It measures everything, in short, except that which makes life worthwhile." And we're now, I think, in a struggle as we cross the millennium of thinking about measures of progress and how well we're going along. And it's long overdue.

So I conclude that the 21st century is indeed going to be a long moment of truth for humanity. The issue is whether human ingenuity can devise and enable a transition from exponentiation to sustainability. And the challenge is a central responsibility for science and technology. Central responsibility. It is we that must provide the options for that. Can we rise to that challenge?

Yes, I think it's possible. Both through invention and through our motive of self-preservation. But I'm not sure about our ability to think and to act with intergenerational interest. So we can do it. But will we?

I think the vision approach that I've talked about today is compelling. It's exciting. But it also requires tough discipline and for people to act in very rationalized self-interest. Namely, the interest of humanity. And fantasy, on the other hand, is alluring.

It is resonant with greed and avarous. It is full of the Rhine River maidens, and also distorted by simple discount series. So I have to confess to you-- while I think yes, indeed we can rise to the occasion and challenge, I cannot be very optimistic about it. I'm saddened to say that, and I fear that more likely than not in the coming century, humankind will fall short of its potential. I hope that you folks can prove me wrong.

And I close with the following comment a person said. He said, "the young should not heed the depressing thoughts of the old, for they can only make the youth wise, when what he needs most of all is courage. How else can he confront the future?" Thank you. I'll entertain a couple, but I'll let you decide when we ought to shut it down.

AUDIENCE: You describe a global approach [INAUDIBLE] to population, energy, and the environment. But a couple days ago, I heard Thomas Schmidt speak, and he emphasized that in his view, population is the primary issue in the world. And it seems to me that the German approach is to limit population. To restrict immigration. To deal with one nation at a time.

Not globally. They have what seems to be very effective environmental practices. They don't have energy practices with the high gasoline tax, fuel tax. It seems to me that they may have within their nation a sustainable approach. If what this does is internalize the impact, in other words, as long as they are concerned only for their own-- of course, this doesn't take care of global warming, but maybe they can deal with that scientifically.

The point is that they can internalize the impact of their own behavior. They can look at the long-term, which you suggest for the next generation. If, in fact you try to globalize things, you run into a situation as in the United States where even if the average American had no children and thereby reduced the population growth, immigration would still cause a problem.

GIBBONS: I think you're right. We have to begin at home.

AUDIENCE: What about just staying at home?

GIBBONS: Well, I like to travel to Boston. I really like it.

AUDIENCE: Why not keep the focus entirely at home and allow other countries, if they don't take care of their own issues to become bogged down in their own problems?

GIBBONS: That's fine, but that aggregates some, I think, implicit responsibilities. For instance, one reason we have very rapid population growth in the third world is that we introduced from the industrial world means of death control at a rate that was almost instantaneous compared to social change. So the birth rates stayed high and the death rate dropped like a stone, and population blossomed. Why?

Because we introduced those technologies while not also introducing the technologies of birth control or its availability. It's not just their problem, it's our problem. And I think we have to begin at home, but at the same time, we have to be leaders in the world of helping devise the technologies and approaches that the world is going to require. 95% of the new people in the world are born in the third world.

AUDIENCE: But that would be self-regulating. Terrible as it sounds--

GIBBONS: I don't believe so. I think self-regulation means that we go down into the ooze and I think that's a hell of a future for mankind. Yeah? Well, let's see. Alfonse and then Gaston-- did you have a question?

AUDIENCE: What is your opinion on the potential for increase of government incentives for and the general possibilities of the commercial development of space both in earth, orbit, moon, and eventually beyond to increase those resources, both energy in terms of [INAUDIBLE] power, material resources, metals and the like, and using industry to increase the standard of living on Earth to reduce the growth rate?

GIBBONS: Well, we certainly have tried to encourage commercial development of space. It's been one of the-- especially in telecommunications, has been one of the great successes of a public investment. At the same time, we don't have a shortage of materials, per se. And to go out to an asteroid to mine for materials, to me at this point in time, is a rather silly way to spend our money.

I think we enjoy the notion of space exploration because it is a great adventure that together we can share at relatively low cost per person. But I personally feel it is foolhardy to think that we're going to find our solution by running off to some other place to solve our problems. I think, as this first gentleman said, we need to start at home. Someone said years ago, I think it was Teddy White who said, I really would feel better about going off and populating other planets and doing those things in space if I felt that I could go into a bank and find a pen that wasn't chained to the desk.

In other words, we ought to start at home with the way we behave and work with ourselves. I don't mean to belittle the notion of resources from beyond the earth, but I think it's all too easily a crutch to lean on. Now Gaston.

AUDIENCE: I share wholeheartedly with you your vision about the challenges and opportunities for the future. But I have some difficulty with the gross national product per capita.

GIBBONS: Oh good.

AUDIENCE: The vision being that if one [INAUDIBLE] uses all the statistics around the globe, there is no example of any kind that has succeeded in offering a life with educated people. People that are not starving, that are not sick, that are not living only 50 years. So the average [INAUDIBLE] of 80, that do not have a high income per capita. And therefore, when we go to the majority of the people around the world, who are the majority of the poor and the aged, and we tell them, look, you have to contribute.

I sense that the answer we always get back is, well, you created the problem. Start contributing. Come a little bit closer to us, and then we will join you.

GIBBONS: Well, I sympathize with your position. Namely that we do enjoy extraordinary economic wealth. I'm not sure it's sustainable over the long-term. It would be nice if it were. And that one of our big, I think, implicit responsibilities as leaders of the world in terms of an individual nation's economy is to try to help the other nations learn from our successes as well as our shortcomings.

And if anything leapfrogs some of our mistakes as we're doing, for instance, in telecommunications, nobody in the third world is laying copper lines anymore. They're learning from our advances. And I would hope that that can be done in all sorts of other areas.

And certainly happiness can't buy money. And I think wealth is an essential ingredient for the future. The question is, are we making our allocations based on real costs of things rather than on the prices, which many times are very, very distorted. Yeah?

AUDIENCE: My point is that we should start doing that more intensely. [INAUDIBLE] than we are doing now.

GIBBONS: Let me finish off that one before I get too-- if you ask the average American what about the money we spend on foreign aid, they say it's too much. And then you say, well, how much do you think would be right? And some of them say, well, we certainly shouldn't be spending 20% of our budget on that. Well, how about 10% or 5%? Well, that sounds about right.

Well, maybe around 5%. Yeah, that's a good number. Turns out we spend less than 1%. So the perception of what we're spending in aiding other nations to grow and also become trading partners with us is enormously distorted.

And that's a general lesson that it's up to us to try to help raise the level of reality about what we are doing, what's real and what's not real in the American scene today. It's all too surreal. All right.

AUDIENCE: Oh, final question, better be good then. Well, let me maybe throw out two.

The email that came to me about this talk was titled "Sustainable Growth." And when I heard you talk, you talked about sustainable development. Now--

GIBBONS: You're right.

AUDIENCE: In the world that I'm working in right now, there is a big difference between those two. And usually when I hear someone say sustainable growth, the response is well, which is it? Is it sustainable or growth? Because that's kind of like a buzz term. At first I thought you were going to be an apologist for industry and you were going to convince us that there is such a thing as sustainable growth.

Which a lot of industry people, a lot of people in Washington harp on that term specifically. And they're trying to push that term and a lot of the reports have come out now from industry. They say sustainable growth. And I'm just wondering, what's been your influence in Washington with what's going on right now, specifically around the usage of that term, sustainable growth, versus sustainable development, and the battle for the mind share of the American voter over those-- the distinction between those concepts?

GIBBONS: Okay, I think I'll give you a short answer on that. Maybe we can talk at the reception. I use the terms almost without thinking, almost interchangeably because I think the problem is that we don't really define our term of growth or of development. And I mentioned a while ago that Kierkegaard talked about progress as being measured in the increase of individuality of people, not in the pounds they consume per year. So the notion of growth itself is a very obscure-- it's beauty is in the eye of the beholders.

I think that's the reason everyone kind of likes sustainable development or sustainable growth. They can make it mean whatever they think of, as growth or development. And at one time, I worried about that. But honestly, I don't worry about it that much anymore because as long as we can all agree we like sustainable growth or development and we may have different definitions of it, maybe that'll work out over time.

And I think growth as progress, development as forward movement rather than filling up the land with houses is the way I think about those two terms. But I think ultimately we need to sharpen up our definitions. But as we do, we will lose a sense of consensus. And I don't want to do that too fast. Thank you.

AUDIENCE: Really wants to ask a question.

GIBBONS: Uh-oh. All right, Gene.

AUDIENCE: I had the great pleasure of being your host during this last year. It was a great pleasure partly because of your enormous sense of optimism, not withstanding your closing pessimistic praise. And somehow that the world can take a very holistic approach to this problem of sustainable-- I don't think the problem is the definition of development versus growth, by the way. I think the problem is the definition of sustainability.

GIBBONS: Yes, that too.

AUDIENCE: Well, not that too. The trouble is, what does it mean? To whom? By using the phrase, it varies all of the choices that are involved. For example, equity between the developing countries and the advancement.

Or the questions of who benefits or who loses in the process, and so on. And you gave an example yourself, right at the very end, about the role of technology, which was not planned. You said the developing countries are leapfrogging us in the communication. No one planned that. If they had planned it, they would never have come up with it. And the thrust of your presentation is somehow we can go through all of these planned [INAUDIBLE] future, and we'll be all right.

And I think that's very misleading in terms of the politics of the situation, in terms of how the technology and the science unfolds. In terms of questions of resources and population. The developed and advanced countries, the problem is not population growth, it's population decline. Not right at the moment, but it is, in fact, that way.

GIBBONS: I think you're wrong, but keep going.

AUDIENCE: No, several of the developed countries, the population growth-- growth is not growth. It's below the replacement level--

GIBBONS: But I don't think you're saying that's necessarily bad or good, are you?

AUDIENCE: No, but you may have to deal with it in a very different way than you would then in an exponentially growing population. And that raises all kinds of very difficult political and economic choices.

GIBBONS: See, Gene has properly put this thing into perspective. It's a tough problem. It's a tough problem, and there's no problem, however complicated, if you look at it carefully enough doesn't become more complicated. And I think that's the thing we're trying to work with. And Jacques, have you got a burning one before Bob chases me out of here?

AUDIENCE: I would like to suggest that we need to add another word to the vocabulary which is design. There's a wonderful gentleman I suspect you know, William McDonough-

GIBBONS: Yes, Bill McDonough.

AUDIENCE: Dean of Architecture at the University of Virginia, who really poses-- he says the challenge is posing the questions. Not that what Jack is saying is wrong, but as you look at those graphs and then say, what are the design goals that we might have to evaluate the choices that you're suggesting that we have to make. Not to limit the choices, but to ask you questions.

Why is it that everything that goes into a house today is clean and what comes out is dirty? Why don't we have a design challenge as to what come into our house will be dirtier than what comes out? In other words, the water that comes out of our house is cleaner than the water that comes in. Everything that comes out of our house will be food.

Either food for the environment or food for the industrial process. So if we ask-- the great optimism for me is the ability to invent new questions. To set design principles, new design goals within which science and technology can flourish with marvelous flowering because all of a sudden there is a new set of questions and design goals.

BIRGENEAU: That's a perfect way to start our reception, I believe. Don't you, Bob? Thank you very much.