Nanonet Lecture

"Can nanotechnology be green?"

Barbara Karn
US EPA/Office of Research and Development detailed to
Woodrow Wilson International Center for Scholars/Emerging Nanotechnologies Project

June 26, 2006
National Institute for Materials Science, NIMS, Japan

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When we talk about research and development in nanotechnology, it is indispensable to look to its impact on human health and environment. Dr. Karn led a research grant program for nanotechnology at the US Environmental Protection Agency (EPA). She represented EPA on the Subcommittee on Nanoscale Science, Engineering and Technology (NSET), National Science and Technology Council. She is currently working for The Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars and focusing on "green nanotechnology."

Dr. Karn visited Japan to attend "The Second International Dialogue on Responsible Research and Development of Nanotechnology" in Tokyo in June 2006. We had an opportunity to have her lecture on green nanotechnology at National Institute for Materials Science (NIMS) in Tsukuba. This is her first visit to Japan and the first lecture in Japan.

Content
What is the National Nanotechnology Initiative?
NNI activities regarding environment, health, safety
EPA, its Research and other Nanotechnology activities
Why should we do Green Nanotechnology?
What is Green Nanotechnology? (Wilson Center program)

The following is a record of her lecture, and she kindly permitted us to put it on our website.

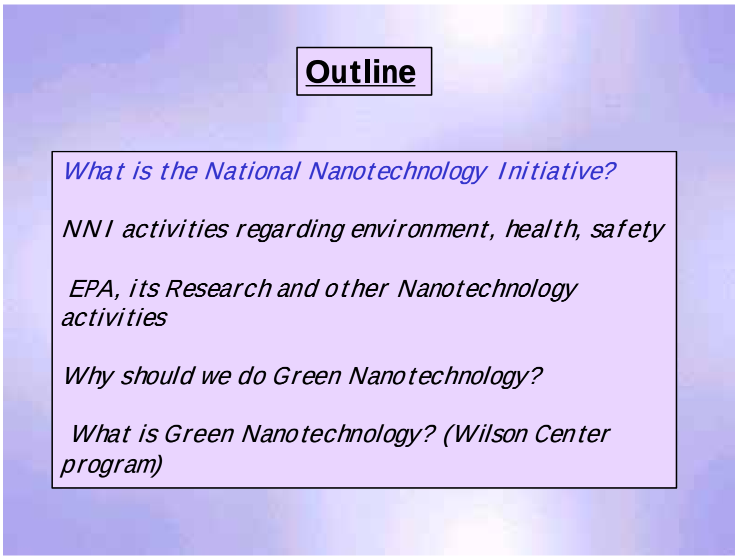
【Dr. Karn】Thank you very much for inviting me and I really look at this as an opportunity to speak to an new audience in a slightly new part of the world.

[Slide 1]
This talk is really going to be in two parts. Part of it will address the Green Nanotechnolgy. And other part will address what we do in the government, the structures with respect to nanotechnology and environment. I know

you are a materials institute here, and so you are making new materials and you are worried more about,”What kind of properties those materials will have?”, ”What they will do?” “What kind of job they will accomplish?” Well, there are another group of people that then takes these questions further and asks, “Is there any risk to having these materials in the environment?”, “Is there a risk to human health? or “Is there a risk to the organisms out there?” And that’s what we are concerned about. So imagine yourself just being a material scientist when somebody asks “Well, what about this material? Is it toxic?” “Are you protecting yourself in the laboratory just in case it is?” “What if it gets out?” “Is it going to kill the fish?” “Is it going to bioaccumulate, so that in the end we get some harmful effect, because we’ve eaten that fish?” It’s a little bit different way of thinking. But we need each other. We need people who are very good at making and characterizing materials and also people who can say; “Maybe we should look at whether these are dangerous or not?” And in making the materials, there may be better ways—this is where the “Greenness” comes in—that you can make them. You have the expertise in materials, and then you can make them in a way that they would not be harmful, if we design them right in the first place.

[Slide 2]

I’m going to talk about the National Nanotechnology Initiative. This is the US federal government program in nanotechnology. I’ll talk about how it works, and I’ll talk about the specific activities in the National Nano Initiative, the NNI, that deal with environment, health and safety. I’ll also talk about my own agency, the Environmental Protection Agency and what kind of research and nano activities we do. And then, I will address why we should do green nanotechnology and what it is. Green Nano is the Wilson Center program.



[Slide 3]

First, a word from our sponsors. The first sponsor is the Environmental Protection Agency. We are the federal US government agency whose mission is dedicated to protecting human health and the environment. We’re the only agency that does that. For example, the National Institutes of Health looks more at disease cures and various devices that

can help human health. When we at EPA refer to human health, we are talking about the health of the general public and also the environment. Our mission is: to protect the environment and human health.

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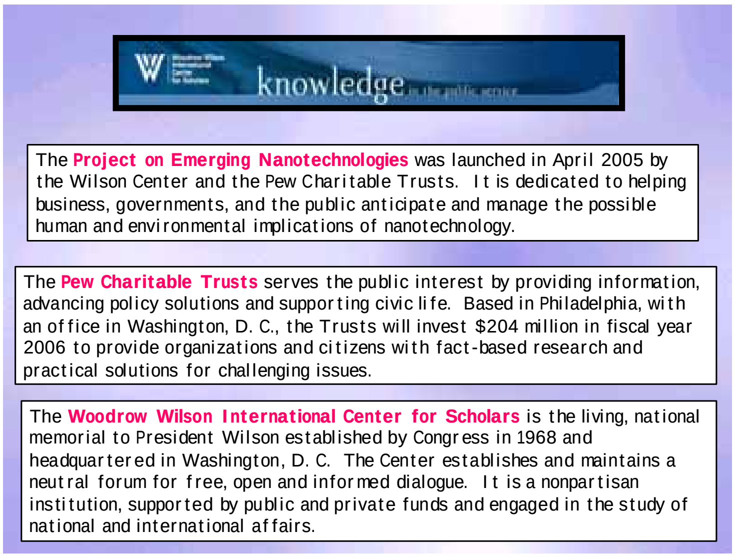

I am an employee of the Environmental Protection Agency, but right now I'm on a sabbatical called a "detail." Since last September, I've been working with the Woodrow Wilson International Center for Scholars. It's a kind of think tank formed by the Congress in '68, as a living memorial to President Woodrow Wilson. It's nonpartisan and basically studies national and international affairs. Everybody in the Wilson Center, except two of us - myself and Andrew Maynard - is in political science or international affairs, or some aspect of policy. The two of us are scientists. So it's quite different being there. The project that we are on is supported by this Pew Charitable Trusts. It's a funding organization that has a lot of large scale projects. For example, they look at a global climate change. They gave the Wilson Center three million dollars over two years to look at emerging nanotechnologies. So, that's what this project is. It was launched a little over a year ago, and it's dedicated to helping the world, business, governments, and the public anticipate and manage the possible human and environmental implications of nanotechnology. I'm going to talk about applications and implications a little bit later. So you'll learn what I mean by this.

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Going back to what is the National Nanotech Initiative. Here is just a little bit of history. In 1991, the National Science Foundation started research in nanoparticle synthesis and processing, and=then five years later, formed a group of some other government agencies which saw that working at nanoscale was a little bit different from working at the molecular scale or at bulk material scale. Then in 1998, an interagency group of federal US agencies was formed to look at nanotechnology. And in 2000, President Clinton announced this National Nanotechnology Initiative. The early agencies were six: National Science Foundation, Department of Energy, Department of Defense, National Institutes of Health, National Aeronautics and Space Administration, and the National Institute of Standards. At that point, in 2000, the 1st Societal Implications Workshop was done. So even as early as six years ago, the National Nanotech Initiative was interested in whether there are some harmful effects or societal changes that we should be aware of ahead of time. We in EPA came on board in 2001. And, right now there are about 24 agencies in the National Nano Initiative.

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The vision of the NNI is to be able to understand and control matter on the nanoscale, leading to a revolution in technology and industry. I'm sure I don't have to tell you that different things happen at that scale, and we are moving into another industrial revolution. There are four goals, mainly, being great in research and development; looking at how this will change society with respect to products, economic growth, and jobs. Also, how do we get an educated skilled work force to do this? However, the one I'm most interested in is this fourth one: to support the responsible development of nanotechnology. Not just the development; not just getting out products, but doing it in the right way in the first place. The 2005 budget was about 1.2 billion US dollars. And the NNI estimate thirty-eight and a half ($38.5) million spent on environmental, health and safety issues, approximately 3% of the NNI. When I add up the numbers, I get about a little less than half of that amount.   So I think we use more like about 1% of this total research effort. There are many groups that are supporting the fact that if we are going to spend all of this money making this new technology, then we should spend a little bit more making sure that it's safe. And that's not just from a public protection standpoint, but it's also from an industrial standpoint. Because, if industry does not bring up the technology right, they may be subject to lawsuits or litigation. Industry needs to make sure that their products are safe, whether they care about the public or not and protect itself while they are protecting rest of the population.

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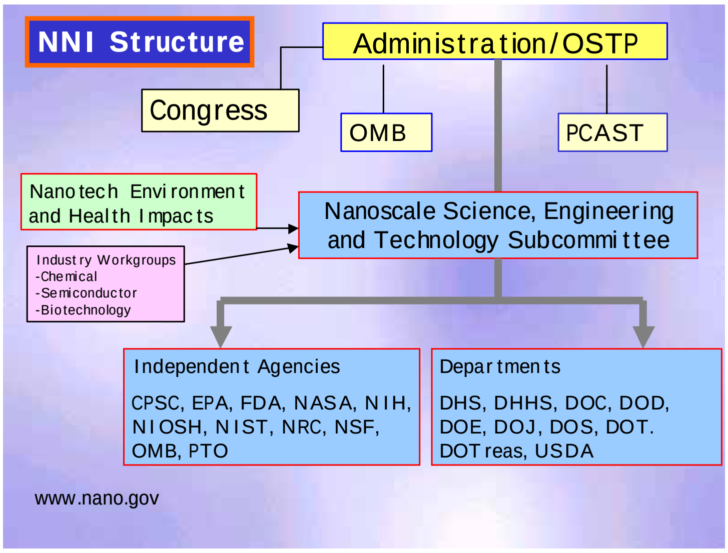

I like organization charts because I like to know where things fit. So the structure of the National Nano Initiative is first the Administration. By this I mean the Executive Office of the President and the Office of Science and Technology Policy. Congress, the Office of Management and Budget, and the President's Council of Advisors on Science and Technology all fit in with this administrative structure. And here we have the interagency group, of 24 agencies under the OSTP. There is a subcommittee called “NEHI”, Nanotech Environment and Health Impacts, and other subcommittees of industry that help to advise the NSET, Nanoscale Science, Engineering, and Technology. These industrial workgroups have some road maps and some research plans for nanotechnology implications, and these are published on the NNI web page.

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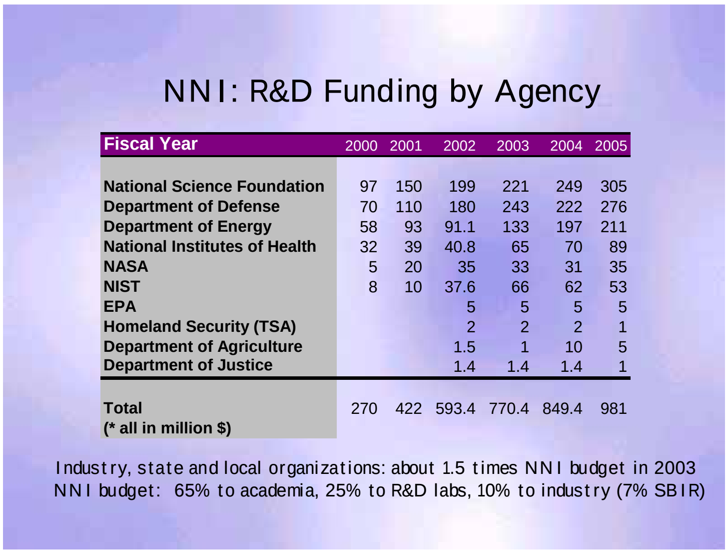

Fiscal Year	2000	2001	2002	2003	2004	2005
National Science Foundation	97	150	199	221	249	305
Department of Defense	70	110	180	243	222	276
Department of Energy	58	93	91.1	133	197	211
National Institutes of Health	32	39	40.8	65	70	89
NASA	5	20	35	33	31	35
NIST	8	10	37.6	66	62	53
EPA			5	5	5	5
Homeland Security (TSA)			2	2	2	1
Department of Agriculture			1.5	1	10	5
Department of Justice			1.4	1.4	1.4	1
Total (* all in million $)	270	422	593.4	770.4	849.4	981

The funding for 2005 is slightly less than a billion. It has always increased. In EPA, we are pretty tiny compared to everybody else. So we have this tiny amount for protecting the environment. The National Science Foundation supports the most research. The Department of Defense is second. The Department of Energy is third and so on. The National Institutes of Health put in more research money, because they are looking at cancer cures through targeted delivery of drug materials. At our standards bureau they are doing a lot of work in the nano area and so forth. In 2003, the budget of industry, state and local organizations was about 150% of the NNI budget. In the NNI, which is federal research, most of it goes to academia, 25% to government labs—these are mostly the Department of Energy’s labs—, and 10% goes to industry. 7% is for SBIR, Small Business Innovative Research, a program for small businesses.

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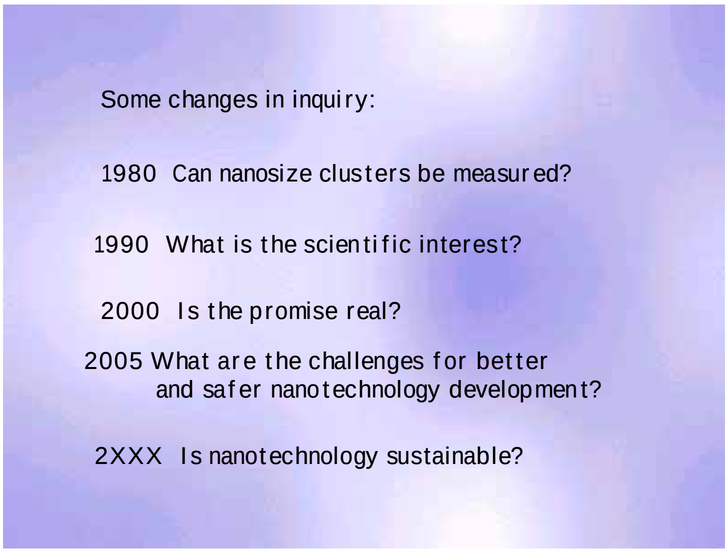

The NNI has changed a little bit over the years. At first, they were asking questions in 1980 - “Can you measure this stuff?” “Is there something different in these materials we just need to measure their size?” In 1990, we asked, “What kind of scientific interest is there in these materials?” And we found there were these really different properties. And so ten years later, we were asking, “What is the promise of these properties? Can we bring it up into commercialization?” And then, we found that we can. So now we are looking at “What are the challenges for better and safer nanotechnology development?” And I added another one here that after we decided whether they are better and safer and they are fine, we should ask: Are they sustainable for the long term?” “Is this a technology that can last forever?”

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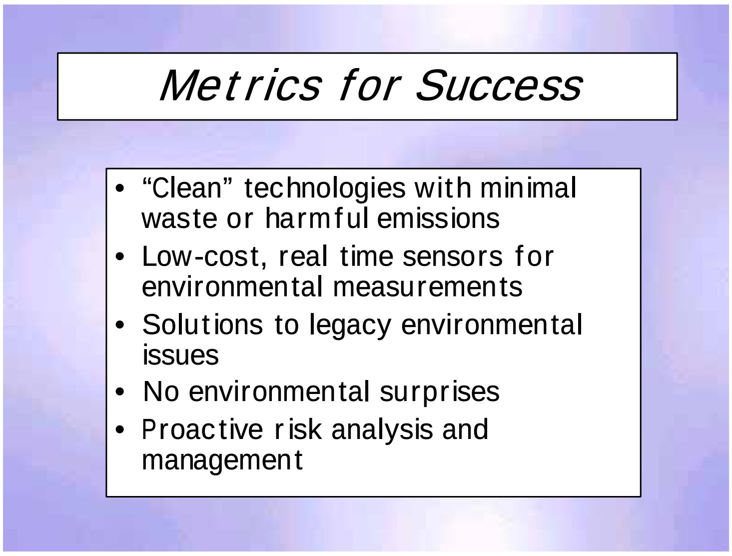

So we look at whether we are successful in this. “Can we bring up these technologies cleanly, with less waste and harmful emissions?” “Can we measure the materials, so that we make sure if there are problems harming the environment?” “Can we solve some of our old / legacy problems?” “If you have a bunch of hazardous materials here, can nanotechnology help that?” “How do we keep them from getting surprises in the environment, something like DDT?” That was a surprise. “Who would’ve thought that something that wonderfully kills insects would destroy bird eggs?” So we have to take DDT off the market. We try to think of everything that’s possible, so that we don’t get surprises. We don’t have to test everything. We just need to start thinking that way. And then, how do we proactively analyze risk and manage it? In other words, “Do we wait for a problem to come along before we do something or not?” It’s probably better to look at it up front. I think our civilization has reached a point where we can start thinking about things proactively.

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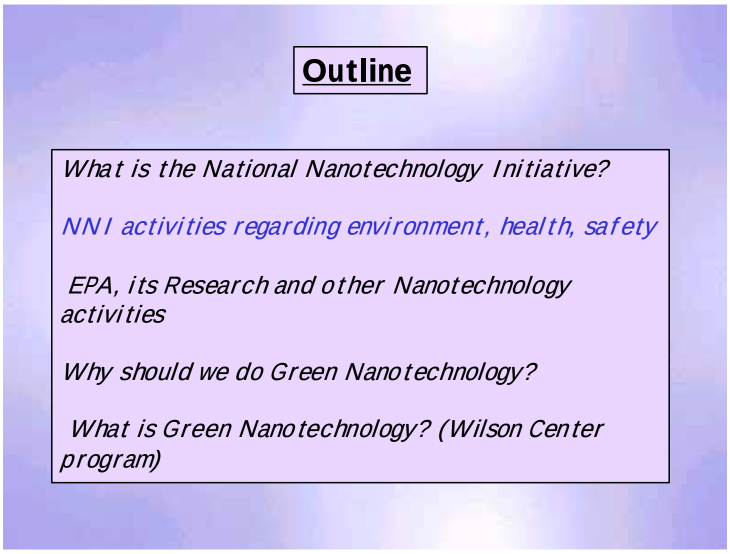

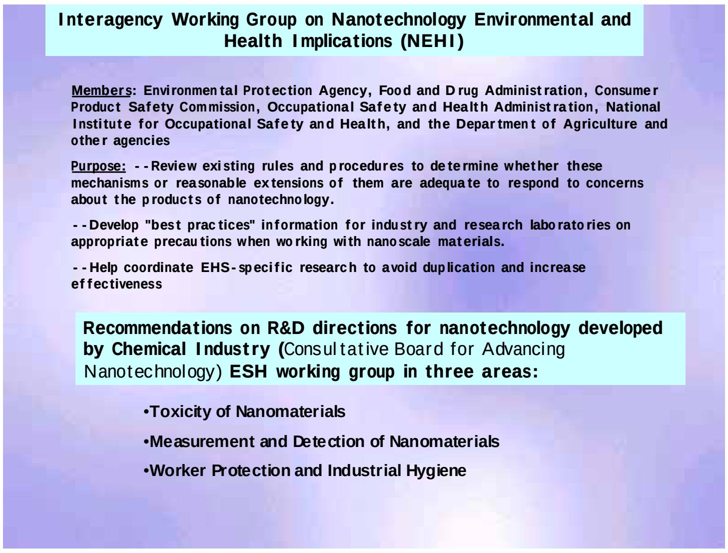

What are the NNI activities in environment, health and safety?" The Nanotechnology Environmental and Health Implications (NEHI) group includes, as its members, those agencies that have regulatory responsibility. So they help to protect the public in their regulations. The purpose of the group is to look at the rules and the kinds of regulations that we have now and see if they are applicable to nanotechnology and to also develop best practices, so that the laboratory workers and occupational workers are protected. And then the NEHI helps coordinate the research that is specific to environmental health and safety. The consultative boards are the industries, and both the chemical industry and the semiconductor industry have already looked at research needs in these areas—toxicity, the measurement and detection, and worker protection and industrial hygiene. This slide lets you know some of the projects that are going on. I'll talk much more in detail about this later.

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The Environmental Protection Agency, EPA, has partnered with other agencies to give out research grants. National Institutes of Health has a cancer effort that I mentioned before. The National Institute of Occupational Safety and Health has research in nanomaterials to help protect workers. Our National Toxicology Program, which is part of the National Institute of Environmental Health and Safety, is looking at four nanomaterials with respect to their toxicity - carbon nanotubes, quantum dots, titanium dioxide, and fullerenes. There are also large research centers that are directed toward various aspects of nanotechnology. One NSF research center at Rice University is specifically looking at the implications of nanotechnology, and there is a Department of Defense grant looking at the effects of nanomaterials on cells. The Department of Energy examines how nanomaterials move through the environment.

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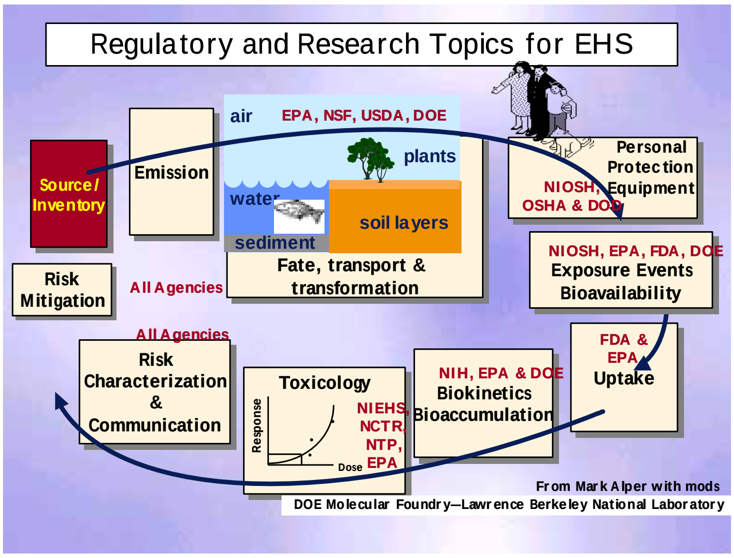

The regulatory perspectives are quite complicated. If you look at where the source is, all the way to the end, you can see that there are various aspects of what we probably want to know about the risk of nanomaterials. In the US, there are many different agencies that are responsible for this. It is probably true here in Japan that your Ministry of Environment is regulating one part and then there is another ministry that's regulating the health part and another one that's regulating the food and the drug part. So to try to coordinate all this around new technology is very difficult.

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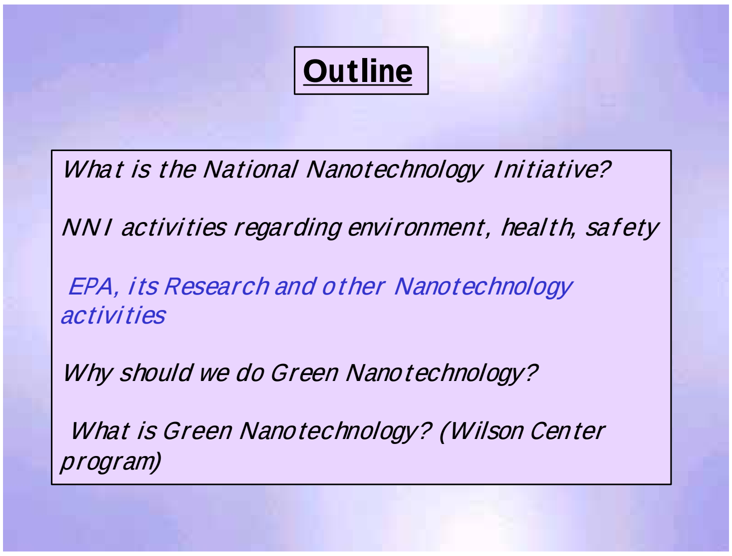
Let's talk more about my agency now…the Environmental Protection Agency… and it's research in nanotechnologies.



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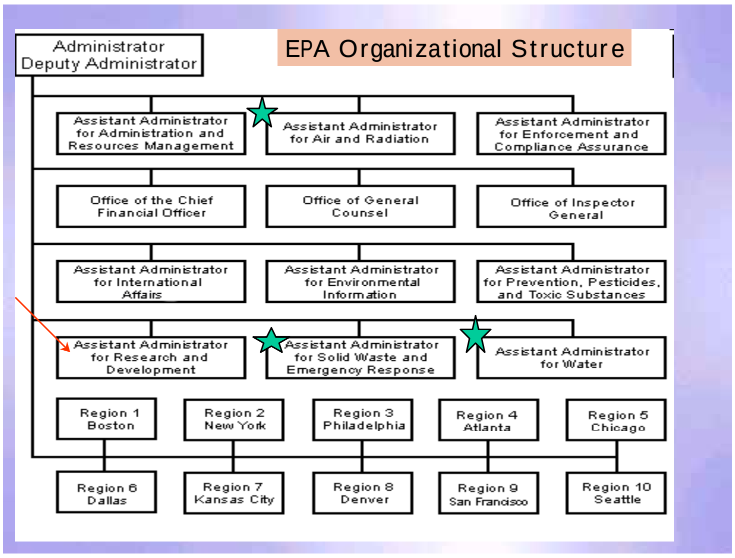
I like organization charts. So here is ours. We have a head office and several program offices. We look at the air, water, and solid waste. These media are the biggest parts of our agency directed toward major statutes of the environment. Another office is for administrative. We have policemen, because we are a regulatory agency. These people enforce the environmental laws. We have people who are accountants. We have lawyers. Then we have some smaller parts to the organization such as where I am in the research and development part of the organization. We have an international office and information office and an office of prevention, pesticides and toxic substances. This office is probably the second most active with respect to nanotechnology, because this is the office that administers new chemicals. With nanomaterials, there is a question; "Are nanomaterials new chemicals or not?" And if they are; then, "What kind of information do we need from the manufactures to make sure that they're safe to put out into commerce?" We do have regional offices too. These regional offices are charged with enforcement activities.



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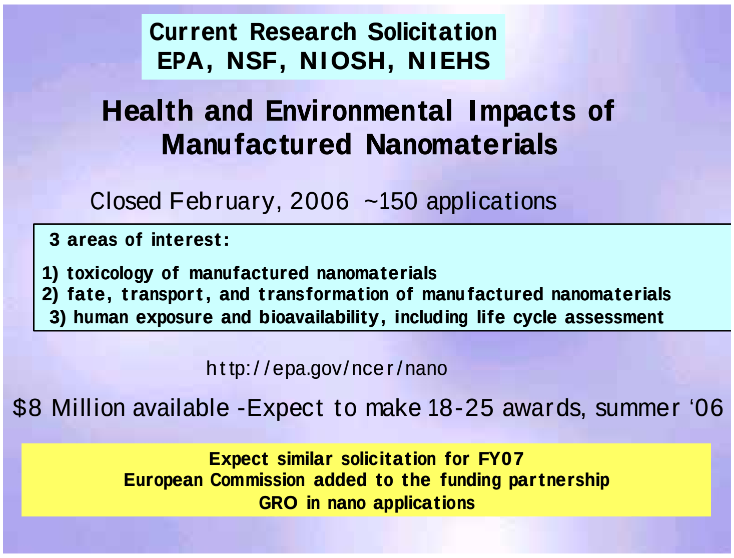

In our part of research and development, we look at solicitations. We call for proposals mainly from academics. Some non-profit institutions also write proposals. These proposals are peer reviewed and then the ones that are most relevant to what we need are funded until we run out of money. Our current solicitation was in partnership with National Science Foundation, NIOSH and NIEHS. It was on health and environmental impacts of manufactured nanomaterials. We are not talking about the combustion products that are nano size or what comes out of the volcanoes or the friction products. We are talking about what we purposefully make, because we can control what we purposefully make by not making it, if it's that bad. So we are researching the impacts of manufactured nanomaterials in three areas: their toxicology; their fate, transport, and transformation in the environment, "Where do they go, and who gets exposed to them?" and then their human exposure and bioavailability, including life cycle assessment. We ask questions like, "Are you getting exposed when you use the materials?" "Are you getting exposed if you are in a work place?" "Are you getting exposed at end of life, maybe when this material is incinerated?" That's where the life cycle assessment comes in. This is a very small solicitation. You can see, it's only eight million dollars, and we're expecting to make 18 to 25 awards—smaller grants to many researchers. We expect a similar kind of solicitation next year (2007). We hope that the European Commission will be added to this, which means it will probably double to about 16 million dollars. There is no reason why this kind of work shouldn't be done internationally, because there is no competitive advantage. The whole international scientific community can cooperate on getting this kind of information to try to protect everybody in the world from the possibility of harm. I'm not saying that there isn't any reason for caution. We know there are some harmful effects from experiments on mice and rats. For example, carbon nanotubes, when they get into the lungs of test animals, cause damage (granuloma). These results cause us to be a little bit more cautious about nanomaterials. When effects occur in these tested organisms, they just might happen in humans. There was a recent article on titanium dioxide being transported into the brain and causing "oxidative stress". Research papers in many different areas give us some cause for caution.

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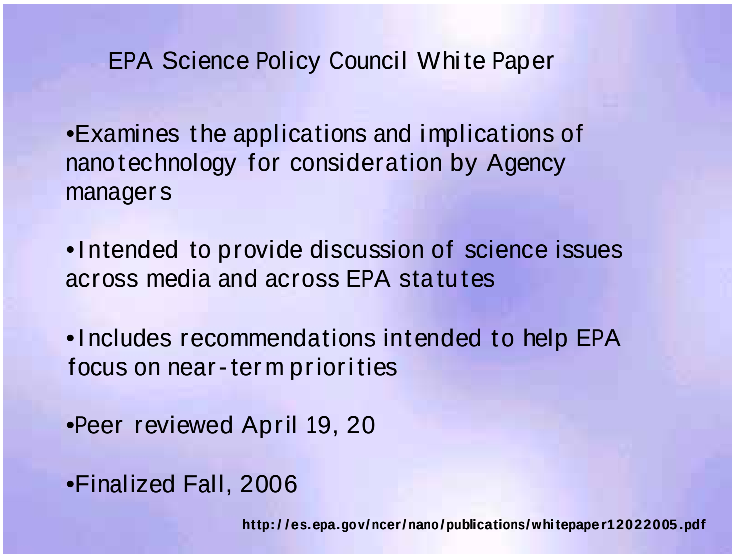
We do have some work in our own EPA laboratories, but not a lot -- little bit on nanotubes, fullerenes, and catalytic nanoparticles and then, the effect of titanium dioxide on cells. We will have an increase in our own laboratory action, but most of work we do now is supported by academics.



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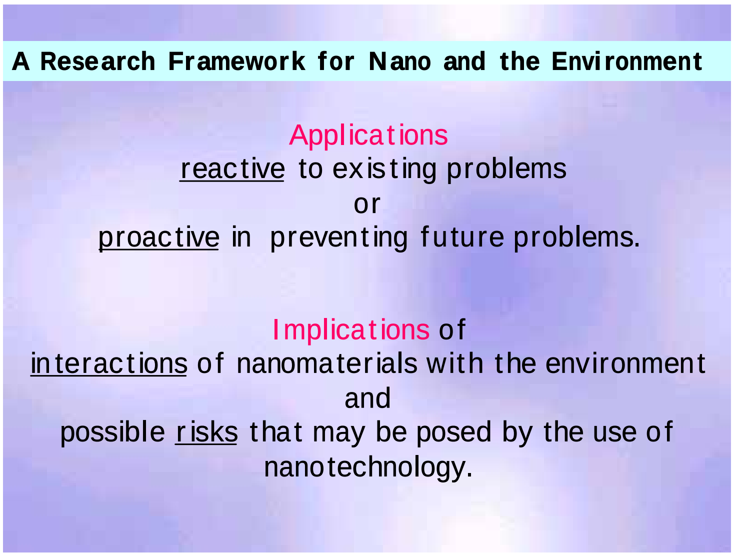
Last fall (2005), the Environmental Protection Agency came out with a draft white paper on nanotechnology that looks at both applications and implications. It is mainly a science document for discussion with some recommendations about where the research should go. It was peer reviewed and will be finalized this fall (2006). If you go to an EPA website (http://www.epa.gov/osa/nanotech.htm), you can find it.



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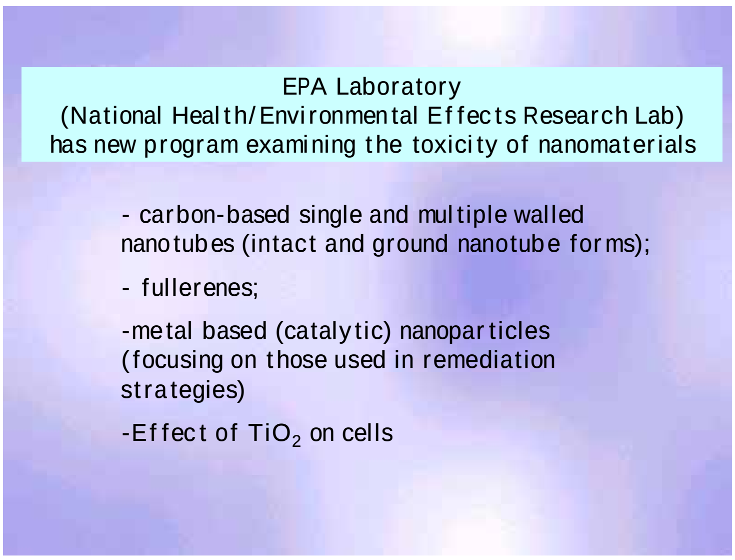
What we are looking at in the framework of nanotechnology and environment is, "What are the applications and what are the implications?" What you are doing here with respect to the environment are really applications. And that's great, because this new technology should be applied to the environment, to the benefit of society. But we also have to worry about whether there are risks. If we find risks, then we have to figure out how to manage them.



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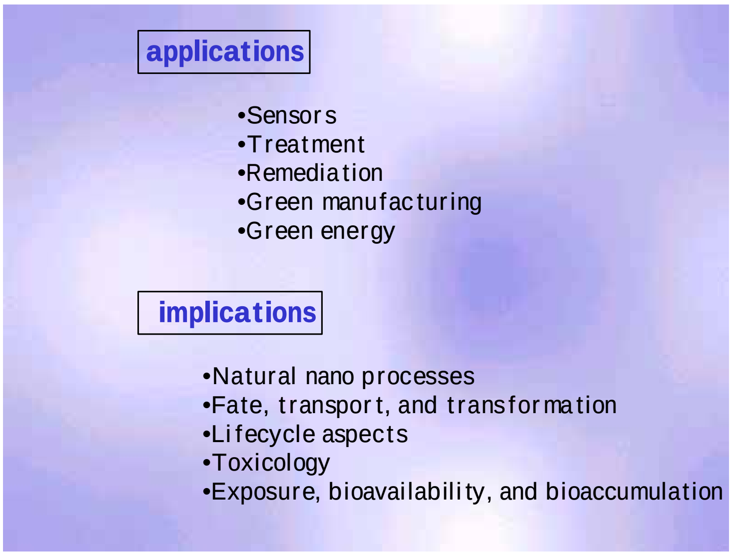
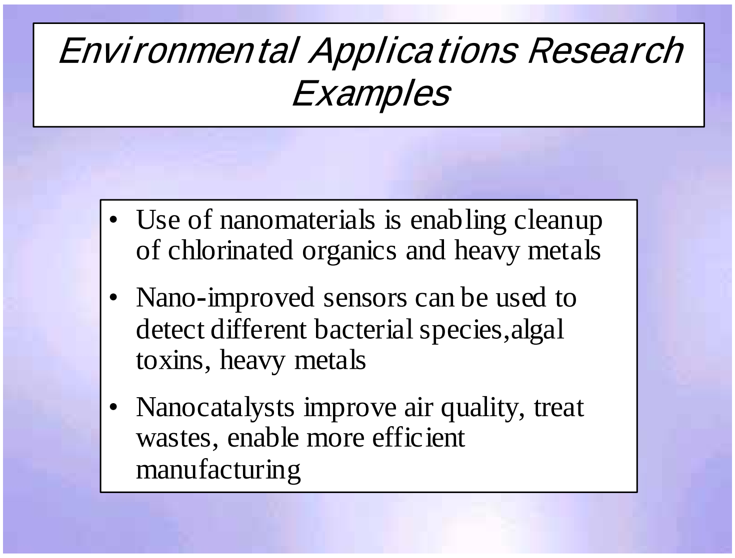
Applications include sensors, treatment of pollutants, remediation. This is a large area, and you probably heard about zero-valent iron. We use nanoscale zero-valent iron in remediation of hazardous waste sites. Applications also include green manufacturing, green energy, for example nano-enabled fuel cells. These are all part of good applications of nanotechnology that help the environment. Our current solicitations deal with implications, including toxicology, fate, transport, lifecycle aspects and exposure, and natural nano processes which we originally looked at to see how they could inform us with respect to our industrial processes. Some of the applications research we've done involve destroying chlorinated organics through zero-valent iron, sensors to detect bacteria and metal species, and catalysts to help improve our air quality, water quality and enable more efficient manufacturing.





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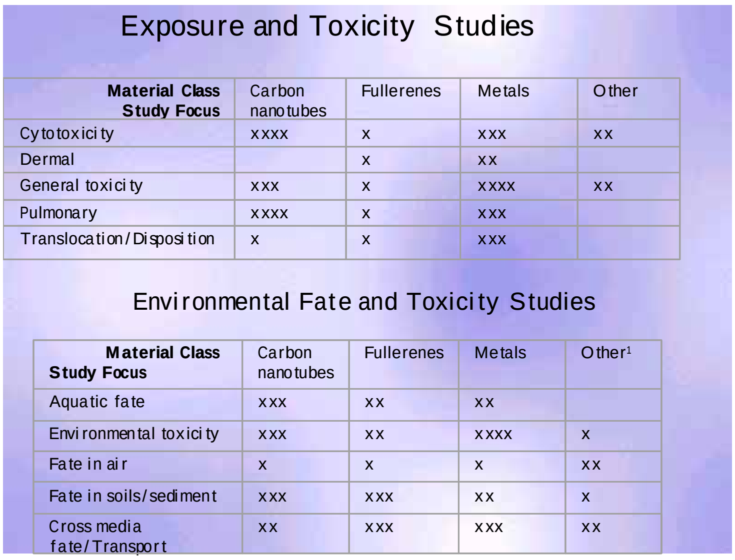
The focus of the study is first in exposures: exposures to cells, exposures through the skin, general toxicity, exposures through the lungs, and then exposures as materials move through humans. In the environmental fate and toxicity study, we look at, "Where does it go in the water? the air? the soils?" And then, "Is it in many different media?" All of these materials are being looked at in various research grants.


Exposure and Toxicity Studies

Material Class / Study Focus	Carbon nanotubes	Fullerenes	Metals	Other
Cytotoxicity	xxxx	x	xxx	xx
Dermal		x	xx	
General toxicity	xxx	x	xxxx	xx
Pulmonary	xxxx	x	xxx	
Translocation/Disposition	x	x	xxx	

Environmental Fate and Toxicity Studies

Material Class / Study Focus	Carbon nanotubes	Fullerenes	Metals	Other[1]
Aquatic fate	xxx	xx	xx	
Environmental toxicity	xxx	xx	xxxx	x
Fate in air	x	x	x	xx
Fate in soils/sediment	xxx	xxx	xx	x
Cross media fate/Transport	xx	xxx	xxx	xx

[Slide 24]

We've got a good overview of the studies. "Whether the materials are toxic?" "Where they are toxic?" "How they might enter the body?" These are just some examples. This information lets you know, "Where we are focused?" "What kind of effects we found?" And, "What were the materials that were tested?"

Human-related Exposure & Toxicology Studies

Study Focus	Examples of specific effects investigated	Nanomaterials Tested
Cytotoxicity	Affinity to cell membranes, oxidative damage, structure-function relationships, mechanisms	aluminum oxide (Al_2O_3), cerium oxide (CeO_2), cupric oxide (CuO) dendrimers, iron oxide (Fe_2O_3), nickel oxide (NiO), silicon dioxide (SiO_2), titanium dioxide (TiO_2), zinc oxide (ZnO)
Dermal toxicity	Dermal absorption, cutaneous toxicity,	cadmium selenide (CdSe), fullerenes, iron (Fe)
General toxicity	Human blood coagulation, induction of inflammatory gene expression, genotoxicity	aluminum oxide (Al_2O_3), cadmium celenide (CdSe), cadmium telluride (CdTe) dendrimers, fullerenes, gallium nitride (GaN),Gemanium, lead selenide (PbSe), nanofibers, nanowires, quantum dots, silicon dioxide (SiO_2), quantum dots, titanium dioxide (TiO_2), zinc sulfide (ZnS)
Pulmonary toxicity	Oxidative stress, inflammation, surface coating effects, nano/non-nano effects, new/aged agglomerated effects, clearance mechanisms	aluminum oxide (Al_2O_3), cerium oxide (CeO_2), cupric oxide (CuO) dendrimers, gold (Au), iron oxide (Fe_2O_3), single walled nanotubes (SWNT), multiwalled nanotubes (MWNT), nickel oxide (NiO), silicon dioxide (SiO_2), silver (Ag), titanium dioxide (TiO_2), zinc oxide (ZnO)
Translocation/Disposition	Translocation to sites distant from original exposure, persistence in vivo.	aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), titanium dioxide (TiO_2), silicon dioxide (SiO_2), zinc oxide (ZnO)

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These are the studies on the environmental fate, transport and toxicity; let you know a little bit more about "What exactly we are testing?" "What kind of effects has been found?"

Environmental Fate/Transport and Environmental Toxicity

Study focus	Examples of specific effects investigated	Nanomaterials Tested
Aquatic fate	Impact on water migration through soil, chemical behavior in estuarine systems, fate in potable water, uptake by aquatic organisms	alumina, magnetite, nanofibers, silicon carbide, silicon dioxide (SiO_2), single walled nanotubes (SWNT), titanium dioxide (TiO_2), zinc oxide (ZnO)
Environmental toxicity	Microbial biomass, organic carbon assimilation rates, deposit feeding, uptake, estuarine invertebrates, toxicity in drinking water, fish, frogs, bacteria, fungi, daphnia, algae	cadmium selenide (CdSe), cupric oxide (CuO), iron oxide (Fe_2O_3), molybdenum disulfide (MoS2), nanofibers, quantum dots, silicon dioxide (SiO_2), single walled nanotubes (SWNT), titanium dioxide (TiO_2), zinc oxide (ZnO)
Fate in air	Emission minimization, sampling and analysis, nucleation rate	fullerenes, silicon dioxide (SiO_2), single walled nanotubes (SWNT) sulphuric acid (H_2SO_4)
Fate in soils/sediment	Desorption and release from nanoparticle surfaces, disposition of contaminants,	aluminum oxide (Al_2O_3), cadmium selenide (CdSe), hyroxylated fullerenes, magnetite
Cross media fate/transport	Effects of oxygen, chlorine, UV light	carbon nanofibers, fullerenes, titanium dioxide (TiO_2), zinc oxide (ZnO)

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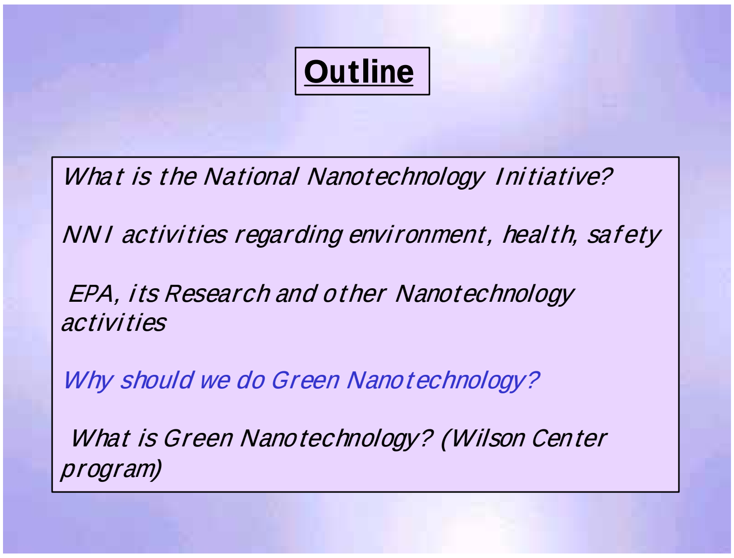
So, let's go on to green nanotechnology.



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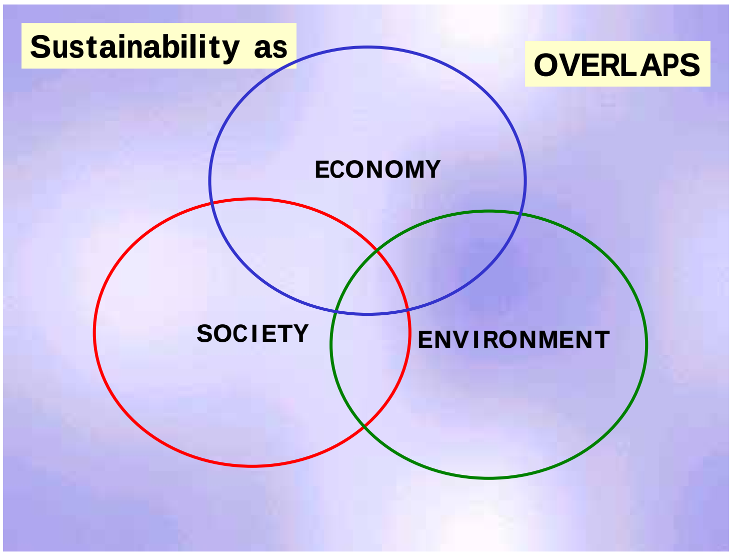

Why do we want to do this? I think we want to do this because of sustainability. You've probably learned about sustainability as being a three-legged stool. If you want to have sustainable development, you have to consider everything. You have to consider the environment. You have to consider the economy. And, you have to consider society. Without these three, you will not be sustainable. You can make something good for the economy as you want, but if it's really harmful to the environment or if it has some societal impacts, it's not going to be sustainable. It'll only going to last for a short time. Something could be very environmentally good, but it's not economical. So that's not going to work. You have to have all three of these.

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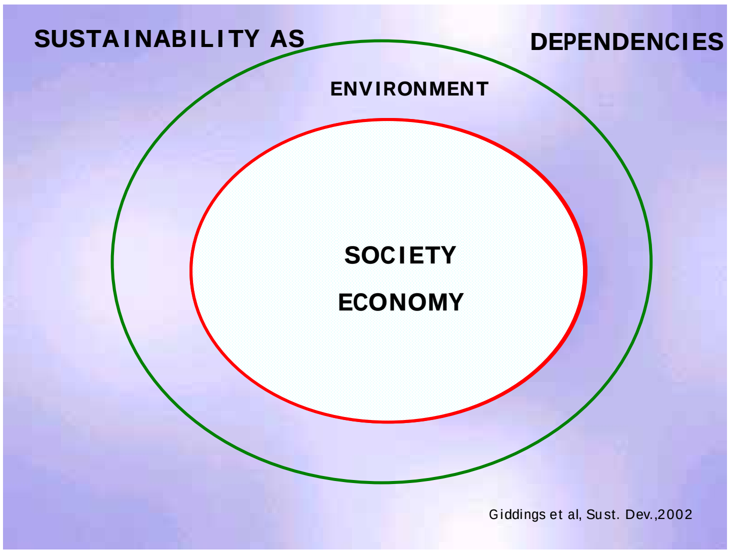

I agree with Giddings here that we really should not look at these as overlapping but look at them as embedded that the economy is embedded in our society and that's absolutely embedded in the environment. The environment provides the natural capital for all of our endeavors. If we lose the air, we are sunk. We can be great at our economies, but economic activity is not going to work if we lose the natural support system. If we lose clean water, we will not be able to support ourselves. So, we really have to have the environment and the support system for society that then allows the economic activity. The society and economy are really supported by what happens in the environment.

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So, let's look at some of those issues of sustainability - the big picture issues: global climate change, that's very married to the energy problems; depletion of natural resources; population-related problems; environmental degradation. "How does nanotechnology fit in with these big issues?" What we are leading up to here is green nanotechnology.

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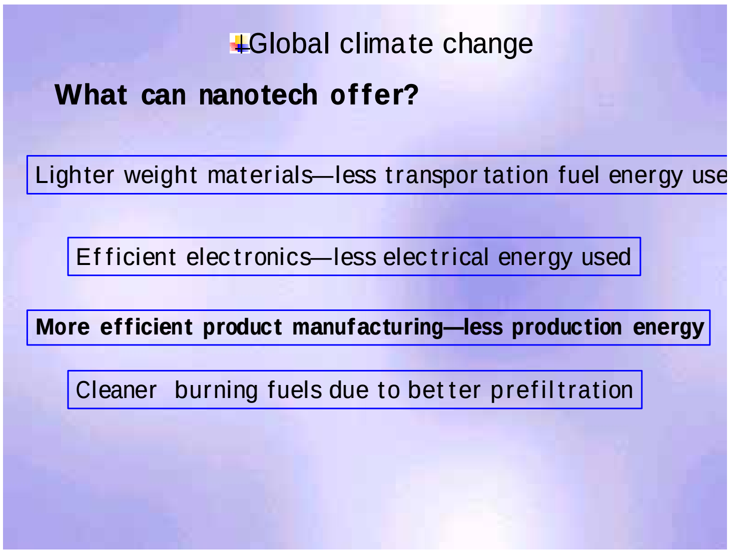
We look at global climate change with just a few examples to get you thinking about this. Maybe you've never thought this way before. You could name thousands of kinds of examples. You probably know a lot more than I could. "How can nanotech help in global climate change in those energy issues that cause the global climate problem?" We have lighter weight materials, so you don't use as much fuels. You have better electronics, and you use less electricity. Nanotechnology can lead to more efficient product manufacturing, cleaner burning fuels, etc.; you know fuel cells and solar cells. All of these sometimes can enable sustainability.



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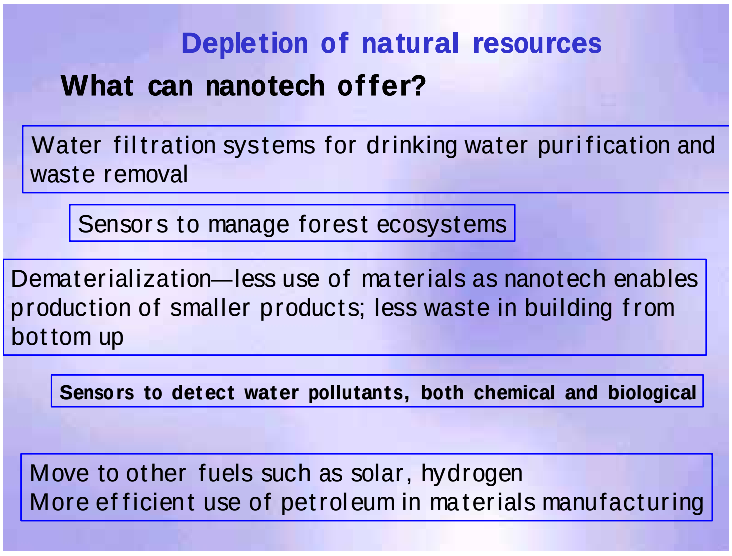

In natural resources, just working on nanomaterials means you are dematerializing. There're two ways to look at dematerialization. One is miniaturization where you actually are using less material. But also, when we talk about dematerialization, we talk about decoupling the economic growth from material growth. So, can you grow an economy without using more resources? That's another way of looking at dematerialization. Nanotechnology can certainly help with that.

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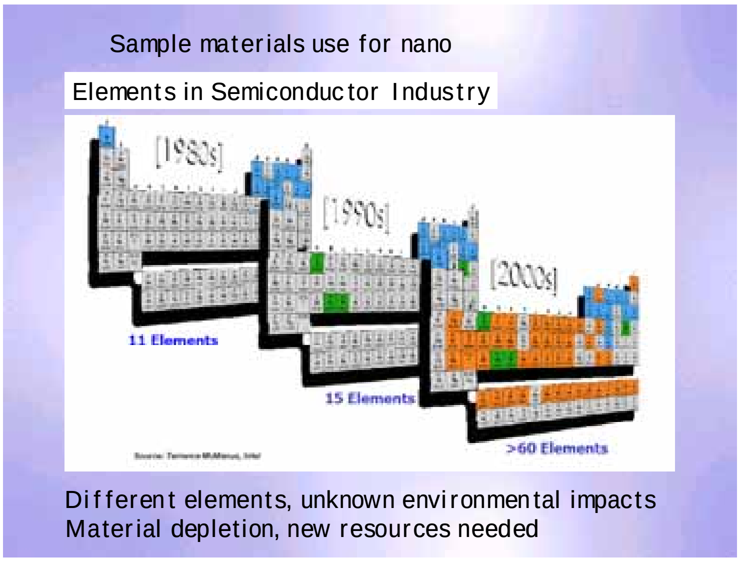

Regarding natural resources, this chart from Intel shows that in the '80s there were eleven elements used in the semiconductor industry. In the '90s, there were fifteen. Ten years later, they grew to over sixty elements. And what's important about this? What's important is that we don't know the environmental impacts of a lot of these new elements that are being used in manufacturing. In addition, there may not be enough of them. We may be running out of these very exotic materials that we want to make our nano products from. And this is something that may not be very sustainable.

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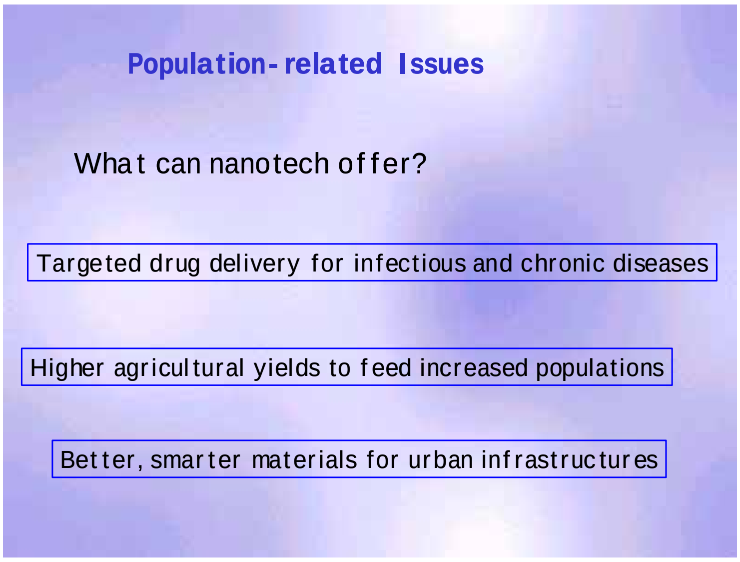
Population related issues are another sustainability issue. We have a lot of infectious diseases partly because of population densities. Nanotechnology can help with drugs for those. Better agricultural yields and better infrastructures will help where we are building mega cities. We need to get rid of much of this concrete and try to find something that's a little bit better and - less environmentally impactful.



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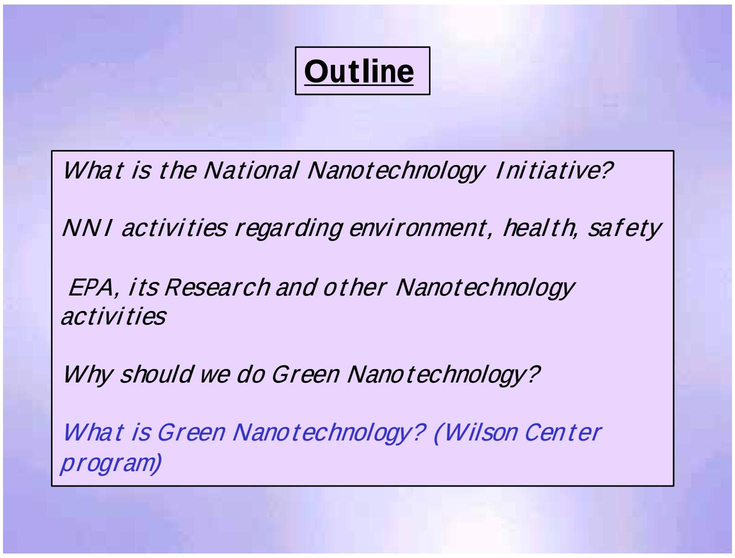
Finally, what is green nanotechnology? This is what I have been focusing on at the Wilson Center.



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Green nano has two goals. First of all, we make nanomaterials and their products without harming the environment or human health. And then we produce nanoproducts that provide solutions to environmental challenges.

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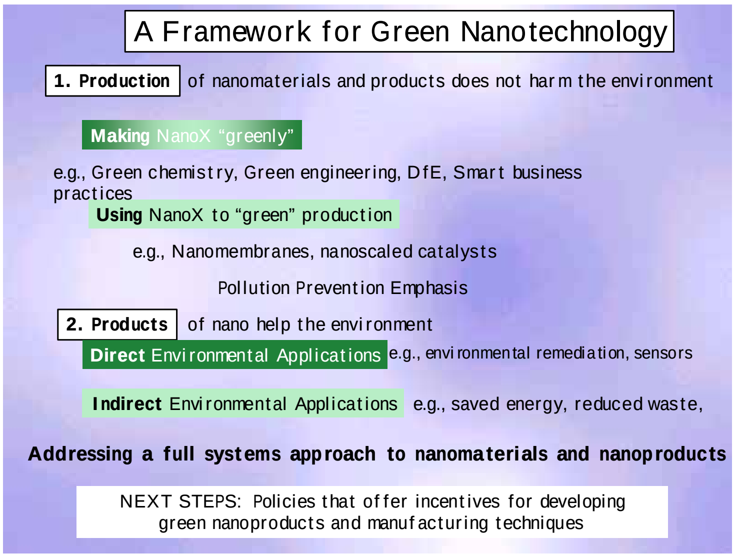
My framework for green nanotechnology looks at two aspects. One is the production, and the other is the product. In production, we are making the nanomaterials and the products that contain those nanomaterials and nano scale systems. And we make sure that in the production, there's no harm to the environment. In the products, we build products that help the environment. So in production, we want to make our stuff / the nano stuff in a green manner. And we want to use nanotechnology to make our current productions greener. What we mean by this is that



we use the rules we already know in upfront green chemistry or green engineer design for the environment or using smart business practices. We can also use nanoscale membranes and nanoscale catalysts to help make our current production a lot better. All of this has a pollution prevention emphasis. When we talk about products, we talk about both direct and indirect environmental applications. Directly, we have those materials that clean up sites. They remediate. We have sensors as direct applications. Indirectly, we help the environment by saving energy or reducing waste. So this framework fits in with the way we should be doing things more proactively. What kind of policies can we put in place at least to encourage the development of green products and manufacturing techniques? You notice that the chart has different colors. In environmental technology, they talk about "light green" and these technologies have an indirect effect. They talk about "deep green," which is the ones that are definitely directed toward the environment. "Right green" is designing it right from the start.

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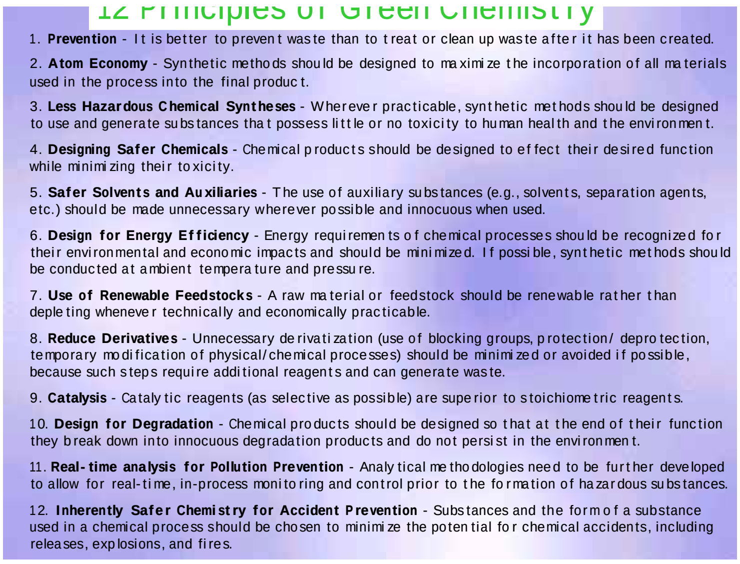
These are the twelve principles of green chemistry. You should have them memorized if you work in a laboratory. At least try to follow them, so you can use your scientific background to make things cleaner.



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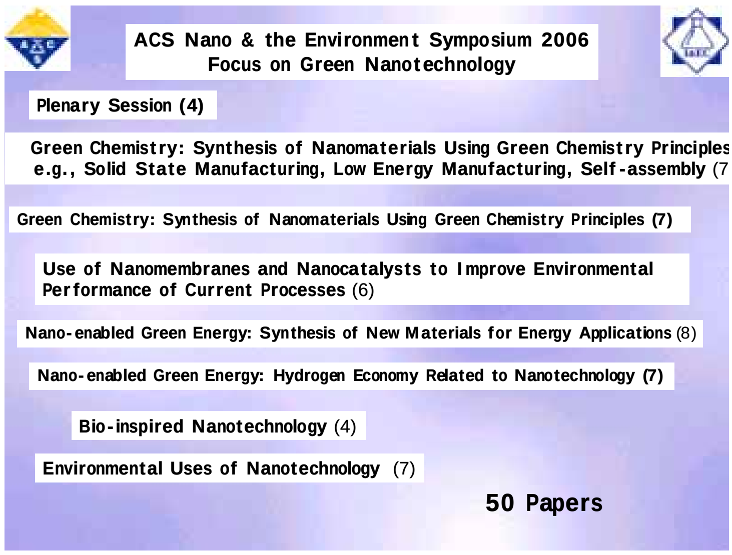

We have been running a symposium at the American Chemical Society. Last year and this year, we focused on green nanotechnology. There will be another one in spring of 2007. These are the kinds of papers that were presented; synthesis of nanomaterials using green chemistry principles, such as solid state, low energy, and self-assembly; using membranes and catalysts to green up processes; nano-enabled green energy -- one specific to hydrogen economy, one specific for new materials in energy --, bio-inspired nanotechnology, and some environmental uses of nanotechnology. Last year we had fifty papers in this symposium.

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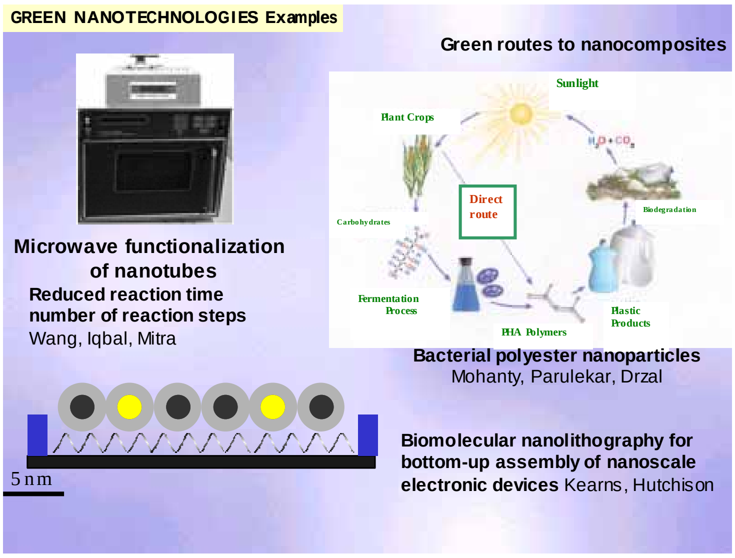
Here some examples that came out of that symposium. There are some DNA templates of gold nanoparticles. We can use a kind of engineered bacteria to make nanoparticles of PHA (polyhydroxyalkanoate). Another example is to lower the energy in fuctionalizing nanotubes by using microwaves. These result from basic research that helps enable a greener kind of manufacturing.



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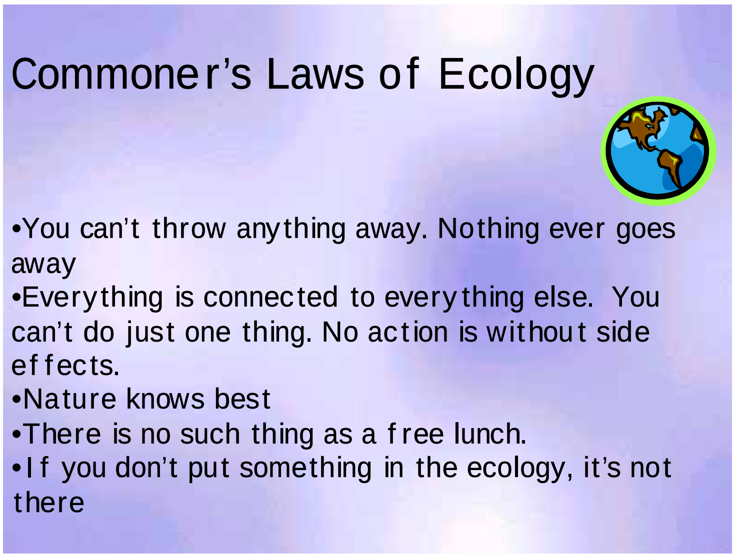
This is out of the '60s-- Barry Commoner's Laws of Ecology, and they still fit. You can't throw any thing away. It doesn't go away. We have conservation of matter. These are physical laws. Everything is connected to everything else. You can't do just one thing; nature knows best. Our natural processes work better without excessive harm to humans or the environment. There is no such thing as a free lunch. That's entropy. You just cannot do anything without losing something. If you don't put something in the ecology, it's not there. So if you don't put something out into the environment, it won't be there.



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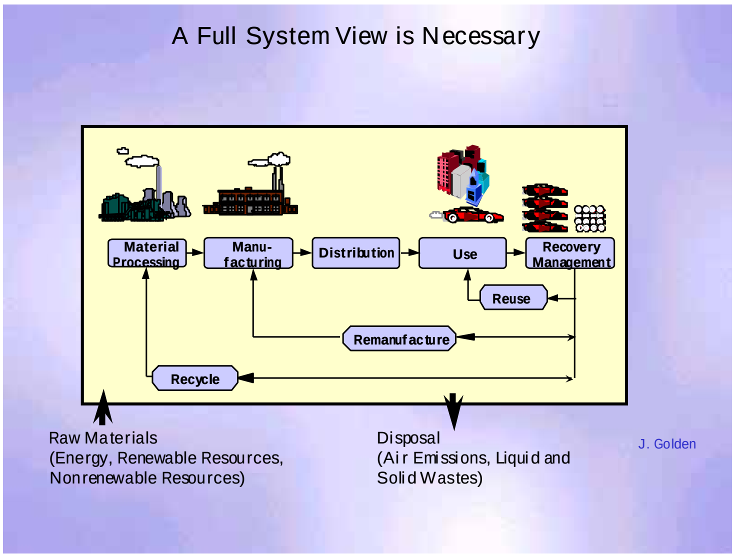
This is a full system here. And you probably have seen this with industrial ecology showing. How can we try to close loops? We recycle, remanufacture, reuse,



and when we get to end of life, we try to recover the kinds of materials and products that we have put out there.

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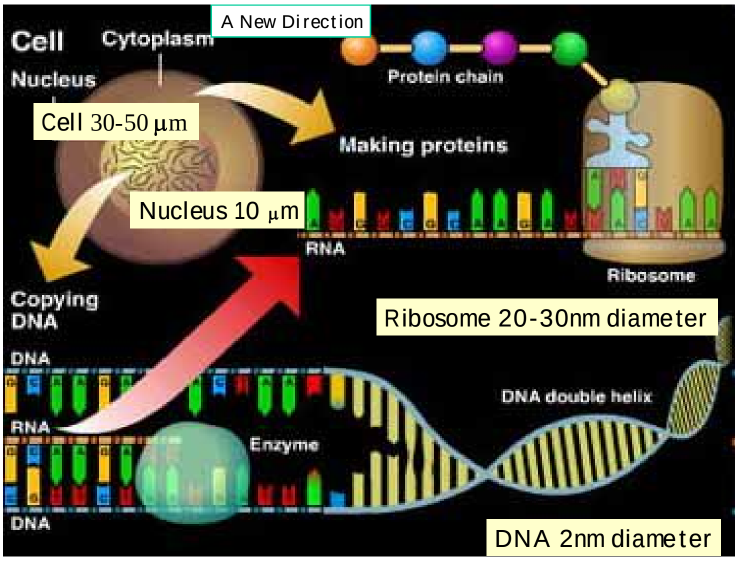

These are mammalian cells. Mammalian cells are about 30-50 μm in diameter. Nucleus is about 10 μm and DNA is 2 nm. Ribosomes are 20-30 nm in diameter. In this 30-50 μm size cell, we have the nucleus that has information bearing material in it. This information-bearing DNA unwinds, templates with RNA, which goes over to ribosome and codes amino acids to form proteins. Proteins are structural or they are catalytic. The structure and the making of new materials through the catalysis form new cells out of this whole nano-manufacturing cell. So it forms new cells, differentiating into tissues, into organs, and finally into a full organism.

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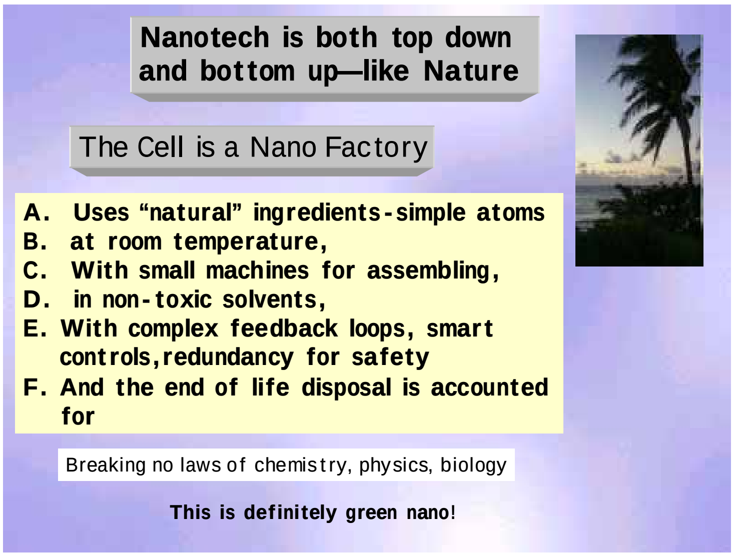

And starting with this nanoscale factory, you can make a whole human being. It’s bottom up using natural ingredients. There are no rare elements in this. We are using simple atoms such as carbon and hydrogen at room temperature. These are not high temperature processes. We have these small machines—ribosomes. They are in water. They are not toxic. There are complex feedback loops through DNA. There is redundancy. And the end of life disposal is accounted for-- some bacteria will “chew up” the organisms. This is definitely green nano. And we have broken no laws of chemistry, physics, or biology in doing this. Nature does it. So the question is; how can we make a refrigerator this way at low temperature using simple ingredients? You can imagine a kind of biopolymer that would work. Keep the cell analogy in mind as a reasonable goal that just might be sustainable. It’s a little far away from the present reality, but it just might happen in the future.

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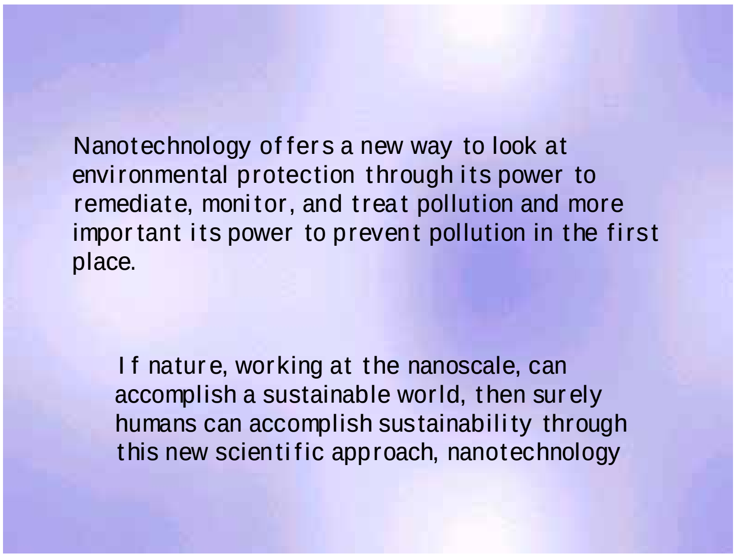
Nanotechnology offers a new way to look at the environmental protection through its power to remediate - so these are the applications - monitor and treat pollution; and more important, its power to prevent pollution in the first place. And then, nature can accomplish a sustainable world. Surely we can accomplish sustainability through this new scientific approach called "nanotechnology."



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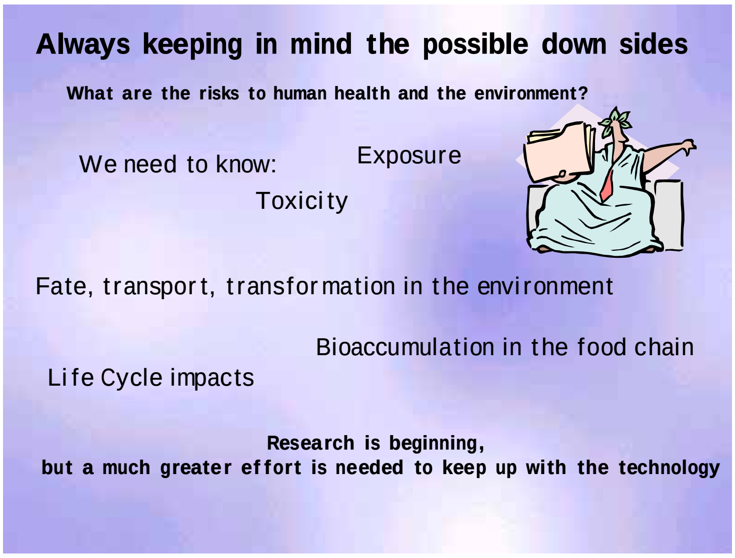
Keeping in mind the possible down sides. We need to know about this so that we can prevent risk in our future activities. So we need information on toxicity, exposure, and those things we talked about before. Research is beginning, but we need a much greater effort to keep up with the technology as it is brought up.



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I'll leave you with a thought that this is a very powerful opportunity. We have the opportunity to do things right in the first place. It is an opportunity that's too important for us to neglect. Thank you very much.

Dr. Barbara Karn
US EPA/Office of Research and Development detailed to
Woodrow Wilson International Center for Scholars/Emerging Nanotechnologies Project

Dr. Karn has led EPA's research grants program for nanotechnologies in the agency's Office of Research and Development since the program's establishment in 2001. She represented EPA on the interagency Nanoscale Science, Engineering, and Technology subcommittee (NSET) of the White House Office of Science and Technology Policy, National Science and Technology Council.

Karn holds a Ph.D. in biology and environmental science from Florida International University. She has master's degrees from Cleveland State University and Case Western Reserve University, and a bachelor's degree in chemistry from Ohio State University. Her professional background ranges from electroplating to polymers, from environmental consulting to small business owner, and from academic administrator to water quality management planner. Dr. Karn is a much sought-after lecturer. She is the lead editor of the new book, Nanotechnology and the Environment: Applications and Implications (Oxford University Press, June 2005).