W. Gary Ernst, PhD

Earth Resources, Global Equity, and Future Sustainability

Thank you very much. It's a great pleasure to be here. It's, it's like returning home, although I have to say when I played hockey at Carlton, we played out on what was called the bald spot. It was frozen in the winter with fire hoses and all that. When I came over here in, what, 1988, and saw this hockey stadium, I thought, what would I have given to play here? On the other hand, Gustavus is probably so much better than we were. Maybe not. Maybe not. [laughter]

Anyway, I want to talk to you today about, well, Earth resources, global equity, or really lack thereof and the future sustainability of the planet. It's going to happen, folks, whether we like it not. That is, we'll be, surviving humans will come into equilibrium with the environment.

Now why do I say this? Because, well, the, there's some very good news in terms of global change. And that is the oldest rocks on the Earth are about 3.9 billion years old in Western Greenland and they are sedimentary rocks. They were laid down in water. There's been sedimentary rocks ever since. Others, too, of course.

But the fact of the matter is, we've had a liquid envelope around this planet at least since 3.9 billion years ago and maybe longer ago. Now there's been ups and downs. We've had glaciations and we've had very warm periods. We're in the middle of a sort of, uh, intermediate period right now.

So there are feedback mechanisms which keeps our Goldilocks planet which is just the right distance from the sun and its mass so that it's not too hot, not too cold, keeps it in a condition that is appropriate for life.

The previous two speakers, uh, Sean and Svante, have talked to us about the, that we’re entering in the sixth global extinction, massive extinction event. In fact, we’re well along on it. And that humanoids and humans have been around this planet at least since 400,000 years ago. Depends how you want to think of the australopithecine couple million years ago.

But since humans have become involved, we’ve entered what is called the Anthropocene, the age, geologists call it, where humans have been a geologic force. And we have over drafted the planet in many ways in terms of resources. Now the planet, it sustains all life. The critical zone, the region near the surface of the earth, including the atmosphere and the oceans and fresh water, that’s the realm where almost all the biosphere lives. And since 3.9, it’s been in a dynamic equilibrium with planet Earth.

But we’ve kind of changed that. So we’ve got to get back to a sustainable development. So that’s what this talk is about. How are we going to do that? Right now we’re over drafting. Short-term gain? Yes. Ultimate catastrophe you don't move on to something better.

Will we do it? Well, what is sustainability? Here are a couple of definitions. They basically say allowing the next generation to be as prosperous or have the same opportunities we have. But as a geologist, I have to tell you, we’re talking 1,000 generations or more. We can't just worry about the next generation. We might make the next generation perfectly comfortable. Although that is also a question. But the real question is, we can’t just take the short term. We’ve got to take the long term. And so we’ve got to think of it in terms of at least 1,000 generations, 20,000 years for a start, how about that?

Well, what are you all upset about? Why are your knickers so twisted? Well, our standard of living tracks very nicely with Earth’s resources

Everything, the biosphere, the whole biosphere, not just us, the whole biosphere needs is involved in nutrients in the solid Earth, the atmosphere, and the fluid Earth. Except for sunlight. That's a critical ingredient. But everything else is on the Earth. And as a geologist, I am concerned about conserving the Earth and its resources for future generations. And especially for the entire biosphere.

To do that, we need energy, a source of energy that will allow us to harvest these resources in a sustainable way. And economics tells us that we can do that, we can do that no matter how much resources we need, if we only have enough energy to do it. But we have to save a viable biosphere in the process. There's lots of ecological values that they service, ecological services, service that we get without even trying.

The wetlands clean up our waters, bees pollinate for us, and so forth. So here's what I've been saying, the unicellular anaerobes began about 3.5 billion years ago, at least, maybe longer ago. And one of their waste products is oxygen. So eventually the, what was a readily reducing atmosphere became more and more oxidized with time and ultimately multicellular oxygen utilizing life arose and by about five or six hundred million years ago, multicellular life, even with hard parts, including back bones, arrived. And the rest, as they say, is history.

But rather recently, we have come to overpower the natural resources of the planet. All that early life dealt with the sunlight and near, near surface resources. And it was renewable on a slow geologic level but at a finite level.

However, beginning in about the, oh, about 9,000 years ago, settled agriculture began. Settled agriculture started in the Middle East and a little later in Central Asia. And by about 4,000 years ago, 2,000 before common era, civilization as we think of it, diversified jobs and so forth, arose. Hunting and gathering gave way to settled farming agriculture, then civilization.

Since then, but especially since about 1800 and the Industrial Revolution, we've been vastly over drafting our resources, and there are many more of us to do it.

The year 1800, there was about a billion people on the planet. You can see where we're going now. That was 1800, but by 1950, it was two and a half billion. Well, we're up around seven point two, a little over seven point two billion now. And they have an impact on the planet.

Here is an outdated map, I mean a diagram that the World Bank published some time ago and the United Nations accepted it, that we're going to have about close to 9 billion people by 2050. Now it looks like it's gonna be 9.6 or more. And who knows what about 2100. It's a long way away.

Anyway, you note very clearly that the developed world is pretty much at a, what shall I say, a dynamic equilibrium at 1.1 billion, whereas the third-world or developing nations are still on a very upward trajectory. Now about 17 years ago, Charlotte and I led a Stanford alumni trip to Indonesia. And the western part of New Guinea is called Irian Jaya and we visited a town there inhabited by the men and women of the Agats tribe, of the Asmat Tribe. Their town, the little town they, that they were associated with was called Agats. And there was a generator there so that they had a television, one television and the internet.

So these people, who live in grass huts, wear almost nothing, eat freshwater shrimp, and the sago palm, the hearts of the sago palm, they don't have very much. You can imagine what they think seeing CNN news and old serials of *Seinfeld*, that sort of thing. Look at the, these people must be so totally foreign from them. And they can't help but wonder how come they have all this and we have just our grass skirts.

Well, it is a function of geography and history, among other things, but the prosperity of the western industrialized nations is related to the harvesting of resources near the surface of the Earth, or deposits. Oil, water, all sorts of minerals. Soil: soil is being degraded.

So prosperity is related to that and that means it's related to energy use. So we're using up the high-grade ore. When I was in high school in St. Paul, we were vastly upset about the lowering, of the decreasing amount of high-grade iron ore in northern Minnesota. And then, of course, they found taconite and other deposits and one thing, another.

So if you want to spend more energy, if energy's cheap enough, you can develop resources that are relatively low-grade. This is a particular pleasant looking mine in Central China, but, South China, but there's a heck of a lot bigger one and not only one, a very large one near Salt Lake City, southwest of it, Bingham Canyon, it can be seen from Earth-orbiting satellites, I mean, if there's somebody in it. And it's enormous.

And they're bringing ore out that's less than 0.5 weight percent copper, copper mine, OK. So one-half of a weight percent copper. And it's okay because, guess what? The price of copper is high. So as long as the price, as economists would say, as long as the price can go up, you can afford to use the energy, if it's cheap enough, and extract it.

Even so, the amount of copper that's in, near surface environments is sufficiently low that a recent projection, as pointed out here in Science Magazine this year, is liable to diminish drastically by the beginning of the next century.

One of the reasons for that is not just that we would use too much energy. We can always raise the price of energy to, or the copper to use it if there's plenty of energy. But there is another problem. When the ore level gets so low, the copper, it does not occur as separate sulfide or oxide minerals, but it occurs camouflaged, as they say, in the crystal structure of other minerals. Then it takes orders of magnitude more energy to separate it, so it becomes really unfeasible.

But this economic concept is fine for most resources present in small amounts. We're having trouble with rare Earth elements right now, but we're opening mines because price is going up and we can mine low-grade material if the Chinese won't sell us theirs.

So most mineral resources which are no renewable on any kind of a civilization lifetime, it, we're going down the scale of, or grade, until we get to very low-grade. But there's some things, like energy itself, that you can reach a finite limit. Once you expend as much energy to get it out of the ground, or whatever it is, and combust it to get the energy out, as you receive when it is degraded, you've reached the point of no return.

There's only so far you can go, therefore, with things like fossil fuels, carbon-based fuels, the rapid oxidation of which provides us with energy to turn steam turbines and the like.

So what is the energy consumption? This is a little bit going onto what Steve said this morning but the point I wish to make is that the big three are coal, natural gas, and, of course, oil. There is plenty of oil underground, especially in the deep sea. We know how good that's going to be. Anyway, there is oil and gas available. But the point is, if we use it, we will be adding a greenhouse gas to the atmosphere, as we already are.

Well, let's look very briefly at shale gas. That's the next big thing for the United States. And I show here a map from the Energy Information

Agency, part of Steve's former haunt, and shows various kinds of traps in sedimentary rocks of oil and gas. There's a lot of that around. All you have to do is drill a well into it and suck it out.

And there's plenty of shale gas available for us, at least for the foreseeable future. Now, of course, that's not forever, but it is at least getting up to 2035. It looks like we may become energy independent.

And if we look at the lower 48, not even worrying about Alaska, there are several really big plays here. The Marcellus shale is the one you've probably heard about before. Bakken is another there, and then there's a couple in Texas, Barnett and Eagle Ford. But nobody's talked yet about California and people are busily licking their chops over the Monterrey Formation, which looks small on this map, but is very rich.

And so if fracking takes place there, hydraulic fracturing, as we say, that will be another source of oil. Should we do it? Well, we're going to do it, whether we should or not. As a matter of fact, we've been doing it for 20 or 30 years. Nobody's been screaming bloody murder over this time but now that it's involved areas in Pennsylvania and New York, there's much more of a hewing cry. And, of course, an echo in California, too.

What is it? You know, an oil well or a gas well in this case, is a hole drilled with a big rock bit on the end of a drilling string which goes down the hole and it, there's a big Gandria [sounds like] crane over it. And eventually they whipstock it, they turn it and move it laterally away horizontally down here somewhere.

But it isn't just one well. There's usually a whole bunch of them that come out from it and hit this particular unit, which is the oil shale. Now the difference between oil shale and a sandstone reservoir, a sandstone reservoir has large pores in which the oil resides. So all you have to do is drill a well down there, case it and then perforate it at the place you want it to suck the oil back out and you can get a good portion of it out. Not all. Never more than about 50 percent.

But shales are very fine-grained mud rocks and so they have very small cores. So you've got a great porosity that is 20 or 30 percent holes, but no permeability. No connectability. So what they have done is this, they've drilled a well, same as they always do, and cased it, put a casing around. Then fracture it, drill holes in it in certain places and pump water down with sand and certain secret refractorants [SP] that open up the fractures in the shale. And that allows the oil, or in this case, gas to come back up the annulus, up to the surface where they then pipe it off into reservoirs of one sort or another, and ultimately the distribution system and refineries.

This process, which means pressurizing a well with water and sand, the sand, little granules, run through it as a slurry and the whole idea is they're supposed to keep the fractures open once the fractures form. And the secret ingredient's the surfactants, the soapy like stuff, is also supposed to reduce cohesion and so forth and so, to cause the oil to flow.

Now this is a big operation. When a well is being pumped, refracted, it requires a lot of input of injury and whatnot. And there are those who say these oil wells, or gas wells, result in a lot of methane, which is a terribly potent greenhouse gas, present in very small amounts in the atmosphere normally, but very potent once it gets into it, to light fire in their faucet. This may have been a made-up shot, but it's something that mobilizes people a lot.

What they don't remember or know is that over 100 years ago, well, nearly 100 years ago, yeah, 150 years ago, Colonel Drake sank a small hole in the ground using what's called a cable tool, just banged a big, on the end of the big cable, a big steel rod into the Earth. No casing, no nothing, got down 70 feet and produced oil, and probably gas. And that may contaminate the local ground water. So that's been going on in Pennsylvania for 150 years or so.

So what do the professionals say? Well, proceeding [sounds like] to the National Academy of Science runs a lot of articles about it and the best you can say is, is yes, probably, and no probably, and maybe and they certainly cause small earthquakes when they re-pressurize the hole at times. Not very, not everywhere but at places. But the likelihood is that some producing wells have reduced a little, have produced a little methane that rises up through broken parts of the casing and so it comes out at the surface. And it's a contaminant.

It is coming up the well, that's for sure, but it is not, most of these producing horizons are down 6,000 feet, 10,000 feet, something like that. And the fracturing is only over a few tens of meters. So the oil or gas is not entering the groundwater from there. The methane is entering the ground water from coming up the hole and where there are some of these casings that are not anymore perfect.

So what are we going to do? Well, we're going to use it, I'm sure. Gas emits, methane emits half the amount of CO_2 that coal does when you burn it. And there are many fewer other pollutants. There's none of the heavy metals like arsenic and uranium or sulfur dioxide and hydrogen sulfide that's emitted by the coal industry, burning coal rather.

And the other thing, the good thing is, we become more or less energy independent. We don't have to depend on our friends in the Middle East for our energy supplies.

The concerns of course is that you used a lot of water, surface water and ground water, and there can be contamination and there's just a pot load of water used. Methane, of course, is a very important greenhouse gas. And it decays over something like 18 or 20 years if it's only present in small amounts.

So the worst thing is, we don't kick our addiction to oil. George Bush told us over 10 years ago, we really must do that. But so far it hasn't happened. So that's a problem. We need to. Because why? We need to move away from global climate change.

And, of course, then there's some fluid, some of this fluid recharge results in earthquakes, moderate earthquakes, pretty small. And this, too, is not new. It's been going on Rangely, Colorado and at the Rocky Mountain Arsenal ever since the 1960s. Nobody objected too much.

But nonetheless, it is a concern, especially in areas that are seismically active for other reasons.

What about the greenhouse effect? Well, you all have heard about it. And what it is is that the gas, the solar radiation coming in from the sun, from outer space, is short-wave lengths, passes through the atmosphere largely and a lot of it is absorbed by low albedo substance such as the ocean water and some of the land. It's re-rated, some of it in longer wave lengths, trapped by greenhouse gases. Also clouds have a trapping and a reflective capability. They're kind of a problem. But the fact is that the total amount of energy that is retained as increased heat, increases the more you put CO_2 in the atmosphere.

This si not a new idea. The Swedish chemist, Arrhenius, noted this in the 1890s. He thought it would be really a good idea for Scandinavia, and probably also Canada and Siberia, to have higher temperatures anyway. He wasn't thinking of the low latitude countries, nor the city of Miami, where a sea level rise may be somewhere more daunting.

What we have to realize is that this has been going on for some time. This is the fourth quadrennial IPCC report which is, came out in 2014, shows that it is clearly a present danger. It is not possibly a maybe and it has largely got an anthropogenic signature. Not entirely, but largely. Most of the CO_2 we put up in the atmosphere is dead CO_2. There's no carbon 14 and it's formed in the upper atmosphere, decays with about a 5500-year lifetime, some time around that. So, anyway, it's dead because the oil and gas that come out of a oil well is millions of years old, not thousands of years old.

We took a Stanford alumni trip, you think maybe that's all Charlotte and I ever did was Stanford alumni trips, from the Canadian Artic over to Provideniya, a real garden spot in Siberia. But we couldn't get through the straights right here, which is called M'Clure. Anyway, so we had to go down past Banks Island and snake around that way. And no big deal, but it tells you that the ice was much more abundant in '93 or '95 than it is now. And you can see the extent of summer ice is now about half what it was in the 70s and 80s.

Now this melting of the ice does not raise sea level, because the ice is already gravitatively floating on the sea, or it plays hob with some species, especially polar bears.

The far more important point that we want to talk about in terms of global climate change involves the tracking, yes, yes, the tracking is quite apparent and may not be causative but I lead you to, I let you decide whether you think these are causative.

What am I looking at? What are we looking at? We're looking at ice cores, like, that's wells, that is bores, through the Antarctic ice sheet, and they've done the same thing in the big Greenland ice sheet. These are great big lenses of ices. Maximum, at their maximum plumination [sounds like] area near the South Pole, let's say at least for Antarctica.

Anyway, what they find is that they have little bubbles that are trapped in the, that, from air, that are trapped in the ice at it fell initially as snow. It also has a fractionation or partition of oxygen and hydrogen isotopes between the ice and the, and the CO_2. Probably also carbon but I don't think we know that.

Anyway, the point is, we can get both the temperature of the ice and the proportion, the temperature of the CO_2 and a proportion of CO_2 in the ice bubble, in these little bubbles. So if you go back to 800,000 years, you can see the start of when they, well, the deepest the ice core got. Important thing is that the temperature, which is usually well above, well below freezing, goes up to almost freezing. Of course, if it's above freezing, you aren't going to have any ice there. That is, it's not going to capture bubbles. And the CO_2 is high when the temperature is relatively high and low when it's low. There, good for you. [laughs]

Anyway, this looks to me like a pretty good tracking over the current 800,000 years. And we've had ice in Antarctica ever seen the Miocene, which is quite a bit longer ago but it's, in the Northern Hemisphere, it's much more recently. Point of importance is, over the past 800,000 years, the CO_2 concentration is varied, from about 180 parts per million to about 280 parts per million, there, up to about here. That's it. About to two-, well, 280. Currently it's three-, well, I think it's now over 400. It was 399 last year.

So the, we have gone outside the bounds of what was going on for the last 800,000 years. Problem? Well, I think so. Some say it's not a cause/effect relationship. But we know that CO_2 is increasing and we know that temperature is increasing. Why? Well, we know that the carbon dioxide content of the atmosphere has been studied at the Mauna Loa Observatory by Scripps, a guy named Keeling. He's been wor-, had worked there for, well, 40 years really. More than that. Somebody else has taken it on, I think, as a matter of fact.

Anyway, the point is, you can see the atmosphere breathing but it's going, the CO_2 content of the atmosphere is increasing with the passage of time. The, and this is in the Northern Hemisphere, so the CO_2 relatively goes down when in the heavy growing season, spring, let's say, and in fall and winter when defoliation is going on, there the CO_2 content goes up. It's not capturing as much CO_2.

So this shows it breathing but it's clearly a systematic trend. You can see what is called the hockey stick effect of the increase in CO_2 over time. And this really is about the time of the Industrial Revolution and the major use of coal.

So what are we going to do about it? Sea level's rising, too. Well, it's risen about, looks like about 20 centimeters, 8 inches over the last 110, 120 years. Is that a problem? Not for Saint Peter, but for Miami it's a problem because if sea level rises much more, and if you notice, the sea level rise seems to be increasing since about 1960, mainly probably because there is just more CO_2 going into the atmosphere. But secondly because we have better data.

So the ocean temperature is also going up. And part of the expansion of the ocean, I was surprised to read this but part of the expansion of the ocean, maybe half of it, is at least, is due to the fact that it's warming and, of course, it expands as it warms, positive thermal expansion, isobaric thermal expansion.

Could this be all natural? Well, it's not due to the sun. Here comes the, here's the radiance from the sun and it varies but not enough to account for anything. Besides we haven't that kind of a system going back and forth around a common line.

Now there’s something called a Milankovitch Cycles, that it’s been described for, well, it’s been known for 60 or 70 years now. It’s eight, made up of four different things, the precession or the wobble of the spin axis, the tilt of the spin axis of the Earth, and the orbital eccentricity, how eccentric or circular it is. And these things have different time scales, 23, 41, 100,000, and 400,000 years.

And they could explain a lot of the recent, the stuff like I showed you the last 800,000 years. And they probably are a good partial explanation for that. But they don't tell us anything about the cretaceous , which was a time interval from about 150 million years ago to 65, which was typified by a total absence of glaciation and there may have been some high latitude polar ice, but it’s not glaciation in the same sense that we had Continental glaciers right here in Southern Minnesota.

So we’ve got to do something about our energy use. I don't think there’s any question that it has to be done. The question is now or later. Are we going to wait until we’ve all died of smoke cancer, lung cancer from smoke? I mean, it’s the same sort of analogy that Steve talked about this morning with the proviso though that unless you talk about secondhand smoke, a person smoking is endangering his own life but he’s not so much dangering [sic] everybody else.

Our use of Humvee II's and one thing, another, is danger, I hope nobody here has a Humvee II. Well, anyway, it has the effect of endangering all of us. Not just Americans either. We’re talking about people around the world.

Are we running out of Earth resources? Well, the people in Irian Jay want what we have. They want those resources, whatever they are. Let’s imagine everybody had what we had, have, had. [laughs] Sorry. Have. Well, I won't dwell on all this but I will just tell you that the stone, gravel, and cement that we use in one year would be enough, if, if everybody, if 10 billion people in the world lived as we do and used gravel, stone, and cement to make concrete, we would have to concrete over a state and a half, like Delaware plus about a third of Virginia to one meter thick concrete. Well, that loses the analogy, you're going to spread it over the whole world. But the fact of the matter is, everybody needs five or six times as much as we're producing and extracting from the Earth today.

Can it be done? It can be done if we have sufficiently inexpensive energy. But we are right now, and I want to emphasize this, though we are not overutilizing the blue water in the world, we are using it at a lower level than it can be resupplied at. It is renewable after all, water, the water cycle does renew on about 50,000 cubic kilometers a year. But other than that, everything else we, look, our ecologic footprint, our material output, carbon footprint, stuff like that, there, we're over drafting and have been ever since settled agriculture began.

So what are geologists to do? Well, it's part of the reason for being here at this lecture to talk about. The thing we need to do is move to sustainable resource utilization. You can do that in a number of different ways.

Conservation is one of the lowest hanging fruits we have. That is, if you use electric appliances that use much less energy, you will save a lot. And Steve showed that this morning. We have to recycle. We have, recycle everything we can.

Energy doesn't recycle so well. That's the problem. We have to explore for more and we have to have development and commercialization of resources, including energy. But the most important thing is that we have to dematerialize our economic growth. We cannot tie our GNP to using more and more resources. We have to use them at a much more efficient level than we have been heretofore.

So energy seems to be the really big problem. So let's talk about. Nuclear: fission and fusion. Fission we have and we seem to be walking away from. Fusion is, has been since 1980, just 10 years out, [laughs] 10 years out.

Photovoltaic, solar thermal. Those are here now and are close to being economically viable.

Geothermal, in certain instances it's very much so. The people in Iceland use geothermal, too, fairly well. It works fine there. But you've got an abundance of it there. Hydroelectric and tidal, these are all sources.

Wind power, of course. Biomass, hey, let's not. Biomass is carbon. Use less if possible.

Hydrogen fuel cells. If you have a good source of energy, that's fine. Hydrogen fuel cells are an energy currency. They're not a source of energy because you have to use more energy to break the hydrogen off from the oxygen than you get back from their combustion. That's sort of the second law of thermodynamics. So we know that really happens.

But, wait, there's more. We could do all this with energy and resources but we still might lose the biosphere. And if we lose the biosphere, we're all going to be in, well, we'll, the biosphere will not go away completely ever. Well, no, that's a probably definite statement, for very many moons. But biodiversity isn't going away. Biodiversity is decreasing massively now. We're on the sixth, sixth major mass extinction in the world.

And it’s not so bad in North American and Western Europe because we’ve already denuded it. But the places where there’s a lot left, we’re going at it at great shakes, like that. Nice place.

Anyway, suppose humanity really succeeds in, you know, developing a sustainable Earth resource usage. Will we be able to maintain a viable biosphere? Because if we don’t, a lot of the ecosystem services we depend on are going to go away. And we’re already apportioning a third of all the net primary productivity of the, of the photosynthetic part of the earth, so we can’t use a whole lot more without disadvantaging the biosphere. Do we want to really do that?

Well, it’s not right. And we shouldn’t do it. But it’s for our own self interest. So maybe we ought to consider that.

[inaudible] the future directions of science, Earth science. I’m here as a geologist and I can tell you the Earth science is changing a pot load from what it was 20 or 30 years ago.

When I was a student now 60 years ago, let’s say, Rachel Carson had not yet written the Silent Spring. We weren’t aware of some of these problems. We are more than aware of it now, and as I said to a group of students at lunch, your job is to solve the problem, clean up the mess we made. We didn't do it very well. In fact, we did very poorly. And one of the students said, ‘Yes, you did.’ [laughs] And that’s true, though. What we need to do is reduce our impact on the, on the planet. And we also have to have a little more equity in terms of what other parts of the world get to have. Because we have now a generation or two that has universally intrusive television and internet services, except for North Korea.

And so these people know what we have. And they want it. And if we don't help them get it, how do you think they’re going to think of us? So it’s in our own self interest to help these other people and somehow we have to do that.

Why should geologists be concerned? It’s our planet. Others, and I won't mention them, except for civil engineers, think it’s partly theirs. And indeed it is. [laughter] Well, you see, we have this problem at Stanford. [laughs] No, the fact of the matter is that we, we, we work on the nature of the planet and its interactive systems all the time now. That is what Earth scientists do. And that’s what we will do in the future. And it won't be just for the next 10 years.

I was once at a meeting with Chevron people and the president of Chevron said, ‘This is the year of the environment.’ I said, I’m glad to hear that but it isn’t really right. From now on it’s going to be the year of the environment, every year will be. This is a moving target. And we’ve got to address it by dematerializing and moving into ways in which we can have an economically viable system that is somewhat divorced from material resources.

Oh, yes, we have to have soil. We have to have water. Things like that. And small amounts of mineral, other mineral resources, but we’ve got to make it more equitable. We’ve got to cut back on our total usage. I think I’ve outstayed my welcome so I will thank you again for a wonderful meeting which is only half over, but I’ve learned so much today that I will go back reinvigorated to my class at Stanford, which is called Earth Systems. Anyway, thank you very much for your attention.