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# INVESTING IN THE FUTURE: R&D NEEDS TO MEET AMERICA'S ENERGY AND CLIMATE CHALLENGES

## HEARING

BEFORE THE

SELECT COMMITTEE ON
ENERGY INDEPENDENCE
AND GLOBAL WARMING
HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

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# INVESTING IN THE FUTURE: R&D NEEDS TO MEET AMERICA'S ENERGY AND CLIMATE CHALLENGE

**WEDNESDAY, SEPTEMBER 10, 2008**

HOUSE OF REPRESENTATIVES,
SELECT COMMITTEE ON ENERGY INDEPENDENCE
AND GLOBAL WARMING,
*Washington, D.C.*

The committee met, pursuant to call, at 10:10 a.m. in room 2175, Rayburn House Office Building, Hon. Edward J. Markey (chairman of the committee) presiding.

Present: Representatives Markey, Inslee, Cleaver and McNerney.

Staff present: Ana Unruh-Cohen and Jonathan Phillips.

The CHAIRMAN. Thank you all for being here at the hearing that we are going to have today on Investing in the Future: R&D Needs to Meet America's Energy and Climate Challenges in the Select Committee on Energy Independence and Global Warming.

America is a Nation of innovators. From the Founding Fathers to the YouTube creators, our country has always cultivated entrepreneurs with an idea about the next big thing. Since World War II, the Federal Government has recognized that it is in the Nation's interest to invest in fundamental research and development to help keep the economic engine of innovation running.

Today, we are confronted with challenges to our national security, our economic security and our environmental security that all stem from our over-reliance on fossil fuels. The imperative to move to a clean, renewable energy system is clear. The need for robust science to guide our way is obvious.

Because of past investments in energy and climate research and development, we have the tools and technologies to begin tackling the climate crisis now. Energy saving technologies abound. Alternative energy sources are looming. Wind, solar and geothermal energy sources are taking market share away from fossil fuel. Hurricane tracking and forecasting helped us prepare for the arrival of Gustav, Hanna and now Ike. But in order to achieve the significant reductions in carbon dioxide necessary to avoid truly catastrophic climate change and respond to the serious impacts that we can no longer avoid, we must invest in further research and development.

The United States once led the world in the development and production of renewable energy technologies. Just as the United States once led the world in broadband technologies. After years of neglect, we are now losing these races, struggling to stay close to our competitors in Japan, Europe and even China. The bitter truth

is that now we are buying technology from abroad that in many cases were developed here in our own universities. In 25 years, U.S. energy R&D has fallen from 10 percent of total R&D down to 2 percent. Instead of building our R&D endowment, we have been slowly chipping away at it. This trend must be reversed.

Some have argued that it is premature for the United States to adopt a domestic cap on global warming pollution because we lack the technology to achieve it. That view is wrong as a factual matter, but, more fundamentally, it reflects a view of America that I do not recognize. As we have heard at numerous Select Committee hearings, technologies exist now that will allow us to make tremendous progress. Enacting legislation will provide a driver for the deployment of the existing technology and an incentive for the development of new technology.

America is a can-do nation. We answered the call to put a man on the moon, to crack the human genome, to build a national information infrastructure. With the resources generated by a cap and invest system, we can increase our energy and climate R&D investment.

Climate legislation will also send a strong signal to our most vital resource, our Nation's students. As we have seen here on Capitol Hill and today's witnesses from our top universities can attest, young people today are bursting with ideas on how to bring about the green energy revolution. When I was a student, the Soviets' launch of Sputnik made us all want to study science. The government responded with significant investments in R&D and trained the next generation of scientists and engineers.

Once again, there is a threat from above us, the dangerous build-up of carbon dioxide in the atmosphere. It is time for us to respond to that threat and unleash America's creative genius on this global challenge.

We heard the delegates at the Republican convention chant "drill, baby, drill". What the Nation should really be chanting to our students, scientists and engineers is "dream, baby, dream". And in order to make these dreams a reality, we must increase our investment in energy and climate research and development and adopt the policies to make it clear that the green energy revolution has begun.

That completes the opening statement of the Chair. We now turn to recognize the gentleman from Washington State, Mr. Inslee, for his opening statement.

[The prepared statement of Mr. Markey follows:]

**Opening Statement of Chairman Markey**

**Hearing on "Investing in the Future: R&D needs to meet America's Energy and Climate Challenges"**

**September 10, 2008**

America is a nation of innovators. From the founding fathers to the YouTube creators, our country has always cultivated entrepreneurs with an idea about the next big thing. Since World War II, the federal government has recognized that it is in the nation's interest to invest in fundamental research and development to help keep the economic engine of innovation running.

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Some have argued that it is premature for the United States to adopt a domestic cap on global warming pollution because we lack the technology to achieve it. That view is wrong as a factual matter, but more fundamentally it reflects a view of America that I don't recognize. As we have heard at numerous Select Committee hearings, technologies exist NOW that will allow us to make tremendous progress. Enacting legislation will provide a driver for the deployment of the existing technology and an incentive for the

development of new technology. America is a can-do nation. We answered the call to put a man on the moon, to crack the human genome, to build a national information infrastructure. With the resources generated by a cap & invest system, we can increase our energy and climate R&D investment.

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We heard the delegates at the Republican convention chant "Drill, Baby, Drill!" What the nation should really be chanting to our students, scientists and engineers is "Dream, Baby, Dream!" And in order to make those dreams a reality, we must increase our investment in energy and climate research and development and adopt the policies that make it clear that the green energy revolution has begun.

Mr. INSLEE. Thank you.

The title of this hearing is Investing in the Future: R&D Needs to Meet America's Energy and Climate Challenges; and I frankly can't think of a more important hearing or a more pathetic situation in the United States when I consider our R&D budget. We are investing I think less than one-sixth trying to save the planet Earth than we did trying to get to the moon. And, you know, Stephen Hawking said we should prepare to go to other planets. I would prefer just to save this one, and I think we can even do it cheaper.

I had some good news and bad news. A couple of weeks ago, I went out to Golden, Colorado, and looked at the National Renewable Lab there, which is a great place. It was really intriguing, saw some amazing things. Saw two plug-in hybrid cars parked underneath about a 15-by-20 PV cell array, and the two plug-in hybrids could be powered by 8 hours apiece just on that array that could fit on top of your rooftop. It was pretty encouraging to see the amazing things going on there.

But what I noted about the National Renewable Energy Lab was that it was about the size of a small junior high school. It would fit into the janitorial locker of the Pentagon, and it was sort of the focus of the Nation's efforts to save the planet from, you know, potential doom due to global warming and all the security threats we have. And it really put in perspective to me how sad our R&D budget is.

Just—if I could hold up this chart here.

This is a comparison of the charts showing the R&D budget for our Defense Department, showing, from 1960, the spike up to about $84 billion. This is the R&D budget for our security issues, which is obviously important.

The middle chart shows our R&D budget in health care that has gone up from, you know, 1 or 2 in '60 up to about $28 billion now.

And then you compare it to our entire energy budget—this budget is not just for clean energy but our entire energy budget for everything, dirty coal, everything else. It is now at about $3.5 billion, 20 times less than our DOD budget. And arguably the best thing we can do for our security is rid ourselves from foreign oil. And yet we have this pathetically small—it has actually gone down since the mid '80s. You can see this decline from here to here.

So even though we have this triple threat—security, global warming and job loss—we have a pathetic R&D budget; and this has to be ramped up exponentially, I believe, to take advantage of the technologies that are now in pre-commercialization stage.

So I think this is a very timely hearing. We have a lot of work to do, and we have got to have a source of funding for this R&D program. Thank you.

The CHAIRMAN. Great. The gentleman's time has expired.

The Chair recognizes the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

There has been a great deal of discussion, certainly on Capitol Hill, with regard to the need for encouraging the utilization of renewables like wind and biomass and solar. And the tragedy—and I think my two colleagues have already mentioned—is that the R&D spending has been abysmal, and I think one of the roles that

this committee should play is continuing to sound the alarm in addition to securing as much factual information as possible.

Martin Luther King in 1966 said, it may well be that the greatest tragedy of this period of social transgression is not the noisiness of the so-called bad people but the appalling silence of the good people. It may be that our generation may have to report that our generation did not do what it should do. We need to speak louder as the children of light than the children of darkness.

And so I think that we must continue to call out what we see as a diabolical misdirection of our Nation. We are not spending the kind of money that we need to spend on research and development. If we are, in fact, serious about saving this planet—and I am. I have children, and I want all of them to have children, and I would like for them to have children—then I think we need to do what is necessary. There is no nation on this planet with the capability of doing what the United States can do. We are simply not doing it.

So I yield back the balance of my time.

[The prepared statement of Mr. Cleaver follows:]

**U.S. Representative Emanuel Cleaver, II**
**5th District, Missouri**
**Statement for the Record**
**House Select Committee on Energy Independence and Global Warming Hearing**
**"Investing in the Future: R&D Needs to meet America's Energy and Climate Challenges"**
**Wednesday, September 10, 2008**

Chairman Markey, Ranking Member Sensenbrenner, other Members of the Select Committee, good morning. I would like to welcome our distinguished panel of witnesses to the hearing today.

For months now, this Congress has been proposing changes to the national energy portfolio by encouraging the utilization of renewables like wind, biomass, and solar. We all know that the use of renewable, domestic sources of energy can help us achieve energy independence and can reduce the effects of global warming. For these reasons we must support the research and development of these – and other new and emerging – technologies. For nearly the past thirty years, the investment in both public and private R&D has declined, however. As the price of gasoline topped $4 this past summer, we need investment in renewables now more than ever. This is especially true as we approach the winter months, when Americans will struggle to pay for their heating costs.

As we visit today with representatives from some of the country's most respected research institutions, I hope we can use this opportunity to discover more about what goes into the R&D of the energy sources of tomorrow. The time to act is overdue, and we need to work with our nation's greatest researchers and scientists in aiding in the energy crisis.

I thank all of our witnesses for their insight and suggestions, and I appreciate them taking the time to visit with our committee today.

Thank you.

The CHAIRMAN. Great. The gentleman's time has expired.

The Chair recognizes the gentleman from California, Mr. McNerney.

Mr. MCNERNEY. Thank you, Mr. Chairman.

I want to welcome the very distinguished panel here this morning, discussing an issue that I feel very strongly and passionately about. I spent my entire career in the new energy technology business, and I had the opportunity and privilege of participating in the development of wind energy technology from its very infancy into what it is now, a successful business. So I see that as an example of the kind of opportunities that are available for our young men and women who get involved and are willing to do the hard work that it takes to master these sciences.

In order to inspire them, we need to be willing to spend the money here in the Federal Government. We have authorized a doubling of R&D budgets over the next 10 years, but the appropriations aren't following those authorizations. So we are not meeting from the Congress, from the United States government, we are not meeting our responsibilities. And we need to have a panel of such experts to convince us to do that. So please feel free to say what needs to be said. Inspire our young people to participate, and let's get the show on the road. Thank you.

The CHAIRMAN. I thank the gentleman.

All time for opening statements has been completed.

I would now like to recognize our first witness, Dr. Susan Hockfield, the President of the Massachusetts Institute of Technology. During her time at MIT Dr. Hockfield has encouraged collaborative work across traditional discipline boundaries in order to pioneer new areas of interdisciplinary study and keep the Institute at the forefront of innovation. She has won many awards.

It is our honor to have you with us here today. Doctor, whenever you are ready, please begin.

## STATEMENT OF SUSAN HOCKFIELD, PRESIDENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Ms. HOCKFIELD. Thank you, Chairman Markey, members of the committee. On behalf of the Massachusetts Institute of Technology, I am grateful for the chance to highlight the overwhelming importance of funding basic energy research. I will echo the comments of all of yours and my own.

As you know, since before World War II, MIT has served the Nation as an honest broker on complex technical issues and also as a source of breakthrough research. In the past year, as part of the MIT initiative on energy, we have delivered landmark reports on coal, nuclear and geothermal energy, which have helped to inform congressional action. Our faculty is now preparing similar reports on cap and trade policy, on solar energy, on natural gas, on nuclear infrastructure and waste disposal and overall energy technology policy, as well as continuing our pioneering work on technologies that will help make those options real.

Today, however, I am here to talk about the research funding required to achieve an energy revolution.

We all know the United States is tangled in what we call a triple knot of difficult problems. First, we have a shaky economy that has

been battered by volatile energy prices, a loss of good jobs and threats to our global technology leadership. Second, we face a geopolitical situation weighed down by issues of energy consumption and security. And, third, there is mounting evidence that global climate change is upon us.

Each knot is daunting on its own, and the three are profoundly tied together. Fortunately, I believe that we have the power to loosen all of these knots at once, with a dramatic new level of Federal investment in energy R&D. If one advance could transform America's prospect, it will be having a range of clean, renewable and low carbon energy technologies ready to power our cars, our buildings, and our industries at scale, while creating jobs and protecting the planet.

If we want to own those future technologies, there is only one path; and it is research. Yet in the last several decades, Federal funding for energy research has dwindled to the point of irrelevance. In 1980, 10 percent of Federal research dollars went to energy; and today, when we really need energy answers, it is an embarrassing 2 percent. From 1980 to 2005, the major OECD countries also diminished their investments but at an average of 39 percent. But in the U.S. our cuts were more drastic. We reduced R&D support by 58 percent.

And we cannot count on private industry to do the job either. Since 1980, research investments by U.S. energy companies paralleled the drop in public research. By 2004, corporate R&D stood at just $1.2 billion in today's dollars. And while this level might suit cost-efficient, mature technologies around fossil fuel-based energy, it is wildly out of step with any industry that depends on innovation.

Pharmaceutical companies invest 18 percent of their revenues in R&D. Semiconductor firms invest 16 percent. Even the auto industry invests 3.3 percent. But U.S. energy companies invest less than a quarter of 1 percent of revenues in R&D. With that level investment, we can't expect an energy revolution. And while we would—and we do—welcome a recent surge in venture funding for green technologies, the fact is that venture money flows not to revolutionary research but to near-market-ready ideas, the very end of the "D" in R&D.

What is the lesson here? It is a simple one. It is that while industry must support development and commercialization, only government can prime the pump of research. Congress funded the basic research that spawned the IT revolution and the biotech revolution. Today, to spark an energy revolution, Congress must lead again.

Now why should you or the taxpayers believe that this investment will work? It is because the same kind of research investment has paid off so spectacularly before. I could call on any number of examples, but let me just give you one.

Over the past 30 years, Congress has allowed the NIH—has supported the NIH to invest $4 per year per American in cardiac research. That investment has cut death from stroke and heart attack by 63 percent. Imagine the same payoff measured in electric cars, safe nuclear technology or a smart new grid. The potential here from the economy to global security to the climate is absolutely boundless.

Yet of course we are not the only ones to have noticed. If we fail to make major strategic investments in energy research now, we will swiftly forfeit the advantage to our competitors. From China and India to Germany and Japan, other countries have the money and the motivation and they are chasing the technology almost as fast as we are. We must make sure in the energy technology markets of the future we have the power to invent, produce and sell and not the obligation to buy.

So how much should we invest in energy R&D? Let's start with how much or, frankly, how little the Federal Government spends today.

We saw your charts, Congressman; and I will say—just repeat it with some numbers.

The total depends on which programs you count. But recognized authorities put the number for 2006 at between $2.4 and $3.4 billion. Just to scale that for comparison, it is less than half of what our major pharmaceutical company spends on R&D every year, less than one half of every company's expenditures. In today's dollars, it is about 2 percent of the total price of the Apollo program.

A range of experts, including the business-led Council on Competitiveness, reports Federal energy research must climb to 3 or even 10 times the current level. In my view, the Nation needs to increase energy R&D sharply, moving promptly to triple the current rates and then increasing further as DOE builds the capacity to translate basic research to the marketplace.

To establish firm funding guidelines, I believe that industry, government and universities must come together to create a detailed energy R&D roadmap. Speaking for MIT and I know for other research universities, we would be honored to help design a strategic plan.

Let me close with a short vignette.

In 1940, when Germany invaded France, President Roosevelt had a visit from a man named Vannevar Bush, who was then Chair of the National Advisory Committee on Aeronautics and was formerly Vice President and Dean of Engineering at MIT. His message to President Roosevelt was simple. For America to win the war, it had no choice but to make aggressive, focused investments in basic science.

The case was so compelling, President Roosevelt approved it in 10 minutes. From radar to the Manhattan Project, the investments in innovation that decision unleashed were the military tools that won the war. What is more, that same Presidential decision launched the enduring partnership between the Federal Government and the Nation's great research universities, a partnership that has vastly enhanced America's military capabilities and national security. It has launched many of our most important industries, produced countless medical advances and spawned virtually all of the technologies that define our modern quality of life.

Vannevar Bush's essential insight was his appreciation for the value of basic research in powering innovation. I believe that we stand on the verge of a global energy technology revolution; and the question before us is, will America lead it and reap the rewards? Or will we surrender the advantage to other countries with clearer vision?

Today, as we face the deeply linked challenges of economic insecurity, energy insecurity and global climate change, we should see in this little bit of history a profoundly hopeful, practical path to America's future through rapid, sustained, broad-based and intensive investment in basic energy research.

Thank you very much.

The CHAIRMAN. Thank you, Dr. Hockfield, very, very much.

[The statement of Ms. Hockfield follows:]

**MIT President Susan Hockfield**
**Testimony before the House Select Committee**
**on Energy Independence and Global Warming**
**Washington, DC**
**September 10, 2008**

Thank you, Chairman Markey, Congressman Sensenbrenner and Members of the Committee. On behalf of the Massachusetts Institute of Technology, I am grateful for this chance to highlight the overwhelming importance of funding basic energy research.

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Each knot is daunting on its own, and the three are profoundly tied together. Fortunately, we have the power to loosen all those knots at once, with a dramatic new level of federal investment in energy R&D. If one advance could transform America's prospects, it would be having a range of clean, renewable, low-carbon energy technologies, ready to power our cars, our buildings and our industries, at scale, while creating jobs and protecting the planet.

If we want to own those future technologies, there is only one path: research.

Yet in the last several decades, federal funding for energy research has dwindled to the point of irrelevance. In 1980, 10 percent of federal research dollars went to energy. Today, when we really need energy answers, it is an embarrassing two percent. From 1980 to 2005, the major OECD countries also reduced energy R&D

an average of 39 percent, but our cuts were more drastic, a funding drop of 58 percent.

Nor can we count on private industry to do the job. Since 1980, research investment by US energy companies paralleled the drop in public research. By 2004, corporate energy R&D stood at just $1.2 billion in today's dollars. This level might suit a cost-efficient and technologically mature fossil-fuel-based energy sector. However, it is wildly out of step with any industry that depends on innovation. Pharmaceutical companies invest 18 percent of their revenues in R&D. Semiconductor firms invest 16 percent. Even the auto industry invests 3.3 percent. But US energy companies invest less than one quarter of one percent of revenues in R&D. With that level of investment, we cannot expect an energy revolution. Moreover, while we should welcome a recent surge in venture funding for "green" technologies, the fact is that venture money flows not to revolutionary research, but to near-market-ready ideas — the very last phase of the "D" in R&D.

The lesson here is that while industry must support development and commercialization, only government can prime the pump of research. Congress funded the basic research that spawned the information technology revolution and the biotechnology revolution. Today, to spark an energy revolution, Congress must lead again.

Why should you or the taxpayers believe this investment will work? Because the same kind of research investment has paid off so spectacularly before. Let me give just one example: Over the past 30 years, Congress gave the National Institutes of Health the money to invest $4 per American per year on cardiac research. That investment has cut deaths from strokes and heart attacks by 63 percent. Imagine the same payoff measured in electric cars, safe nuclear technology or a smart new grid.

The potential here, from the economy to global security to the climate, is boundless. Yet we are not the only ones who have noticed. If we fail to make major strategic investments in energy research now, we will swiftly forfeit the advantage to our competitors, from China and India to Germany and Japan. Other countries have the money and motivation, and they are chasing the technology almost as fast as we are. We must make sure that in the energy technology markets of the future, we have the power to invent, produce and sell, not the obligation to buy.

How much should we invest in energy R&D? Let's start with how much – or, frankly, how little – the federal government spends today. The total depends on which programs one counts, but recognized authorities put the number for 2006

at between $2.4 and 3.4 billion. For comparison, that is less than half of what our largest pharmaceutical company alone spends on R&D every year. In today's dollars, it is about two percent of the total price of the Apollo program.

A range of experts, including the business-led Council on Competitiveness, reports that federal energy research must climb to twice or even ten times the current level.

In my view, the nation needs to increase energy R&D sharply, moving promptly to triple current rates, and then increasing further as the Department of Energy builds its capacity to translate basic research to the marketplace. To establish firm funding guidelines, industry, government and universities must come together to create a detailed energy R&D roadmap. Speaking for MIT, and I know for other research universities, we would be honored to help design such a strategic plan.

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Today, as we face the deeply linked challenges of economic insecurity, energy insecurity and global climate change, we should see in this historic story a

profoundly hopeful, practical path to America's future — through rapid, sustained, broad-based and intensive investment in basic energy research.

The CHAIRMAN. Our next witness is Dr. Stephen Forrest, who is the Vice President for Research at the University of Michigan. He is a physicist by training. He has made many important contributions in the area of communications, semiconductors and, more recently, highly efficient lighting appliances.

We welcome you, sir. Whenever you feel comfortable, please begin.

**STATEMENT OF STEPHEN FORREST, VICE PRESIDENT FOR RESEARCH, THE UNIVERSITY OF MICHIGAN**

Mr. FORREST. Thank you, Chairman Markey.

Transforming our fossil fuel economy into one based on renewable carbon-free solutions is a national priority of the highest magnitude. Solutions to this problem are not simple, and there is no single path to energy security, reduce carbon emissions and low energy costs. Nevertheless, America's research universities, homes to the highest-risk innovation and discovery, are ready and eager to join in a partnership with government and industry to solve what is the largest single problem confronting us in the 21st century.

Unfortunately, the U.S. has not responded proportionately to the magnitude of the crisis. Today, alternative energy research is only .02 percent of our GDP. In comparison, for example, to Japan, where it is four times that amount. In fact, only 1.6 percent of all Federal R&D goes to energy research.

To put this in perspective, the past 5 years of the DOE budget, which includes money that goes for the large network of national labs, has averaged $8.9 billion, compared to $28.1 billion for the NIH and $73.5 billion for defense. This is remarkable considering that the immense U.S. energy industry, a nearly $2 trillion industry, is bigger than either health or defense. Given how underfunded we are at the present and how unprepared we are to meet the urgent challenges facing us, we can only conclude that Federal investments are not nearly enough.

DOE itself has been crucial to advancing energy research. Its network of national labs has long guided energy research to our Nation's immense benefit; and initiatives like, for example, DOE's solid state lighting program, which supports both industry and academia, already has produced successes that will soon make the very inefficient incandescent bulb obsolete for interior lighting.

However, to face today's crisis, DOE's programs must be enlarged to include new initiatives that encourage collaboration and truly promote the transformation of our energy economy. It will take more than just increased funding. We also need better policy to make it easier and more efficient to collaborate across these sectors, to make collaboration both streamlined and nimble.

Even Michigan, with a manufacturing economy under siege, can show what great opportunities we have before us. Innovative partnerships between universities, government and industry are showing a clear path to win-win situations. We can come up with energy solutions and strengthen economies.

Michigan and the Great Lakes regional economies are rooted in the heavy manufacturing base that fueled America's greatness in the last century. We now can build on that to find new answers to our energy challenges.

Look at the auto industry, for example, where fuel costs and carbon emissions dictate that the automobile must be reinvented. Internal combustion engines will give way to cars powered by electricity and hydrogen. This change will not only solve energy problems. It will also spawn new business and a new economy.

My home State already is moving ahead to change our economic base to one focused on knowledge and energy industries. The Governor's Centers of Energy Excellence matches companies, universities and training facilities so that research innovations can make it to the market.

Therefore, to augment DOE's expertise and strengthen the drive for alternative energy, we must make two policy changes: fully fund the Advanced Research Projects Agency for Energy, or ARPA–E, and establish a network of discovery and innovation institutes.

Last year, Congress established ARPA–E, an independent agency at DOE, to serve as a critical bridge between universities that are the incubators of new ideas and companies. Establishing ARPA–E is truly a milestone, but we must move quickly to fund it to the recommended level of $300 million. We have already lost too much time in our race to create a secure and clean energy future.

Discovery and Innovation Institutes, recommended by the National Academy of Engineering, represent a second way to address multidisciplinary energy challenges. DIIs bring Federal agencies, research universities and industry together as collaborative R&D labs. DIIs will be regional, ensuring that they will draw on local strengths to work in a system that seamlessly spans from basic science to commercialization. And since it takes more than just science and innovation to build a sustainable energy infrastructure, DIIs can also be equipped to address socioeconomic and policy issues. This approach can provide unique training grounds for the next generation of technologists and leaders.

So the time to act decisively is upon us. Our national security, the sustained health of the economy, and our environment depend on our success in this mission.

Thank you.

The CHAIRMAN. Thank you, Dr. Forrest, very much.

[The statement of Mr. Forrest follows:]

**Witness Testimony of**
**Stephen R. Forrest**
**Vice President for Research**
**The University of Michigan**

**Before the**
**House Select Committee on Energy Independence and Global Warming**

**Hearing on Investing in the Future: R&D Needs to Met America's Energy and Climate Challenges**

**September 10, 2008**

**Introduction**

Chairman Markey, Ranking Member Sensenbrenner and members of the Select Committee, thank you for the invitation to testify today. It is my great pleasure to contribute to the ongoing discussion over how our nation can best meet its biggest challenge of the 21st century: creating a new energy economy that frees us from dependence on foreign oil, is affordable and protects our global environment. This is a task of highest priority that will engage all of our citizens, our best ideas, and a consistent long-term will to attain our goals. Together with industry and the federal and state governments, America's research universities will play a special role as our nation charts its way toward its new energy future.

I joined the University of Michigan in January 2006 as its Vice President for Research. Prior to moving to Ann Arbor, I have worked at Bell Labs, then the University of Southern California, and Princeton University as a professor and entrepreneur. I have more than 180 U.S. patents, have published over 420 papers in scientific journals, many of them in the field of energy generation and use, and I have co-founded or have been a founding participant in several successful companies, including Sensors Unlimited, Epitaxx, Inc., Global Photonic Energy Corp., Universal Display Corporation, and Apogee Photonics. Presently, my own research focus is on energy devices -- both those that

harvest energy from the sun, and new white light sources that will soon replace the highly inefficient incandescent bulb. Indeed, twenty percent of our electrical energy usage is devoted to room illumination. So, a few "bright ideas" in this area can lead to potentially huge energy savings.

My involvement in energy research and development (R&D) has spanned much of my career. Along with many of you, I have seen how interest in energy research has waxed and waned, often in correlation with the price of fossil fuels. Today, we are hearing a crescendo of concern about our current situation, as the cost of energy has skyrocketed and has begun to seriously affect the economic prospects of our nation. And while many different perspectives and prescriptions are on the table, it is everyone's hope that the scientists, engineers and policy makers of America can, once again, make the discoveries and produce the solutions that will help us toward our goal of the new energy economy. I am here to tell you that our research universities are ready and eager to join with our colleagues in government and business to take up the challenge.

Every day, a wide cross section of faculty and students at the University of Michigan is actively engaged in energy research and teaching. Just as one example, to respond to the increasingly intense interests expressed by our students, U-M's College of Literature, Science, and the Arts has devoted this year's education and research theme to our "Energy Future." Just yesterday, U-M held its 13th annual Energy Fest on campus which showcased the university's efforts and commitment to energy conservation, energy efficiency and alternative energy technologies.

In direct response to the challenges faced in meeting our energy needs, in 2006 U-M initiated a new research institute called the Michigan Memorial Phoenix Energy Institute (MMPEI). It is named after our Phoenix Memorial Laboratory, home of the Ford Nuclear Reactor that was founded as part of the *Atoms for Peace Program* in the 1950s, whose original purpose was to explore the peaceful uses of nuclear energy. Prior to founding MMPEI, the Phoenix Memorial was built to honor University of Michigan alumni, students and faculty who gave their lives in World War II. Today, the mission of MMPEI has broadened to move beyond just nuclear energy, and now covers all aspects of renewable energy research. The Institute works to convene world experts in energy science and technology to develop new ways to generate, convert, and store all forms of energy. But, beyond science and technology, the Institute has a broad mission to explore the "third dimension" of energy research: the policy, economic and societal facets of our energy system. We must understand how potentially disruptive energy technologies may (or may not) be adopted by the public, and how the new inventions or policies might lead to unintended consequences. MMPEI's focus is essential because, as the subcommittee knows all too well, the pathway to successful implementation of technological solutions is often guided by public policy decisions, economics and societal change.

For the remainder of my remarks, I will focus on our mutual goal: pursuing research opportunities needed to bring about a transformed energy economy, and how my own state of Michigan can serve as a model for future federal research initiatives.

**Our Nation's Energy Crisis**

There are few contemporary challenges facing the nation – and the world -- more threatening than the unsustainable nature of our current energy infrastructure. Our economy and communities are dependent upon the secure availability of clean, affordable and flexible energy resources.

Yet, our current fossil fuels-dependent energy infrastructure is unsustainable. This is a problem with potentially catastrophic consequences. Global oil production is expected to peak within the next ten years (if it hasn't already done so), with natural gas production peaking soon thereafter. This is in the context of a rapidly increasing need and competition for low-cost energy coming from the developing world, most notably China and India. While there are substantial reserves of coal and tar sands, the mining, processing and burning of these fossil fuels poses increasingly unacceptable biological and environmental risks, particularly within the context of global climate change. Furthermore, the security of our nation is threatened by our reliance on foreign energy imports primarily coming from unstable regions of the world.

At this critical juncture, a bold and broad approach is needed to radically transform how the United States meets its energy needs. Inexpensive and carbon-free energy solutions that are renewable must be found – and I am confident that they are out there.

To just put things into context, in 20 minutes the sunlight falling on the earth delivers enough power to meet humankind's energy demand for an entire year. Put another way, if we constructed six solar cell fields 120 miles on a side and placed them in the temperate zones of the earth, we would more than exceed today's demand for electrical energy. But, the problem with solar, and other forms of renewable energy, is that they are often not cost-competitive with that supplied by fossil fuels purchased on the world's markets. Our challenge is to make the breakthroughs that will reduce the cost of existing alternative energy sources, and develop *new* energy production, conversion, and storage technologies.

To succeed at this task, which is acknowledged as the biggest challenge facing humankind in this century, we must truly harness the brainpower of scientists and engineers across the country. Scientists from both academia and industry already have a solid history in finding solutions to meet our energy priorities. For example, at MIT, research has led to the discovery of a new nanostructured cathode material for battery applications which has became the A123 battery to be used in General Motor's electric drive E-Flex system for its hybrid vehicles.

University of Chicago's Professor Roland Winston is the person behind an innovative light funnel called a "compound parabolic concentrator." His device can concentrate sunlight up to 84,000 times the natural level of sunlight at the earth's surface. This solar energy collector is very effective in producing electricity for large cities such as Chicago which, in 2004 purchased $5 million in solar energy systems based on Professor Winston's technological breakthrough.[1]

My own research in light sources has brought me to the Department of Energy's (DOE's) Solid State Lighting initiative. This program brings together a dynamic group of entrepreneurs, government experts, and university researchers that now stands on the edge of revolutionizing the lighting industry after 120 years dominated by the use of highly inefficient incandescent light bulbs.

Many of the young researchers I encounter are eager to join in and devote their entire careers to this grand effort. However, their enthusiasm is tempered by what has been the unpredictable and steadily declining level of support for energy R&D over the last two decades. Simply put, the U.S. has not responded in a manner proportionate to the threat posed by entering an energy-insecure future. It is essential that America's energy research campaigns be sustained over time and are sized to match the need. Now is not the time to approach this crisis through incremental change. Indeed, when faced with clear threats to our future and our well-being in the past, America has always responded forcefully and with a clear mission to accept nothing less than full success. We must do the same now, since the threat is clear, and the solutions are within our reach.

So how do we meet the challenges to rebalance our energy needs and sources? President Hockfield has highlighted a key step in her testimony – by dramatically increasing the funding for energy research. As she notes, a range of experts estimates that federal energy research must climb to up to ten times the current level.[2] There is no question that the range of proposed increases indicate that current federal investments are woefully inadequate when balanced against the urgency, complexity, and scale of the challenges in building a sustainable energy infrastructure for the United States. Whether this is funded through dollars derived from a Cap-and-Trade System, or through the regular appropriations process, it simply must be done to respond to the currently deepening energy crisis.

It is only a matter of recognizing priorities, and nothing today stands as a higher priority than filling our energy needs with clean, secure and renewable sources. Other countries have set such priorities. According to the attached tables in Appendix I based on statistics

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[1] *Solar Energy from the Windy City*. The Science Coalition, 2006. http://www.sciencecoalition.org/universityresearch.cfm?page=14

[2] Hockfield Susan. Testimony before the House Select Committee on Energy Independence and Global Warming, Washington, DC, September 10, 2008, p. 3.

from the International Energy Agency, Japan's energy Research, Development and Deployment (RD&D) dollars made up 0.08 percent of its Gross National Product while, in contrast U.S. energy RD&D makes up just ¼ of that investment.[3] To be the leaders that we believe ourselves to be, and to secure our energy security and competitiveness, we must have at least the same level commitment to transform the basis of our energy economy.

A high-level task force created by the Secretary of Energy's Advisory Board firmly stated that "America can meet its energy needs if and only if the nation commits to a strong and sustained investment in research in physical sciences, engineering, and applicable areas of life science, and if we translate advancing scientific knowledge into practice."[4] Yet, as my fellow witness, Dan Kammen, has pointed out in his research, energy R&D declined from ten percent of all U.S. R&D in 1980 to just 2 percent in 2005.[5]

Today, only 1.6 percent of all federal R&D goes to DOE research including nuclear energy.[6] The entire FY08 allocation for DOE R&D is $9.66 billion (with $3.57 billion dedicated to basic research programs at the Office of Science). This stands in sharp contrast to the FY08 National Institutes of Health budget of $29.46 billion and the $77.78 billion R&D budget for the Department of Defense. This is especially troubling considering that the energy sector of the U.S. economy, at $1.9 trillion, is our largest single industry, larger than the $1.7 trillion health sector and the $1.2 trillion national defense sector. Clearly, energy independence has not been given the priority it deserves to make the U.S. an economic leader, as well as energy secure.

Alternative energy technologies such as electric cars, hydrogen fuels, and renewable sources such as solar, wind or biofuels still require considerable R&D before they evolve to the point of affordable use by American families. Without a consistent vision for achieving these goals, progress will move in fits and starts at best, and we will be rapidly overtaken by our global competitors. Indeed, that is happening even now.

In addition to sufficient R&D funding, organizational changes must be made in the ways that our federal government, academic institutions and energy industry coordinate and collaborate in their research initiatives. The process must become more nimble, creative

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[3] *R&D Statistics Database*, International Energy Agency, 2008. http://www.iea.org/Textbase/stats/rd.asp

[4] Vest, Charles M. (Chair), Critical Choices: Science, Energy and Security. Final Report of the Secretary of Energy Advisory Board Task Force on the Future of Science programs at the Department of Energy. October 2003.

[5] Kammen, Daniel M. and Nemet, Gregory F. Reserving the Incredible Shrinking Energy R&D Budget, Issues in Science and Technology, Fall 2005.

[6] American Association for the Advancement of Science Report XXXIII: R&D FY 2009, February 2008. http://www.aaas.org/spp/rd/fy09.htm

and streamlined to succeed in the competitive worldwide environment pursuing alternative energy sources and technologies.

**The Role of Universities in Energy R&D**

The academic environment provides a unique freedom to explore, where university researchers are encouraged to look for revolutionary, not simply evolutionary, ideas to solve large-scale problems. This approach is often not accessible to the private sector, as the risks may outweigh potential economic rewards. However, by forging close partnerships between industry and university, companies can identify the most promising new ideas developed in the research lab, and take them rapidly through to commercialization.

The freedom to explore at America's university campuses creates a dynamic climate that, since the Second World War, is among the most precious assets our country possesses. Today, university researchers are looking for solutions to our energy challenge from all vantage points – hydrogen research, improved lighting sources, biofuels, energy storage, urban planning, solar cells, wind, geothermal, and alternative fuel cars, as only a few examples. As this research proceeds, universities are training the new workforce – building the supply of future scientists, engineers and entrepreneurs who's talent and innovative thinking will bring concepts to reality.

**Michigan: A Model for Energy and Economic Transformation**

As you know, the Midwest is struggling to overcome what appears to be permanent structural shifts in our economy. Nowhere is this economic change felt stronger than in Michigan where the latest unemployment statistics shows the state continuing to post the highest jobless rate in the country at 8.5 percent – 2.4 percent higher than the national average of 6.1 percent.[7] Michigan households are among the least likely to encourage their children to go on to a college education – a ranking we share with Mississippi, Alabama and Tennessee.

So, it may come as a surprise when I say that the future of Michigan is bright. This is a great time to invest in the Great Lakes Region, because when things are looking bleakest, the opportunities for finding new directions leading to economic advantage are the greatest. In Michigan, our state government, industry and universities have indeed seized this pivotal moment of change to develop new ways to collaborate to ease the economic travails of our state. A focus of our economic transformation, as emphasized by Gov. Granholm in her State of the State Address, is on developing the enormously rich and broad prospects of the alternative energy industry.

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[7] *Regional and State Employment, July 2008.* Bureau of Labor Statistics, August 15, 2008.

Michigan's economy is rooted in the manufacturing business that fueled America's greatness throughout the 20th century. These historical assets give it the potential to share and drive the economic successes of the new century, and in doing so address the energy challenges facing the United States. That is where universities come in. We are fortunate in that our state is home to remarkably strong and competitive higher education institutions. Together, our public colleges and universities draw more than $1.5 billion in R&D funding each year into the state and work together to create a nearly unlimited and constantly renewable resource of creativity, innovation, human and physical capital, and business acumen ready to be leveraged to our state's and our nation's advantage.

The opportunities in Michigan, and specifically with the participation of great state institutions of higher education, have never been better with regard to the new challenges we face in energy. Much has been said about the vulnerability of our automobile industry posed by rising fuel costs, and global competitiveness leading to loss of market share. However, I argue that never has there been a more exciting time than the present for this same industry. In effect, the automobile is facing the most exciting time for innovations since the invention of the internal combustion engine. Given the concerns about fuel costs and the costs associated with limiting carbon emissions, we now are entering a period when the automobile must be re-invented. In effect, like Edison's light bulb, the 100-year run of the internal combustion engine is drawing to a close. How do American manufacturers rise to meet this challenge, and thereby reclaim their leadership role in the world? The answer is simple: through rapid, focused and successful innovation that starts today. And in this effort, their collaboration with universities must play a central role to be successful.

In recognition of these emerging opportunities, the Michigan Economic Development Corporation (MEDC) has launched a new Centers of Energy Excellence program. This innovative grant program brings businesses, universities and the state together to create jobs in the alternative and advanced energy industry. To quote Mr. James Epolito, the President and CEO of the MEDC, "With our world-class universities and pool of highly skilled workers, Michigan has the potential to lead the nation in the growth and development of the alternative energy field."[8] The program will identify companies with the necessary infrastructure to bring cutting-edge energy technology to the market. It then will match such companies with universities, federal labs, and training facilities to accelerate next generation research, workforce development and commercialization. The centers will focus on areas where our state has competitive advantages in workforce and

[8] "MEDC Launches Centers of Energy Excellence Program." Michigan Economic Development Corporation Press Release, August 28, 2008. http://www.themedc.org/News-Media/Press-Releases/Detail.aspx?ContentId=18c230b5-e597-4faf-a6e7-d025396d18d5

intellectual property, but where funding is still needed to overcome technical and supply chain hurdles that could prevent or stall the final commercialization process.

The University of Michigan is similarly dedicated to such partnerships, and is taking large steps to ensure a seamless linkage with industry to spur the rapid economic success so vital to our state and nation. Given U-M's renowned breadth of excellence, the concentration of entrepreneurs and business leaders seeking collaboration and assistance at the University of Michigan have sometimes found themselves overwhelmed by the sheer volume and variety of the research underway. Therefore, last fall, we established the *Business Engagement Center (BEC)* to strengthen ties to our business and community partners. With the goal of helping to revitalize and diversify Michigan's economy, the BEC serves as an information portal where entrepreneurs can rapidly be connected with leading faculty members who have expertise that overlaps with the needs of their companies. The university also will build on its numerous and long-standing energy research collaborations with firms in Michigan. These include not only the Big Three automotive companies, but also solar energy companies such as UniSolar, energy technology providers such as DTE, and chemical companies such as Dow Chemical which is headquartered in Midland.

A second example is the outreach efforts of the University Research Corridor (URC) partners -- University of Michigan, Michigan State University and Wayne State University. Along with industry and government, the URC was founded with the purpose of creating new economies based on innovations that emerge from the research labs of its large cadre of researchers. Formed to connect the scientists and engineers of the three campuses with the economic planners of the state, the URC has made approximately $1 million in seed investments in several revolutionary but feasible research projects that employ nanotechnology to address our energy challenges. This is one of many examples of how we are putting our own resources to work to ensure a bright and competitive future for our state, region, and nation.

The theme of government-industry-university collaboration is common in all these endeavors, and based on a long and productive history, one that we are confident will succeed. Now is the time to harness such efforts and maximize the return on investment of federal, academic and private funds. Meeting the energy challenge will require all of us to re-think how we do business together.

**The Role of the Department of Energy in Energy Research**

As you know, DOE plays a critical role in advancing U.S. scientific interests. Today, it is the leading source of federal funds and resources for research in the physical sciences –

providing two-thirds of the federal investment in this area.[9] The DOE is the primary government sponsor of high energy and nuclear physics, nuclear medicine, heavy element chemistry, plasma physics, and magnetic fusion. It also ranks high in overall federal support for research in computer science and engineering, and it sponsors research in biology and environmental sciences. DOE's programs and facilities have promoted the work of thousands of researchers, and played vital roles in many significant discoveries. However, to face today's energy predicament head on, our nation needs a new research model. In the past, we have relied on large industrial labs, such as Bell Laboratories, for rapid-response cutting-edge technological innovations. But these labs have all but vanished, leaving the university community with the responsibility, and opportunity, to fill this gap.

Nearly half the DOE Science research and development budget goes to supporting our system of National Laboratories.[10] The National Laboratories play a crucial role in meeting a wide range of important needs, such as nuclear weapons development, energy security, providing widely available computational resources, new energy sources, and homeland security. They set standards, plot specific directions that the energy community should follow, implement solutions, and provide massive and often costly resources to support energy research. However, to conduct the critical research needed to alter the basis of our fossil fuel dependence, emphasis on their core missions (*e.g.* nuclear weapons development) must be augmented by more research in the private and educational sectors to provide the breadth of solutions that times demand.

**What Should Be Done: Advanced Research Project Agency for Energy**

As I mentioned in my April 2007 testimony to the House Science and Technology Subcommittee on Energy, I strongly support the recommendation made in the National Academies' 2005 report, *Rising Above the Gathering Storm Gathering Storm*: create an Advanced Research Projects Agency for Energy, or ARPA-E. It is heartening to see seed funding for the agency in the FY09 House Energy and Water Appropriations bill. This flexible and independent federal agency, authorized by the America COMPETES Act at $300 million per year, "would be charged with sponsoring research and development programs to meet the nation's long-term energy challenges."[11] According to the National Academies report, the new agency "would support creative 'out-of-the-box' transformational generic energy research."[12]

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[9] American Association for the Advancement of Science, *DOE Science Leads the Pack in 2008*, Washington, DC (March 21, 2007), page 6.
[10] Ibid, page 2.
[11] The National Academies, *Rising Above the Gathering Storm: Executive Summary*, Washington, DC (2005), page 7.
[12] Ibid.

ARPA-E is modeled on the Pentagon's successful Defense Advanced Research Projects Agency (DARPA). Created in response to the Soviet technological threat, DARPA became a critical bridge between the defense needs of the time and the experts at universities and private corporations who could provide the answers.[13] Over the course of its history, it has nurtured long-term innovative research and development investments in a way that private industry could not always afford to. Through DARPA's support came ground-breaking technological advances such as the internet, gallium arsenide semiconductor technology now the backbone of cell phones, and high volume optical communications.

A similar independent research agency at DOE can bring together the best minds from around the country to guide us in developing solutions for the future. It is designed to have the autonomy and freedom from bureaucratic impediments to encourage collaborations to solve immense and common problems facing the energy sector. Ultimately, funding from this new agency will lead to the generation of a robust private industry that would provide solutions while strengthening our domestic markets.

An agile, mission-oriented ARPA-E will connect universities with large and small industry hungry for new advances in technology. With their more practical perspectives, the companies can take university innovations through to commercialization. With ARPA-E as a bridge between the two worlds, the best ideas will rapidly emerge to find their place in the commercial marketplace.

Furthermore, ARPA-E sponsorship of university research would contribute to the training of the workforce – helping to create the future scientists, engineers and entrepreneurs who will continue to innovate to solve the energy crisis that is now upon us. As America fights to maintain its competitive edge in the world, this next generation of experts will become increasingly important.

Hence, while the establishment of ARPA-E represents a milestone in our thinking of how best to address the current and growing crisis in energy independence, the time to fully fund this agency cannot be delayed. We have already lost too much time in our race to create a secure and clean energy future for our nation and planet. The U.S. can and must lead in this race if we are to maintain our global competitiveness and economic independence. ARPA-E represents a critical step in accomplishing these goals.

**What Should Be Done: Discovery Innovation Institutes**

To develop and successfully implement new pivotal energy technology and policies we must create significant additional opportunities for regional energy research initiatives. In

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[13] William Bonvillian, Power Play: the DARPA Model and U.S. Energy Policy, The American Interest, Washington, DC (November/December 2006), p. 44.

this area, I recommend looking into creating what are called Discovery and Innovation Institutes, or DIIs, recommended by the National Academy of Engineering. DIIs represent the new paradigm for addressing multidisciplinary challenges by linking federal agencies, research universities, industry, entrepreneurs, and the investment community. They manage and focus the strengths of each on the full spectrum of research, from basic science on through commercialization.

According to these recommendations, a national network of DIIs would be capable of rapid transfer of cutting-edge technologies and systems into specific sectors of the energy marketplace. These institutes would be operated by research university consortia as Federally Funded Research and Development Centers and would be closely linked to the National Labs and key industry partners. Each institute would be supported by federal funding that would eventually build to a level of $200 million per year and augmented with additional dollars from state, industry, foundation and university sources when possible.

Each DII would be responsive to the unique regional needs and capabilities where it is located. For example, for the energy-intensive Great Lakes region, which is dependent upon heavy manufacturing, agriculture and transportation, a DII could lead research in areas such as alternative transportation fuels, advanced energy efficient automobiles, and energy efficient manufacturing technologies. In contrast, a DII for the Intermountain West could focus on the energy needs of a rapidly growing population and activity dispersed over fragile ecosystems with limited water resources but significant primary energy sources.[14]

Since a successful sustainable energy infrastructure depends as much on socioeconomic, political and policy issues as upon science and engineering, these institutes also would provide a comprehensive approach that would encompass disciplines ranging from the social and behavioral sciences, business administration and public policy. Furthermore, they would serve as unique training grounds for the new generations of scientists and entrepreneurs who will have to look at every possibility from all angles to find cutting-edge answers to our energy needs.[15]

**Conclusion**

Thank you again for the opportunity to testify today. I look forward to continuing this discussion. Generating and deploying pivotal new technologies is vital as the nation faces the likely collapse of our traditional fossil fuel economy in the not-too-distant future.

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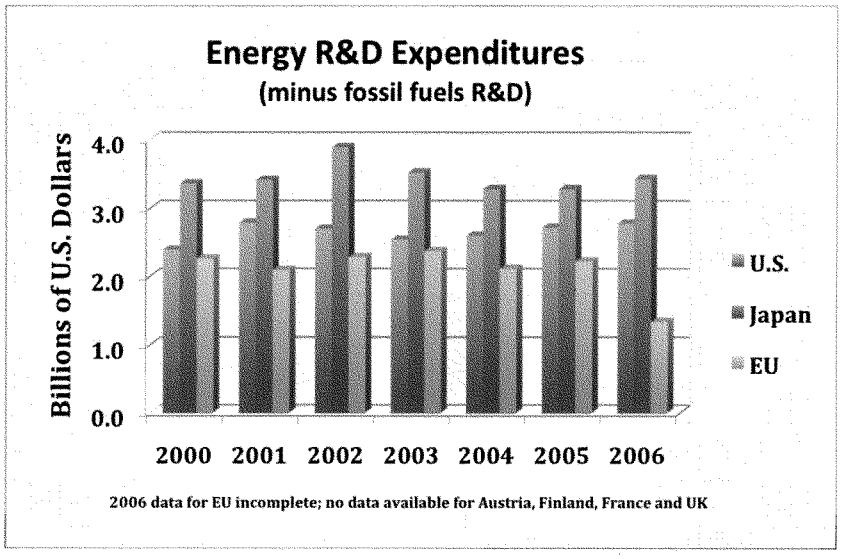
[14] "Creating a National Energy Research Network: A Step toward America's Energy Sustainability" (draft). Next Energy Project Working Group, May 1, 2008.

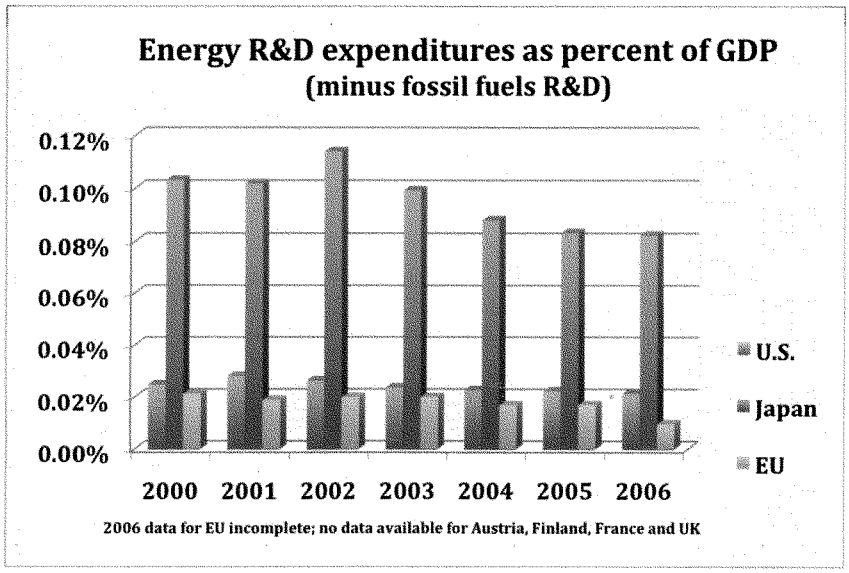
[15] Duderstadt, James J. *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education*, The Millennium Project, p. 76-79.

There is no single, simple solution, but our nation's security, our standard of living, and the health of the planet hinges on our ability to the shift away from our current reliance on fossil fuels. The state of Michigan is taking steps in that direction. ARPA-E and the DIIs also represent the kind of new and bold partnerships between academia, industry and government that must be forged to make this transformation successful. We must all pull together – academia, industry, the investment communities, government (both federal and state) and foundations.

Our solutions will require openness to new ideas, and a willingness to invest in these changes over the long term. In setting national priorities, it is increasingly apparent that transforming our energy economy now represents the single highest priority to assuring a bright future for our nation. America's research universities are up to the challenge and are eager to play a major role. It is an honor to contribute our intellectual depth and productivity to help the country survive what will be a long and disruptive transition in its energy use away from traditional fossil fuel sources. If given the opportunity, I am certain that we will succeed. As in meeting the grand challenges faced by our nation in the past, we simply have no alternative.

**Appendix I**




Source of R&D expenditure data: R&D Statistics Database, International Energy Agency, 2008.
Source of GDP data: International Monetary Fund.

The CHAIRMAN. I would now like to recognize our next witness, who is Dr. Daniel Kammen. He is a professor at the University of California, Berkeley, and the Director of the Renewable and Appropriate Energy Laboratory. His work focuses on the analysis of national and international energy policy. He is a member of the Intergovernmental Panel on Climate Change, and he has been working closely with the State of California as they implement their groundbreaking climate legislation, AB 32.

We welcome you, Dr. Kammen. Whenever you are ready, please begin.

**STATEMENT OF DANIEL KAMMEN, PROFESSOR, UNIVERSITY OF CALIFORNIA-BERKELEY**

Mr. KAMMEN. Thank you very much. It is an honor to speak. And I do have some slides if they could be put up.

First of all, it is an honor to appear before this committee. I can't think of a more vital task, and I am delighted with the attention and innovative approaches that the committee has been working on. I would like to start with a few key findings and then move from there to some of the details of what has taken place and what has not taken place in crafting our national energy plan.

The first and perhaps most troubling finding is that the global rate of decarbonization of the economy, which had been progressing at about 1 percent per year for the past three decades, over the last 8 years has now stalled. In fact, we have seen a flat line in the sense that the global economy has not been improving in its ability to generate dollars of GNP and gross world product without producing carbon. This is a critical issue, and the lead economies must take a role in reversing this trend if we have any hope of meeting our climate goals. That is a vital first part of the story.

The second piece is that public money alone will not solve and will not even begin to solve the climate problem. But, pardoning the analogy, it is vital that the public sector prime the pump in this area. There are a number of features, both in terms of the actual dollars spent and their impact on the private sector, for which we have a great deal of data, that if the public sector does not play a major role in this area, the private sector cannot move ahead in the ways that it needs to do.

There are powerful examples. We have already heard about the story in the national health field where a concerted effort, a planned effort to double the Federal NIH budget over about a decade resulted in a far larger increase in private sector investment. In fact, while public sector moneys doubled, the stability and the path demonstrated resulted in a factor of 11 to 12 increase in the private sector money.

We have not seen any plan comparable to that in the energy field; and, in fact, a colleague of mine noted that what this means is that we will likely live long enough to see the error of our ways.

So a vital issue has been left before us. In the semiconductor field, where the United States was demonstrably trailing Japan, coordinated public-private sector effort resulted in SEMATECH that charted a new course and in fact led to a whole range of innovations, so powerful in fact that the public money was effectively no

longer needed; and this carried through at the private-sector effort with a range of innovations and a vital part of the overall story.

The key message in this is that without a plan, without a plan that coordinates energy efforts and ties it to our climate needs, it is impossible for even a set of well-crafted individual programs to get us where we want to go. No matter how good a job one does with a particular effort on a subset of nuclear or solar or biofuel technology, without that vision it is impossible to carry these things through in times of budget stress and in crises when money is needed for further areas.

That is the single most critical part of the story, and that is why it is so critical the bill you proposed and the versions go forward that lays out a climate plan and ties the energy investments to it.

We have already heard about how critically small the energy investment has been as a part of our overall economy; and, in fact, the energy field is investing at roughly 1/10 the average rate of reinvestment of revenues back into research of the economy overall. And as the President has already mentioned, we have already seen higher levels in biotech and other areas, where investments at 10 to 15 percent of total revenues have been put back into some of the areas of biotech. This is the sort of investment that is possible in the energy area; and, in fact, this is the sort of investment that is critical in the energy area to meet the goals ahead of us.

We have a number of key things that we have done relatively quickly. Right now, we have a relatively poor program to transfer technologies from our national labs and from some universities into the public sector. We have had times in the past where various arrangements like credas have been successful in bringing these technologies to the market, and we need to unleash that potential again.

We also have a wide range of international initiatives where the United States could profitably partner, both in terms of technology research and development sharing and in outreach and dissemination. There are important opportunities for the U.S. in India, the U.S. in China, United States and Europe to move ahead. And in fact the most compelling message you will hear when talking to European leaders is how critical it is for the United States to reengage and to reap the lion's share of the benefits in this area.

This is not a selfish endeavor. This is one where we critically must see those investments.

And I will highlight one item on this final slide. This shows the composite aggregate growth rates in investment in clean energy when you look at Europe, North America and Asia. It is notable not only that we are seeing high rates in other parts of the world, but in fact the rates have increased in Europe, and in Asia are far outstripping the current investment rates in the United States. This is a shame, and this is bad for our economy.

We see the world's largest wind company in Denmark, a country of 5 million. The next Google of wind, of solar, of fuel cells should all be U.S. companies. We actually have the technology innovation centers, Silicon Valley, Route 128, the Austin area, areas evolving in the Detroit area are all primed to do this. But without that strong Federal signal that public moneys and public investment

and universities will focus on these areas, you send a very mixed message to industry that we will move ahead in these areas.

So I urge us to use as the basic part of this equation the need to push dramatically ahead on funding as all of us, I believe, are advocating for, but also to set the critical policy environment where a price for pollution will be part of the equation, where efforts will be targeted at lowest-cost programs, not at pet programs, and a program where the Federal Government will take the lead by beginning to do carbon-based, cost-effectiveness analysis of Federal programs both on the research side and on the deployment side. And it is vital to link those two parts of the equation.

While the Vannevar Bush story is an awesomely powerful one and we cite it for good reason in many situations, the immediacy of climate change now dictates that we highlight equally the R&D side and the deployment side. If we don't focus on both, it will be impossible to achieve our climate goals.

Thank you very much for the chance to address the committee, and I look forward to the question and answer period.

The CHAIRMAN. Thank you, Dr. Kammen, very much.

[The statement of Dr. Kammen follows:]

**United States House of Representatives**
**Select Committee on Energy Independence and Global Warming**
**Testimony for the September 10, 2008 Hearing on:**

# Investing in the Future: R&D Needs to Meet America's Energy and Climate Challenges

by

**Daniel M. Kammen**

Class of 1935 Distinguished Professor of Energy in the
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Congressman Edward Markey, Committee Chairman, Ranking Member James Sensenbrenner, and the rest of the Committee on Oversight and Government Reform, I am very pleased to have the opportunity to appear before you. I very much appreciate the attention you are giving to the vital issues of greenhouse gas emissions reduction and climate protection.

I have served as a Coordinating Lead Author for the Intergovernmental Panel on Climate Change. Along with hundreds of other climate and energy scientists, economic and policy analysts, I am tremendously pleased to share in the honor and the continuing responsibility to provide our collective best assessments on the state of climate science, and of both the need and the opportunities to effectively and efficiently address this national and global challenge. My research group -- the Renewable and Appropriate Energy Laboratory -- at the University of California, Berkeley, is focused on energy efficiency and renewable energy science, technology, and implementation. In addition, I also serve on the Executive Committee of the $500 million Energy Biosciences Institute funded by BP, and am involved in the development of renewable energy technologies for use in both developed and developing nations.

**The Low-Carbon Imperative**

As a contributing researcher to the Intergovernmental Panel on Climate Change (IPCC) I can now state unambiguously that the risks of climate change – risks that the research community has been documenting for years -- are now coming into increasing local, regional, national and international focus. In fact, an ominous sign is that in field after field – from glaciology to oceanography to forestry – the most common refrain is that 'the experts who know the most, are the most worried." We may not know all of the details, but the risks of continuing the current trajectory of emissions are very clear. Most troubling from a policy perspective is the fact that as

individuals and as a society, we readily purchase home, vehicle, and other forms of insurance for events far less likely than the potentially devastating impacts of climate change.
In responding to a threat such as climate change, it is abundantly clear that knowledge and resources are our best and most vital defense, and they are the only resource that has the potential to turn this risk into an economic and social opportunity.

Before I address the specific questions posed by the committee, one vital over-arching statement needs to be made: the threat of climate change is so pervasive, and our patterns of energy use are so deeply intertwined with our economic system, that this issue *can not be approached without an integrated vision.*

It is not enough to design a few, or even many, well-structured programs. To confront climate change and to design a more sustainable energy system, a set of goals, public and private sector objectives, and organizing principles need to be developed, articulated, and applied fairly across the economy. Special attention needs to be given to the situation of poor and disadvantaged communities, as well as ways to encourage and disseminate innovative new clean energy technologies, practices, and accords. Such a policy framework must address basic research and dissemination and diffusion of technology, and must address energy and climate decisions made the household to community, to the national and international scales as well. To date we have no such organizing framework, although thankfully a number of states and regions have begun this process. Important examples include the California Global Warming Solutions Act (AB 32) and the Western Climate Initiative, the Regional Greenhouse Gas Initiative (RGGI) in the northeast and mid-Atlantic states, and the Midwest Governors Pledge to Fight Climate Warming. In addition, *a majority* of U. S. states now have renewable energy portfolio standards, targeting clean energy development as part of the required electricity blend (Kammen, 2007a). Finally, it is critical to recognize that a transformation of the energy system to a low-carbon one cannot be expected to succeed without sending the right economic signals. At present we have failed to put a price on global greenhouse pollution.

Developing a viable carbon emissions trading system must become a national priority.

**What is the current state of R&D funding in the United States? How does it compare to past funding, and to funding in other countries?**

Innovation is the life-blood of economic growth and renewal. In fact, it has been known for decades that the bulk of new economic growth results from the re-invention and invention of new scientific and technological opportunities. Economics Nobel Laureate Robert Solow estimated that over 90% of new economic growth results from public and private sector investments in innovation (Solow, 1957). A range of estimates using diverse methods from other researchers and government agencies support this finding.

By this measure, the energy field is sorely lacking. While investment in research and development is roughly 3% of gross domestic product, it is roughly *one-tenth* that in the energy sector. By contrast, R&D investments in the medical and biotechnology field are roughly 15% of sales, almost a staggering *40 times* more than in the energy field (Figure 1). Certainly energy is no less of a national priority than these other sectors – and arguably is our number one security threat. This argues that, *at minimum*, energy R&D should be increased to the national average of

3% of GDP, if not more. In a recent set of papers, my former student and now Professor at the University of Wisconsin, Madison, and I argue developed a set of metrics that led to the conclusion that as a starting point, the federal energy R&D investment should be increased from its current anemic level of $ 3 – 4 billion/year, to five to then times that amount. A tripling of that, to roughly $15 billion/year is a natural and achievable interim target.

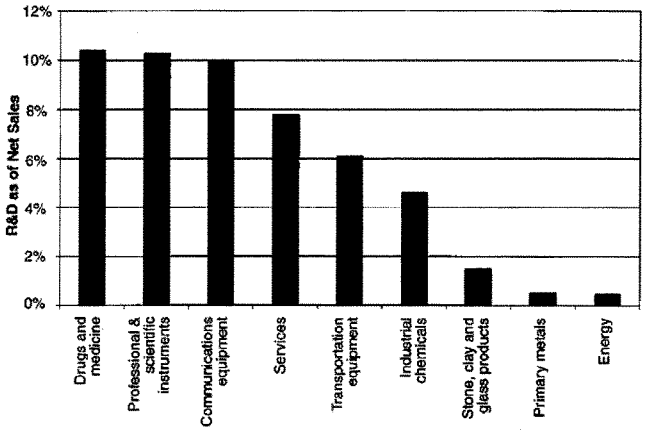


**Figure 1: R&D 'intensity', or R&D as a percentage of net sales for selected sectors in the United States. The data shown include both public and private funding for R&D. Energy R&D as a percentage of net sales was calculated from total (public and private) industrial energy R&D (*17*) and total energy expenditures in the United States (*19*). Services include business, health, engineering, and other services. Source: Margolis and Kammen, 1999.**

Total R&D funding in the United States is far too low given its importance to our economic and geopolitical security and to the sustainability of the environment. The Congress and the Executive Office need to recognize the vital role that leadership in energy can play in our outlook for economic growth.

In terms of federal investment – financially and in terms of commitment – is clean and secure energy, we have simply not become serious.

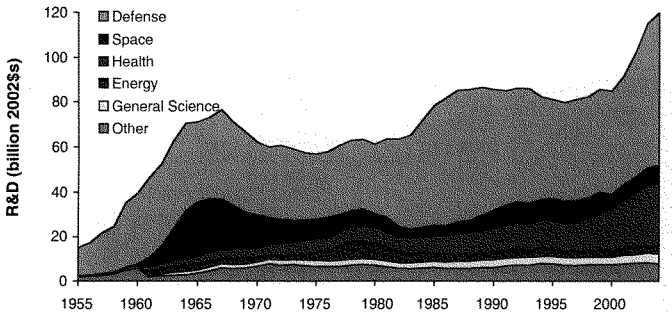


**Figure 2: U.S. federal R&D programs since 1955. Energy is the the thin strip with the short-lived expansion during the late 1970s and early 1980s showing how small the energy R&D program is relative to the others. The current budgets for energy R&D would continue this situation, or even reduce R&D investment (Kammen and Nemet, 2005).**

Figure 2, showing federal R&D investments in science and technology provides a number of lessons:

- The energy R&D budget has, once, been increased significantly, in fact by a factor of three between 1975 and 1979 in response to the OPEC oil embargo, but this increase was not sustained. In fact, the increase and then decrease in the budget was particularly wasteful because a number of potentially important programs were initiated, then cancelled, leaving talented individuals and innovative companies greatly disillusioned and distrustful of federal efforts in the energy area. In fact, retrospective analysis demonstrates that not only were a set of important technological innovations started during this brief period (e.g. greatly improved solar cells and wind-turbines that have, ironically, been generally commercialized by non-U.S. companies.

- The failure to engage in serious long-term planning in the energy area contrasts significantly with the story in the biotechnogy sector. During the 1980s and 1990s a widely discussed plan emerged to double federal support for medical/biotechnology research (Kaiser, 2002). This program was justified on the basis of its ability to energize private sector spending by demonstrating that the federal government would develop a plan to 'prime the pump' and to stick to that plan. The result was dramatic, particularly in contrast to the lack of federal commitment in the energy area. While the private sector did not respond to the short-term boost in federal energy support during the1975 – 1979 period (arguably because the 'crisis' in energy costs was seen as largely geopolitical, not

one of either truly limited supply or other trends, such as global warming), the private sector *did* respond strongly to the changes in the biomedical research budget (Figure 3).

Although energy R&D exceeded that of the biotechnology industry 20 years ago, today R&D investment by biotechnology firms is an order of magnitude larger than that of energy firms (Figure 3). Today, total private sector energy R&D is less than the R&D budgets of individual biotech companies such as Amgen and Genentech. In fact, while private sector research in energy has never exceeded public sector spending by a significant amount, *private sector spending on biotechnology R&D is over eleven-times that of the federal government.* Sustained investment and commitment beget greater attention and returns in the private sector.

This dramatic difference between the private sector's response in the biotechnology and energy sectors – and the immediacy of the threat of climate change – has been wonderfully and sadly captured in the comments of energy analyst Joe Romm in his assessment of thise data. In reading our paper (Kammen and Nemet, 2006), Joe's poignant comment was that, "well, at least we will live long enough to see the folly of our ways."

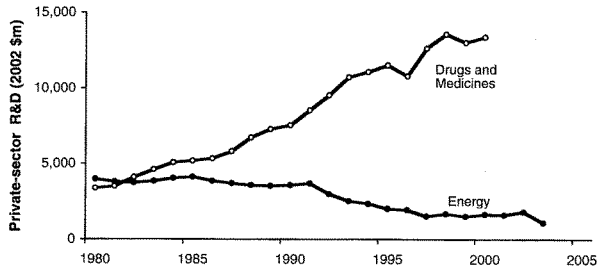


**Figure 3: Private sector R&D investment: energy vs. drugs and medicines. Source: Kammen and Nemet, 2005.**

The story is perhaps even more depressing because we know that investing in energy research *works.* In a series of studies, my students and I have documented that significant payoffs in innovation and commercialization *did clearly result from investments in energy research* (Margolis and Kammen, 1999; Kammen and Nemet, 2005, 2007; Nemet, 2007).

One of the clearest findings from tracking actual investment histories, is that there is a very strong correlation between investment in innovation and demonstrated changes in performance and cost of technologies available in the market. In the case of solar photovoltaics, a 50% increase in PV efficiency occurred immediately after unprecedented $1 billion global investment in PV R&D (1978-85). From there, we observed significant efficiency improvements, which accounts for fully 30% of the cost reductions in PV over the past two decades.

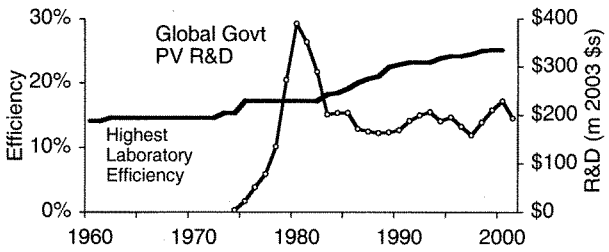


**Figure 4: Clear Benefits of R&D Investments in Improving Products in the Market.** ***Source: G. Nemet, Nemet, G. F. (2006). "Beyond the learning curve: factors influencing cost reductions in photovoltaics,: Energy Policy 34(17): 3218 - 3232.***

The story shown in Figure 4 for photovoltaics is not at all unique, as can be seen in Figure 5.

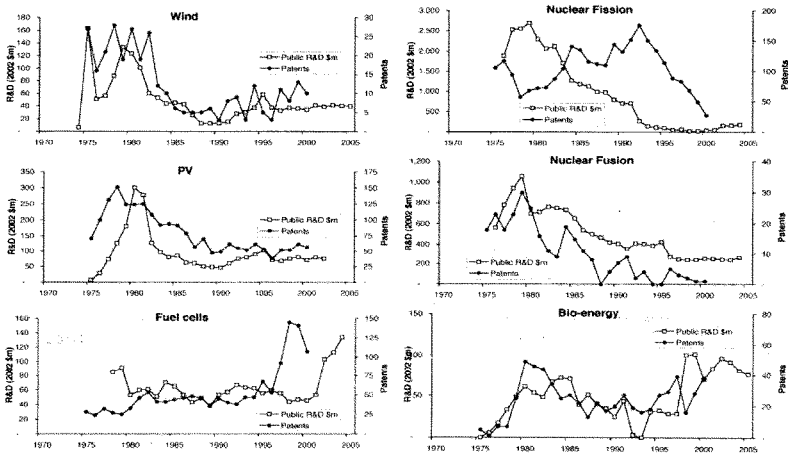


**Figure 5: Correlation between funding and patents (innovation) for energy technologies (Kammen and Nemet, 2005; 2007).**

A number of nations have been far more consistent, bullish, in fact, on the value of clean energy research and deployment. Denmark, Norway, Germany, Spain, and Portugal and other nations have invested substantially in clean energy, and it has paid important dividends. While different nations have focused on different technologies and market mechanisms to encourage adoption, wind power is above or approaching 20% of the total electricity supply in Denmark and Germany, and in each of the nations listed, factory orders for solar, wind, and other low- and no-carbon technologies has produced tremendous job growth (Kammen, 2007b) *and* long-waiting lists from overseas buyers. Green energy that is also early to rapidly deploy and to meet changing urban and rural demographics. A summary of investment growth by region is included in Figure 6.

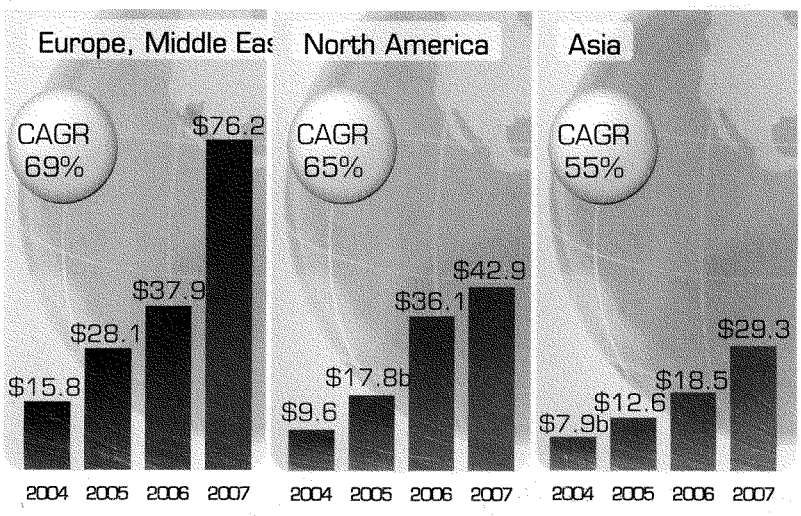


**Figure 6: Global geographic breakdown of new investment in clean energy projects and rates of growth. Europe dominates clean energy technology development and commercialization, despite that fact that many of the basic innovations took place at U. S. institutions. CAGR: composite annual growth rate. Source: New Energy Finance.**

The most consistent message from these 'cleantech' leaders is that a sustained and clearly articulated clean energy roadmap and strategy was developed and followed. Investment works; while, not surprisingly, neglect fails – both to provide us new business opportunities, as well as to provide critically needed options in a world changing due to greenhouse gas emissions.

**Positive Signs to Build Upon with a National Clean Energy Agenda**

A number of important developments have taken place that a visionary House, Senate, and Executive Branch can utilize to launch the clean energy economy.

First, innovations and funding flows are taking place across the 'cleantech' field. Figure 7 highlights the rapid growth in a truly diverse set of clean energy systems.

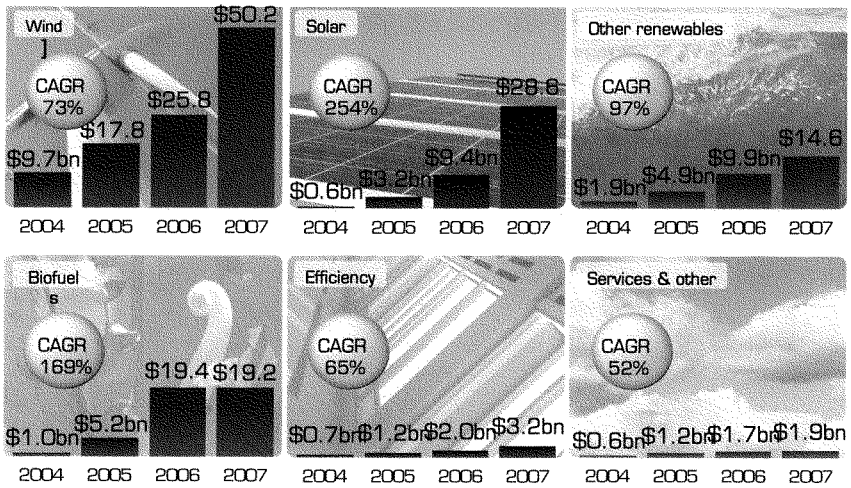


**Figure 7: New Investment by Sector, 2004 – 2007. CAGR: composite annual growth rate. Source: New Energy Finance.**

Second, a clear relationship exists been learning-by-doing in the manufacturing and deployment field, and the basic costs of new technology. Figure 8 documents this 'learning curve', where roughly a 20% cost decrease reliably occurs when the total number of units is manufactured and deployed. This process has been found to be robust for technologies such as solar panels and wind turbines that can be mass-produced, but is found *not* to hold for technologies where each unit is largely or partially unique, as is often the case for ultra-large, locally-tailored, goods.

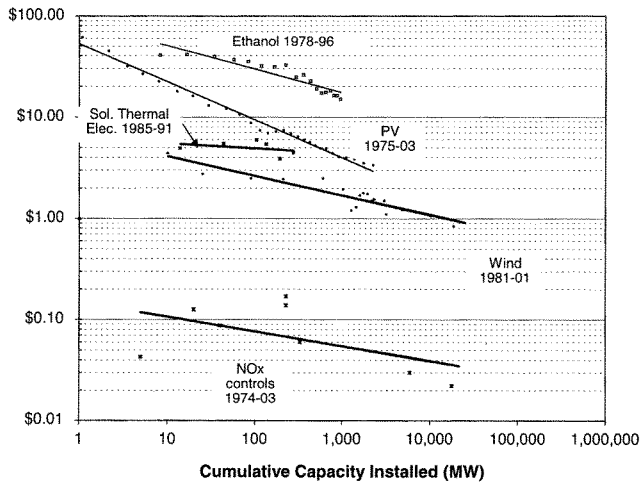


**Figure 8: The 'learning curve', showing the cost declines in clean energy and pollution control technologies than accompanies expanded commercial production. A rougly 20% decrease in per unit cost typically accompanies each doubling of cumulative production (Duke and Kammen, 1999).**

Finally, there is a consistent job creation dividend associated with building a new industry, which the clean, renewable, and energy efficiency fields remain today.

A number of analysts have charted an additional benefit of developing the clean energy options of efficiency and renewable energy technologies: job creation. My laboratory conducted a study of job growth in the clean energy industry across the nation relative to that seen in the fossil-fuel sector. We found (Kammen, Kapadia and Fripp, 2004; Kammen, 2007b) that on average, *three to five times as many jobs were created by a similar investment in renewable energy versus that when the same investment was made in fossil-fuel energy systems.*

The U. S. Government Accounting Office conducted its own study of the job creation potential of a clean energy economy (GAO, 2004). In an important assessment of rural employment and income opportunities, they found that:

> … a farmer who leases land for a wind project can expect to receive $2,000 to $5,000 per turbine per year in lease payments. In addition, large wind power projects in some of the nation's poorest rural counties have added much needed tax revenues and employment opportunities.

**Recommendations**

- **Make Energy and the Environment a Core Area of Education in the United States.** Public interest and action on energy and environmental themes requires attention to make us 'eco-literate and economically savvy.' We must develop in both K-12 and college education a core of instruction in the linkages between energy and both our social and natural environment. The Upward Bound Math-Science Program and the Summer Science Program each serve as highly successful models that could be adapted to the theme of energy for a sustainable society at all educational levels. The launch of Sputnik in 1957 mobilized U. S. science and technology to an unprecedented extent, and should serve as a lesson in how powerful a use-inspired drive to educate and innovate can become. The Spring 2005 Yale Environment Survey found overwhelming interest in energy and environmental sustainability. Contrast that interest with the results of the Third International Mathematics and Science Study (TIMSS) where American secondary school students ranked 19th out of 21 countries surveyed in both math and science general knowledge. The United States can and should reverse this trend, and sustaining our natural heritage and greening the global energy system is the right place to begin.

  A clean energy education act could reward internship work in the clean energy sector - both domestically and in service to developing nations and poor communities, with semesters of paid college tuition.

- **Develop and Deploy a 'Smart' Grid as a Clean Energy Superhighway**
  Invest in both the development and deployment of a federal backbone for clean energy commerce: 1) grid expansion linking clean energy resources with population centers (as Texas has authorized to bring west Texas wind to Dallas/Ft. Worth); and 2) energy storage and power electronics must become areas of national research and deployment priority.

- **Establish a Set of Energy Challenges Worthy of Federal Action.** Establish *SustainableEnergy USA* awards – modeled after the successful efforts of the Ashoka Innovators awards for social entrepreneurs and the Ansari X Prize initially given for space vehicle launch - that inspire and mobilize our remarkable resources of academia, industry, civil society, and government. These initiatives would support and encourage groups to take action on pressing challenges. An initial set of challenges include:

  - Buildings that cleanly generate significant portions of their own energy needs ('zero energy buildings');

  - Commercial production of 100 mile per gallon vehicles, as can be achieved today with prototype plug-in hybrids using a low-carbon generation technologies accessed over the power grid, or direct charging by renewably generated electricity, and efficient biofuel vehicles operating on ethanol derived from cellulosic feedstocks.

  - Zero Energy Appliances (Appliances that generate their own power)

- 'Distributed Utilities'; challenges and milestones for utilities to act as markets for clean power generated at residences, businesses, and industries.

It is vital, however, to *make sure that technology development is linked to market access* through such policies as a federal renewable energy portfolio standard, a ten-year extension of the production and investment tax credits (PTC and ITC) that bring market stability to clean energy investments, evaluation and design of a national Feed-In Tariff. These mechanisms ensure that a balanced 'technology push' and 'demand pull' dynamic exists in the economy.

- **Expand International Collaborations that Benefit Developing Nations at a Carbon Benefit.** The needs of many developing nations are focused on the challenges meet fundamental economic and environment goals for their people. At the same time, these are our goals as well, both as a nation that must lead the charge to a sustainable and equitable world, and as citizens of a world where we share the rights and responsibilities to protect the atmosphere. Greenhouse gases emitted anywhere impact us all, not only today but for decades to come. In many cases, tremendous opportunities exist to offset future greenhouse gas emissions and to protect local ecosystems both at *very* low cost, but also to directly address critical development needs such as sustainable fuel sources, the provision of affordable electricity, health, and clean water. My laboratory has recently detailed the local development, health, *and* the global carbon benefits of research programs and partnerships on improved stoves and forestry practices (Bailis, Ezzati, and Kammen, 2005) across Africa. Far from an isolated example, such opportunities exist everywhere, with the recent wave of interest in 'sustainability science' (Jacobson and Kammen, 2005) a resource, aid, and business opportunity that the U. S. should embrace.

  Consider international debt-relief based on deployment of low-carbon technologies in poorer nations.

- **Begin a Serious Federal Discussion of Market-Based Schemes to Make the Price of Carbon Emissions Reflect their Social Cost.** A carbon tax and a tradable permit program both provide simple, logical, and transparent methods to permit industries and households to reward clean energy systems and tax that which harms our economy and the environment. Cap and trade schemes have been used with great success in the US to reduce other pollutants and several northeastern states are experimenting with greenhouse gas emissions trading. Taxing carbon emissions to compensate for negative social and environmental impacts would offer the opportunity to simplify the national tax code while remaining, if so desired, essentially revenue neutral. A portion of the revenues from a carbon tax could also be used to offset any regressive aspects of the tax, for example by helping to compensate low-income individuals and communities reliant on jobs in fossil fuel extraction and production.

**Commit to a Culture of Clean and Secure Energy Innovation and Commercialization**

History shows that investing in innovation pays significant and long-lasting dividends – but it requires thoughtful and sustained support. Frivolous programs based on the 'flash' of a specific technology are far less successful – both in terms of technical breakthroughs and on a cost/effectiveness basis.

Important examples exist that back this simple prescription, including:

- *Semiconductors*: In the wake of the U. S. losing its leading position to Japan during the mid 1980s, a well-designed effort involving federal planning, university research, and a public-private partnership yielded remarkable results. SEMATECH (the Semiconductor Manufacturing Technology) is a non-profit consortium that performs basic research into semiconductor manufacturing (Wessner, 2003). Sematech began operating in 1988 after a careful examination of the need for both a goal-setting and road-mapping effort to guide the industry. Sematech is a partnership between the United States government and 14 U.S.-based semiconductor manufacturers to solve common manufacturing, and was funded over five years by public subsidies coming from the US Department of Defense via the Defense Advanced Research Projects Agency (DARPA) for a total of $500 million. Today Sematech exists largely with private contributions, and has three subsidiaries, the Advanced Technology Development Facility (ATDF), the Advanced Materials Research Center (AMRC), and the International Sematech Manufacturing Initiative (ISMI).
- *Nanotechnology and Biotechnology*: The Stanford Research Institute reports a 19:1 return on sustained investments in nanotechnology, while in the medical and biotechnology case described above in Figure 3, a 11:1 return was realized on federal investments in biotechnology.

*Combining Technology and Financial Innovation – the Next Wave of Greenhouse Gas Abatement*

As states and cities explore greenhouse gas emission reduction opportunities, new and important financial models are also emerging. The City of Berkeley, California provides one recent example that has already attracted international attention.

A Sustainable Energy Financing District is being developed as part of the City of Berkeley's implementation of Measure G – a successful 2006 ballot measure setting greenhouse gas reduction targets of a full 80% reduction in emissions by 2050.

The financing mechanism is loosely based on existing "underground utility districts" where the City serves as the financing agent for a neighborhood when they move utility poles and wires underground. In this case, individual property owners would contract directly with qualified private solar installers and contractors for energy efficiency and solar projects on their building. The City provides the funding for the project from a bond or loan fund that it repays through assessments on participating property owners' tax bills for 20 years. Cities may also be able to aggregate bonds, and states governments can facilitate this program in a number of ways.

No property owner would pay an assessment unless they had work done on their property as part of the program. Those who choose to pay for energy efficiency first, and then solar and energy installations through this program would pay only for the cost of their project, interest, and a small administrative fee.

The Financing District solves many of the financial hurdles facing property owners. First, there would be little upfront cost to the property owner. Second, the total cost of the solar system and energy improvements may be less when compared to financing through a traditional equity line or mortgage refinancing because the well-secured bond will provide lower interest rates than is commercially available. Third, the tax assessment is transferable between owners. Therefore, if an individual sells their property prior to the end of the 20-year repayment period, the next owner takes over the assessment as part of their property tax bill.

This mechanism, announced publicly on October 23, 2007, has attracted statewide attention as other cities, and now the state government, looks to find ways to expand the Financing District model statewide. Further, the U. S. Department of Energy has expressed its willingness to facilitate the dissemination of the program to other cities, states, and regions. My laboratory works with the Cities of Berkeley, Austin, Lisbon (Portugal), and others in their efforts to implement this financial innovation.

Thank you for the opportunity to appear before your committee and I welcome the opportunity to address any questions.

**Acknowledgments**

This work was supported by a grant from the Energy Foundation, the Karsten Family Foundation endowment of the Renewable and Appropriate Energy Laboratory, and the support of the University of California Class of 1935. Much of the work cited in this testimony was conducted in collaboration with Professor Greg Nemet of the University of Wisconsin at Madison. It is a pleasure to thank him for assistance and ongoing discussions and collaborations.

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The CHAIRMAN. Our final witness is Dr. Jack Fellows. He is Vice President at the University Corporation for Atmospheric Research. He worked in the White House Office of Management and Budget, where he oversaw the budget and policy issues related to NASA, NSF, Federal-wide R&D programs that helped initiate the U.S. Global Change Research Program.

We welcome you, sir. Whenever you are ready, please begin.

**STATEMENT OF JACK D. FELLOWS, VICE PRESIDENT, UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH**

Mr. FELLOWS. I would like to thank the committee for this opportunity to testify today, also; and I commend the committee for your tireless efforts on this important topic, including, Chairman Markey, your introduction of the recent iCAP legislation.

As you said, my name is Jack Fellows. I am the Vice President of a nonprofit consortium of over 70 universities that are very interested in this hearing. Every member of the committee actually has one of my university members either in your State or in your district.

I will respond to the steering committee questions in just a minute, but I want to emphasize that my responses are based on a community document that provides advice to the next administration and Congress on making our Nation resilient to severe weather and climate change. It was created by eight organizations that represent thousands of experts in the public, private and academic weather and climate enterprise, and I have submitted that document as a part of my testimony.

Our 50 States are battered by billions of dollars of weather and climate-related damages and losses each year, and it isn't clear how these impacts are going to change as the climate changes. I am talking about floods, tornadoes, hurricanes, drought, sea level change; and adapting to these changes will be crucial for economic and social stability and in particular making water, food and energy supplies reliable and sustainable into the future.

Our country has made substantial investments to improve weather and climate tools and information, and we have made tremendous progress over the last 40 years. We are very grateful for this support. But due to the complexity of this problem and years of declining budgets, these community partners who wrote this document are concerned that our Nation does not have all the tools we need for an effective energy and climate strategy. In particular, one that helps local and regional decisionmakers deal with climate change, one that supports the implementation of carbon emissions reduction proposals like iCAP and one that helps actually build a prosperous, carbon-free economy, including making forecasts for green industries like wind and solar.

Our ability to provide the right scale and type of information in these areas is hampered by the lack of key observations, computing, research and modelling and effective coordination. Regardless, a lot of local and regional decisionmakers are moving forward with inadequate information in the face of substantial climate feedback, uncertainties that may prove very costly to civilization—for example, how quickly the polar ice caps are actually melting.

Given the urgency of the situation, the community partners have actually provided this document to the Obama and McCain campaigns and also collected nominations for weather and climate positions in the next administration.

Let me address the questions that the committee gave me.

The first one was, what are the current Earth observing and climate modelling investments and how do they compare to the past and with other countries?

There is really no effective inventory of these activities in the U.S. right now. That is one of the recommendations of the community document, to create that kind of inventory.

There is something called the Climate Change Science Program that provides the best estimates that we have. This is a program that involves 13 Federal agencies and we hope has about $1.9 billion appropriated in 2009. In my testimony, I actually provided a funding history of the Climate Change Science Program, but a brief summary, the funding is roughly back to where it was in the early 1990s. So whatever gains we have made over the last couple of decades, we have lost. I am not familiar with the current funding in other countries right now, but in the past it has been roughly equivalent to the U.S. investment.

The other question you ask is what investments are needed to meet our energy and climate challenges now?

These community partners are making recommendations in the areas of observation, computing, research modelling, societal relevance and leadership and management. And in that document it includes a budget table with specific program and budget estimates that total $9 billion over the next 5-years, well within the kind of $7 to $9 billion that the iCAP legislation is trying to raise for domestic climate adaptation activities each year.

Third and fourth question I was asked is, what policies are needed to optimize these investments and what should be the private, public and academic roles in this effort?

The community partners provide an entire section in our document on leadership and management recommendations and how these three sectors ought to work together. Leadership will be a key ingredient to optimize these investments, and that is why the community partners are actually collecting nominations for leadership positions in the next administration.

This section also includes a set of policy and management approaches that build on proven management tools that were available in the 1990s, and that includes a climate leader at a level equivalent to the President's national security and economic advisors, an effective interagency coordination and oversight mechanism, an annual integrated weather and climate program and budget review and evaluation mechanisms to make sure that we are making progress toward our goal.

That concludes my remarks, and thank you very much for the opportunity to testify.

The CHAIRMAN. Thank you, Dr. Fellows, very much.

[The statement of Mr. Fellows follows:]

**Testimony of Jack D. Fellows, Ph.D.**
**Vice President, University Corporation for Atmospheric Research**
**Select Committee on Energy Independence and Global Warming**
**"Investing in the Future: R&D needs to meet America's Energy and Climate Challenges"**
**10 September 2008**

Mr. Chairman and Members of the Select Committee:

Thank you for the opportunity to testify before your Committee on this important topic.

I am Jack Fellows, Vice President of the University Corporation for Atmospheric Research, a non-profit consortium of over 70 universities involved in weather and climate research and applications. I joined UCAR in 1997 after overseeing many of the federal weather and climate related agencies and interagency programs for many years in the Office of Management and Budget But today, I'm summarizing a *transition document* that provides program, management, and budget recommendations to the next administration and Congress on R&D needs to meet our nation's energy and climate change challenges – and more specifically how to make our nation more resilient to severe weather and climate change (floods, tornadoes, hurricanes, drought, sea level rise, etc.).

Our 50 states are battered by billions of dollars in weather and climate related damages and losses each year and it isn't fully clear how these impacts will change as the climate changes. The threats associated with extreme weather and climate change are substantial and adapting to climate change will be crucial to economic and social stability, in particular making future water, food and energy supplies reliable and sustainable. Our concern is that our nation is not prepared to adapt to climate change and related severe weather. Decision makers need local and regional scale information, but our models are hampered by the lack of research, observations, and computing at this scale.

The *transition document* is entitled *Advice to the New Administration and Congress: Actions to Make Our Nation Resilient to Severe Weather and Climate Change* and was produced by the following organizations:

- University Corporation for Atmospheric Research
- Weather Coalition
- American Meteorological Society
- American Geophysical Union
- Consortium of Universities for the Advancement of Hydrologic Science
- National Association of State Universities and Land-Grant Colleges
- Consortium for Ocean Leadership
- Alliance for Earth Observations

These organizations represent thousands of experts in the public, private, and academic weather and climate enterprise and they have undertaken this task for a variety of economic, public health and safety, and national security issues that are highlighted in *transition document*. These partners are also collecting nominations for key weather and climate leadership positions in the next administration and will provide those nominations as the transition progresses.

At this Committee's 31 July 2008 hearing entitled, "Renewing America's Future: Energy Visions of Tomorrow, Today", my respected colleague, Dr. Aristides Patrinos, stated, "Our nation and the world stand at an important crossroads. Decisions we make during the next few years will affect the trajectory

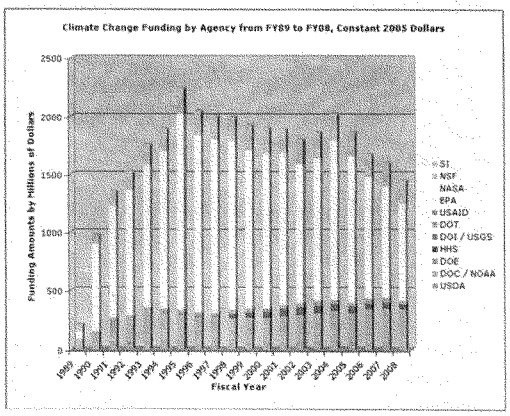
of human civilization well into the next century." Dr. Patrinos outlined the world's increasing demand and reliance on oil from unstable parts of the world, the alarming increase in global atmospheric concentrations of carbon dioxide, and the 2007 Intergovernmental Panel on Climate Change's conclusions that warming of our climate system is unequivocal, as evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

Our organizations share this concern that our nation is standing at a defining moment in human history. We believe that having the science and policy tools to make our nation more resilient to weather and climate hazards must be a critical component of our country's energy and climate strategy. Many of our weather and climate research and operations programs have suffered through years of declining budgets at the very time we need improved weather and climate tools and information to: (1) help local and regional decision makers, (2) support the implementation of carbon emission reduction proposals (e.g., cap-and-trade), and (3) help build a prosperous carbon-free economy (e.g., wind and solar forecasting). In the mean time, local and regional decision makers are moving forward with inadequate information and in the face of substantial climate impacts and adaptation feedback uncertainties — feedbacks that may prove very costly to civilization (e.g., polar ice melting faster than expected, massive carbon release in a warming Arctic, hurricane intensity forecasting shortfalls like Hurricane Gustav, etc.).

The hearing questions provided to me by the Select Committee are addressed thoroughly in the *transition document*, which can found at www.ucar.edu/td. I'm also submitting that document and its program, management, and budget recommendations as the balance of my testimony after the following brief responses to the hearing questions:

1. What is the current investment in the Earth observations and climate modeling in the United States? How does this compare with past funding? How does this compare with funding in other countries?
   **Response:** Unfortunately, there isn't a centralized inventory of Earth observations and climate modeling programs in our country, so reliable estimate are very difficult to find. Having this type of Federal-wide inventory and coordination is a major recommendation of the *transition document*. In the absence of such a complete inventory, the Climate Change Science Program (which grew out of the U.S. Global Change Research Program) provides the best estimate we have today, although it does not include all the pieces (e.g., operational weather budgets in NOAA). That said, we hope the 13 agencies involved in CCSP will have a budget around $1.9 billion in 2009 and beyond (see the budget recommendations in the *transition document*). The graph entitled "History of

**History of USGCRP/CCSP Funding**



USGCRP/CCSP Funding" shows how this funding has changed over time. Currently, we are roughly back to the levels of funding when the USGCRP was initiated in the early 1990s. So, the funding gains have largely been lost over the past decade and this has happened for a variety of reasons. I'm not familiar with the current Earth observation and climate modeling funding in other countries. In the past, it has been roughly equivalent to the U.S. investment.

2. In your view, what investments are needed going forward to meet our energy and climate challenges? **Response:** The transition document makes the following recommendations to help make our nation resilient to severe weather and climate change:
   a. **Observations.** Fully fund the satellite and ground-based observations recommended by the National Research Council.
   b. **Computing.** Greatly increase the computer power available for weather and climate research and operations.
   c. **Research and Modeling.** Support weather and climate research and modeling to advance our understanding of these events and their impacts on society.
   d. **Societal Relevance.** Support education, training, and communication efforts on how to use the weather and climate tools and information to the maximum benefit of society.
   e. **Leadership and Management.** Implement effective leadership, management, and evaluation approaches to ensure that these investments are done in the best interest of the nation.

   These recommendations are based on community documents (e.g., National Research Council) and will require an investment of roughly $9 billion between 2010-2014 to implement. Please see the *transition document* for more details on these investments, in particularly the budget table and budget explanations in the *Budget Estimates* section of the *transition document*.

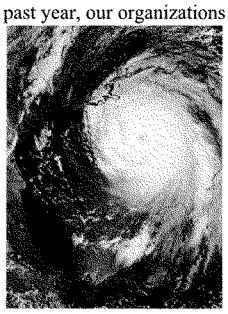
3. What, if any, new policies are needed to support and optimize this investment? **Response:** Leadership will be a key ingredient to support and optimize these investments. That is why the *transition document* partners are collecting nominations for key weather and climate related position in the next administration. The document makes a broad range of leadership and management policy recommendations to ensure that these investments are made wisely and effectively. Many of the authors of the *transition document* have been extensively involved in trying to focus and coordinate these activities and fully understand what is needed to implement these recommendations. Please see the transition document's *Recommendation 5 (Leadership and Management)* section for our policy recommendations on how to support and optimize these investment, including a set of proven policy and management tools that have not be available for roughly the last decade.

4. What is the role of America's universities in supporting and providing Earth observations and climate modeling? How can the government and private industries work with universities to maximize return for investments in these areas? **Response:** As you will read in the *transition document*, implementing the document's recommendations will require the involvement of all sectors of the weather and climate enterprise (private, public, and academic) and these respective roles are outlined throughout the document.

## Advice to the New Administration and Congress: Actions to make our Nation resilient to severe weather and climate change

*"Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important challenges for society as it seeks to achieve prosperity, health, and sustainability."* – *National Research Council, 2007*

**Executive Summary.** Our organizations represent thousands of experts in the public, private, and academic weather and climate enterprise and we fully agree with the National Research Council position above (see "Sponsoring Organizations" on the last page). Over the past year, our organizations have developed this document to help guide the transition to the next Administration and Congress. This document provides recommendations and budget estimates for what is needed to make our nation more resilient to severe weather and climate change. We have undertaken this task for the following reasons:



1. Our health, safety, economy, environment, transportation systems, and national security continue to be battered by billions of dollars in weather-related damages and losses each year.
2. Mayors, governors, and local decision makers trying to plan for climate change and related weather changes need help—they are not waiting for the federal carbon emission reduction debates to conclude.
3. Implementing carbon emission reductions (e.g., cap-and-trade, carbon tax, etc.) or moving to a prosperous carbon-free economy will be inhibited by the lack of weather and climate tools and information (e.g., carbon monitoring, forecasts for green industries, etc.).
4. Substantial uncertainties remain over climate impacts and adaptation feedbacks—feedbacks that may prove very costly to civilization (e.g., the release of carbon frozen in a warming Arctic that will dwarf the human carbon contribution to the atmosphere).
5. Science is key to understanding these impacts, but funding for weather and climate research and operations has been flat or declining for years due to the budget debates in Washington.

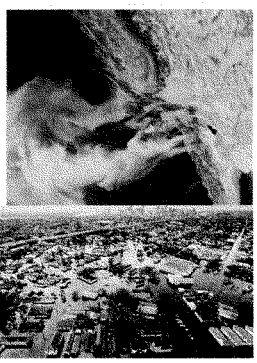
Understanding these regional and local climate and severe weather impacts and having the science and policy tools to make our nation more resilient to these hazards must be a high priority for our country. To achieve this goal, the next Administration and Congress must:

1. **Observations.** Fully fund the Earth observing system from satellite and ground-based instruments as recommended by the National Research Council.
2. **Computing.** Greatly increase the computer power available for weather and climate research, predictions, and related applications.
3. **Research and Modeling.** Support a broad fundamental and applied research program in Earth sciences and related fields to advance present understanding of weather and climate and their impacts on society.
4. **Societal Relevance.** Support education, training, and communication efforts to use the observations, models, and application tools for the maximum benefit of society.
5. **Leadership and Management.** Implement effective leadership, management, and evaluation approaches to ensure that these investments are done in the best interest of the nation.

This document is intended to provide the next Administration and Congress with the information needed to understand this challenge our nation is facing. Implementing these recommendations over the

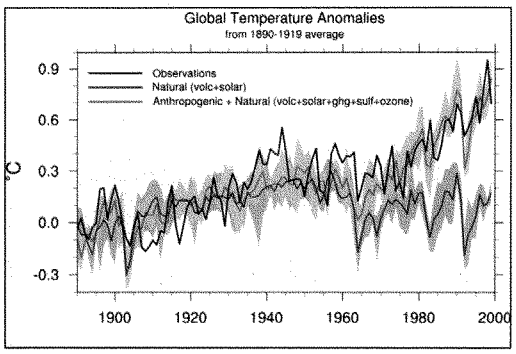
next five years will cost roughly $9 billion beyond what our nation is planning to invest in this area between 2010 and 2014 and will require the involvement of all sectors of the weather and climate enterprise (private, public, and academic). Our goal is to provide this document to transition teams and other interested parties to help guide them in this important area of weather and climate. Below you will find the needed details on how to best implement these recommendations, including specific management actions and budget estimates. We are collecting nominations for key weather and climate leaders to be provided to the next Administration.

**Economic, Security, and Societal Impacts of Weather and Climate on Our Nation.** More than 75 percent of natural disasters around the world are triggered directly or indirectly by weather and climate. Each year, our nation sustains billions of dollars in weather-related damages associated with hurricanes, tornadoes, forest fires, flooding, heavy snows, and drought. All 50 states are affected, and many of these events will be exacerbated by climate change. Hurricane Katrina, the multiple year droughts in the southeastern and southwestern United States, the 2007 and 2008 California wildfires, the record number of tornadoes in 2008, and the 2008 Midwest floods all show the devastating impacts on our nation's people and economy. These events have caused $100s of billions in losses and disrupted millions of lives.

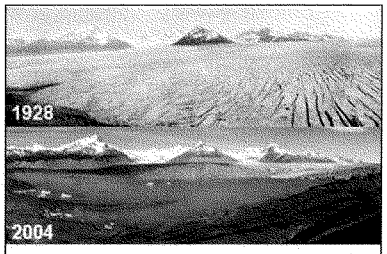


With more than a quarter of the U.S. gross national product (over $2 trillion) sensitive to weather and climate, these events substantially impact our national health, safety, economy, environment, transportation systems, and military readiness. While the threats associated with extreme weather and climate change are substantial, adaptation measures will provide crucial economic stability, for example by making future water, food, and energy supplies reliable and sustainable. We want to both help the decision makers facing these challenges (practical applications) and fully understand the process and uncertainties associated with these changes (basic knowledge).

**How are the Climate and Weather Changing?** Greenhouse gases such as carbon dioxide are beneficial to life on Earth. They have kept our planet within a reasonable temperature range for thousands of years. However, rapid increases in greenhouse gases can produce a new, warmer climate that can be challenging to life in many ways. Indeed, both greenhouse gases and temperatures are currently increasing at alarming rates. It is clear from models and observations that without greenhouse emissions from human activities we cannot fully explain the dramatic temperature increases since the 1960s. This is demonstrated in the Global Temperature Anomalies graph produced by the NCAR/DOE Parallel Climate Model and presented in a

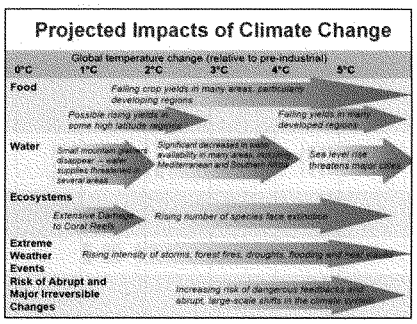


2004 paper by Meehl et. al. in the Journal of Climate (Vol. 17 3721-3727). The black line represents actual observations; the blue line represents model output with only natural forcing; and the red line represents model output with natural and human forcing. This graph is based on a model that clearly reproduces the historical climate quite well. Similar analyses are being produced by hundreds of scientists around the world. These scientists get together every four years to examine the state-of-knowledge of climate science and its relevance to society and policy through the Intergovernmental Panel on Climate Change (IPCC). The IPCC shared the 2007 Nobel Peace Prize for its work. This level of warming is becoming evident in dramatic ways, for example in the retreat of the Upsala glacier in Argentina between 1928 and 2004 shown in these images taken by Dr. Lonnie Thompson from Ohio State University.



Upsala glacier in the Andes, Argentina

As will be described in more detail below, we are being hampered in our efforts to understand the impacts of these changes by lack of political leadership and needed resources for science, observation, and computing. That said, the IPCC and the U.S. Climate Change Science Program have attempted to evaluate what the impacts of various temperature changes might be on key human resources (food, water, ecosystems, extreme weather events, etc.—see Projected Impacts box). We need better answers to these impact questions and we need them soon. For more details on understanding climate change, see the NRC report entitled *Understanding and Responding to Climate Change 2008 Edition* (http://dels.nas.edu/dels/rpt_briefs/climate_change_2008_final.pdf)




The 2007 IPCC report documents how humans are contributing to climate change and notes that we are already committed to a significant level of climate change over the next few decades regardless of our near-term mitigation strategies (e.g., controlling greenhouse gas emissions). In addition, a recent scientific report concludes that climate change and global warming will almost certainly lead to more extreme weather and climate events (http://www.climatescience.gov/Library/sap/sap3-3/final-report/default.htm ):

- Abnormally hot days and nights, along with heat waves, are very likely to become more common.
- Cold nights are very likely to become less common.
- Sea ice extent is expected to continue to decrease and may even disappear in the Arctic Ocean in summer in coming decades.
- Precipitation, on average, is likely to be less frequent but more intense.
- Droughts are likely to become more frequent and severe in some regions.
- Hurricanes will likely have increased precipitation and wind.

- The strongest cold-season storms in the Atlantic and Pacific are likely to produce stronger winds and higher extreme waves.

Even the national security community is expressing concerns about these matters. On June 25, 2008, before a joint hearing involving the House Permanent Committee on Intelligence and the House Select Committee on Energy Independence and Global Warming, the chairman of the National Intelligence Council said,

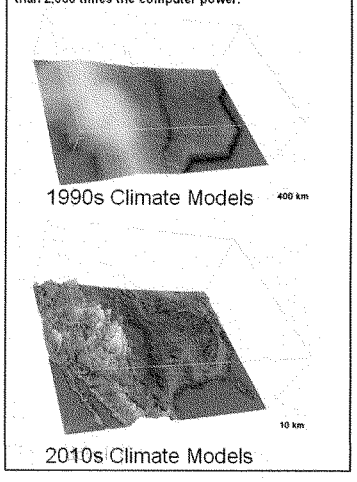
> *From a national security perspective, climate change has the potential to affect lives (for example, through food and water shortages, increased health problems including the spread of disease, and increased potential for conflict), property (for example through ground subsidence, flooding, coastal erosion, and extreme weather events), and other security interests. The United States depends on a smooth-functioning international system ensuring the flow of trade and market access to critical raw materials such as oil and gas, and security for its allies and partners. Climate change and climate change policies could affect all of these—domestic stability in a number of key states, the opening of new sea lanes and access to raw materials, and the global economy more broadly—with significant geopolitical consequences.*

**Build on the strengths of the weather and climate enterprise.** We must have a 21st century program of Earth observations, science, and information to guide policy choices and to determine whether these choices are having the desired effects. Building on advances in observing systems and forecasting skills over the past three decades, government, industry, and policy makers at all levels can potentially implement much more effective strategies to deal with weather and climate challenges. But we are faced with significant hurdles to achieve that objective, including:

- Federal law requires the President to develop a coordinated national policy on global climate change. Yet, coordination of federal weather and climate activities remains inadequate. A recent National Research Council evaluation of the U.S. Climate Change Science Program concluded that while our ability to predict climate change has improved, our understanding of the impacts on society is "relatively immature" (see the NRC *Understanding and Responding to Climate Change 2008 Edition* report).

- Policy debates and emerging legislative initiatives are calling for global change research that is more relevant to decision makers. However, creating integrated atmosphere-ocean-land predictions that are relevant to local and regional decision making is hampered by the lack of key Earth observations, computer resources, and ways to merge science output with management tools in water, agriculture, transportation, and other sectors. There has been an erosion of key observational and science programs at NASA, NOAA, and NSF at precisely the time when they are most needed. In addition, these science programs will be crucial in developing and monitoring the success of current and

**These two images illustrate the importance of high-resolution models. The top image is an early climate model running at 400 kilometer resolution and the bottom at 10 kilometers. The sharper image produces more accurate analysis, but requires more than 2,000 times the computer power.**



proposed climate policy initiatives, such as carbon cap-and-trade systems or a carbon tax.

- We are particularly disappointed with the outcome of the Fiscal Year 2008 federal budget and the outlook for Fiscal Year 2009. In the years when we need to be making substantial progress understanding the processes underlying climate change and severe weather and how we might mitigate or adapt to these changes, Congress and the Administration have produced omnibus budgets that substantially cut these programs. Those reductions occurred even though Congress and the Administration had proposed substantial increases for these programs in individual appropriations bills. Partisan politics should not prevent scientific progress and the training of the next generation of leaders in this important area given how rapidly things are changing around the world. For example, reductions of Arctic sea ice are occurring faster than climate models predict, and we don't really understand why. Some models are predicting an ice-free Arctic Ocean in the 2030s, and we don't fully understand how this influences other related impacts that may occur in this same time frame (e.g., the release of vast amounts of carbon and methane frozen into melting tundra).

**Recommendation Implementation.** To implement the recommendations above will require three critical ingredients: (1) strong leadership, (2) effective management, and (3) adequate and wisely invested resources. The rest of this document will provide guidance on these three areas for each of our recommendations.

- **Recommendation 1 (Observations): Fully fund the Earth observing system from satellite and ground-based instruments as recommended by the National Research Council (NRC).** Observations from both space and the ground are key to monitoring climate and weather variables and developing climate and weather models. These observations will be essential in monitoring the progress and success of any carbon emission reduction initiative (e.g., cap-and-trade). The NRC has produced two community documents that the next Congress and Administration should strongly support (see budget estimates for this recommendations below):
  - **Space.** The study entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (http://books.nap.edu/catalog.php?record_id=11820)
  - recommends that: *"The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications."* This report is often referred to as the Earth sciences "Decadal Survey." This community report prioritizes the needed satellite observations for the foreseeable future, including seventeen that must be undertaken if we hope to understand and monitor critical environmental issues related to climate change and severe weather.
  - **Ground.** An NRC study, entitled *Observing Weather and Climate From the Ground Up, A Nationwide Network of Networks* will recommend a national public-private partnership to renew our strategic investment in ground-based, storm-scale observing systems that are crucial to the prediction of extreme weather, the health and safety of our citizenry, and the impacts of local climate and climate variability. This report is scheduled to be released by the NRC in September–October 2008 and we anticipate will include budget estimates for ground-based observing systems that are essential to severe weather prediction and modeling (e.g., radar technologies).

- **Recommendation 2 (Computing): Greatly increase the computer power available for weather and climate research, predictions, and related applications.** As mentioned above, current

climate models do a reasonable job of providing useful information at the global level, but most climate change and severe weather impacts will be managed at local and regional levels (e.g., public health and safety, water and ecosystem management, energy production and use, food production, transportation services, recreation opportunities, military readiness). To provide this level of information will require a better understanding of local and regional user needs and computer models that perform effectively at this scale (i.e., 10 kilometer versus today's 100 kilometer). There are computers today that can perform at this level (petascale computers), but the climate community does not have enough access to them to meet the demand of modeling climate at these local and regional scales. Such high-resolution computers and model codes can also be used for severe weather to improve forecast for hurricane intensity and landfall, tornadoes, and winter storms, which continue to put many thousands of American lives at risk each year. NASA, NSF, NOAA, and DOE are all involved in climate modeling and the coordination of these efforts must be improved (Recommendations 5). See budget estimates for this recommendation below.

- **Recommendation 3 (Research and Modeling): Support a broad fundamental and applied research program in Earth sciences and related fields to advance present understanding of weather and climate and their impacts on society.** To support all of these recommendations will require the next Administration and the Congress to provide adequate resources for key federal agency weather and climate programs. Most of the proposed climate and energy policy legislation, like the Lieberman-Warner Climate Security Act of 2008 (S.3036), will require these key science programs to implement and evaluate progress. We don't start from zero—the U.S. Global Change Research Program (USGCRP) and the Climate Change Science Program (CCSP) provide a substantial base of funding to work from. See budget estimates for this recommendation below.

- **Recommendation 4 (Societal Relevance): Support education, training, and communications efforts to use the observations, models, and application tools for the maximum benefit of society.** We need to support programs that teach children at an early age to collect, analyze, and apply data to pressing environmental problems in a way that will help develop the next generation of environmental leaders. We also need to equip emergency managers and other public and private officials with the needed tools and information to make local and regional decisions. Years ago, a national climate assessment was undertaken to establish and better understand these partnerships between users, researchers, and providers. This national assessment should be reinvigorated. The process could begin with a national dialog led by the American Meteorology Society and University Corporation for Atmospheric Research to help define the goals of the assessment. That dialog could be one national meeting or several regional meetings, but should involve all stakeholders—scientists, political leaders, and users and providers of weather and climate information. See budget estimates for this recommendation below.

- **Recommendation 5 (Leadership and Management): Implement effective leadership, management, and evaluation approaches to ensure that these investments are done in the best interest of the nation.** Our recommendations are not just about funding—equally important will be key leaders and effective management to implement these programs:
  - **Leadership.** Strong, qualified leaders must be appointed to top policy positions. Most important, an experienced and knowledgeable leader coordinating the overall federal effort should report directly to the President. This leader will need to understand that all sectors of the research and operational weather and climate enterprise (public, private, and academic) are needed to address these issues. Similarly, it will be vital for the new leaders in all the involved agencies to understand weather and climate issues and support a CCSP/USGCRP-like interagency process (see Management below). Our organizations have collected nominations

for key weather and climate leadership positions and stand ready to provide them to the new Administration and Congress. With respect to our Earth observation recommendations, the United States has played a significant leadership role in developing the Global Earth Observing System of Systems though the international Group on Earth Observations or GEO (http://www.earthobservations.org/geoss.shtml). International cooperation on these critical global observations is extremely important, and U.S. leaders must continue to be involved and lead in the GEO process.

- **Management.** The Executive Branch offices and federal agencies must take more leadership in coordinating weather and climate programs, including OMB, OSTP, NOAA, NASA, NSF, USDA, DOE, DOI, DOT, and EPA. The USGCRP (www.usgcrp.gov) has existed since the late 1980s and has made substantial progress on understanding Earth processes and coordinating the federal agency efforts in this area. This multi-agency effort worked best in the years when there was a strong partnership between the research agencies and OMB/OSTP that supported an effective, integrated program and budget approval process. **We are recommending that the next Administration and the Congress adopt the very best management tools from the USGCRP/CCSP's history and create CCSP Version 2.0:**
  1. The leader of this effort should report to the President and at a level equivalent to an economic or national security advisor. The leader must have an effective staff, enough of a budget to influence the agency programs in key priority areas, the ability to get outside advice from the broad weather and climate enterprise, and an open and transparent manner of conducting business.
  2. OMB/OSTP and agency leaders should be selected to support this critical interagency process and OMB/OSTP staff should be given the authority, resources, and time to support it. OMB, in particular, should examine how it is structured to ensure that the involved agencies are overseen in an effective, integrated fashion. In the past, differences between key OMB leaders have eroded the effectiveness of this interagency process.
  3. OMB/OSTP should implement an annual integrated weather and climate program and budget review and submit an integrated program plan and budget to the Congress as part of the President's budget.
  4. These programs should be considered national priorities and protected from internal agency budget cuts and tradeoffs. This should be implemented via the normal OMB budget development and passback process.
  5. The U.S. Global Change Research Program Act of 1990 may need to be updated to reflect a greater focus on adaptation and to ensure that the critical management approaches mentioned above are followed.
  6. Other related management issues:
     - **The Role of OSTP.** The Woodrow Wilson International Center for Scholars recently produced a report entitled *OSTP 2.0* that outlines the key role the President's science advisor should play in this area and how proven interagency management and review mechanisms should be applied (http://wilsoncenter.org/news/docs/OSTP%20Paper1.pdf). We support the recommendations in *OSTP 2.0*. There are many people in our organizations who played key roles in these past interagency efforts and can provide additional guidance on their effective implementation.
     - **An Earth System Agency.** The USGCRP interagency process that worked so effectively in the 1990s can clearly be reimplemented today with the right leadership. However, there have also been proposals to create a national climate service or an

Earth system science agency (e.g., combining NOAA and the USGS—http://www.sciencemag.org/cgi/content/full/321/5885/44) or make changes to the interagency process (e.g., S.2037, S.2355, H.R.906, etc.). There are many options that should be examined (e.g., run within an agency, led by an agency, led by an interagency federation, run by a non-profit with federal sponsorship, etc.) These are bold and creative ideas that have strong merit and should be seriously considered—provided they don't divert attention from the real problem of consistent underfunding of these weather and climate research and operational programs. Our community has provided feedback on the merits and shortcomings of these proposals and would welcome the opportunity to provide this input to the new Administration and Congress.

- **Research to Operations Transitions.** For years, the hope has been that NASA and NOAA would develop a comprehensive strategy to transition research satellites into operational NOAA weather and climate satellites. To date, this has not happened effectively for a variety of reasons, including budget constraints and agency mission differences. The issue is too important to leave to chance or agency culture. Leaders must be chosen for these agencies who will support these important transition issues or, perhaps, the functions need to be folded into the Earth System Agency mentioned above.
- **Climate Models and Computing.** We do not support a single climate modeling or climate computation center. Our nation has four key climate modeling groups (NSF's National Center for Atmospheric Research, NOAA's Geophysical Fluid Dynamics Lab, NASA's Goddard Institute for Space Studies, and DOE lab contributions to both climate modeling and computing). These groups serve distinctly different communities and purposes (e.g., NCAR serves the broad university community and GFDL works with NOAA on application activities). Our nation has been well served by having several groups because: (1) history shows that an average across several models outperforms a single model, (2) competition between groups spawns creative innovation, (3) modeling groups can take very different and equally important approaches, and (4) having multiple models and entry points permits more people to participate in model development. Today, it takes roughly $20 million per year to support a cutting-edge climate modeling group (that sum does not include observations or computing). All these groups will need access to computational resources that can be "tuned" and dedicated to very specific climate modeling efforts. Some groups will continue to develop critical high-resolution global climate models, while others will work at "nesting" advanced weather models into climate models to provide very specific local and regional information about climate change. Some efforts will be for research and others will have an operational focus. All of these approaches are extremely important, but will have very different computational needs and environments. A general petascale computational center designed for all scientific disciplines will not effectively support a national climate modeling effort. We strongly recommend that the national climate/weather computation and modeling effort be coordinated and managed within the CCSP Version 2.0 management principles and that the management structure include a mechanism to provide guidance from the climate modeling and user communities.

- **Evaluation.** We must have mechanisms to evaluate whether we are making progress toward creating and using knowledge that can help society adapt to climate change and severe weather. Congress should vigorously exercise its oversight responsibilities to assist in the implementation

of these and other policy recommendations. We also call for the establishment of a presidential committee that will advise, assess, and report on progress toward the recommendations mentioned above and on their impacts with respect to national policy. This high-level advisory committee should include representatives from across the weather and climate enterprise, including the public, private, and academic sectors.

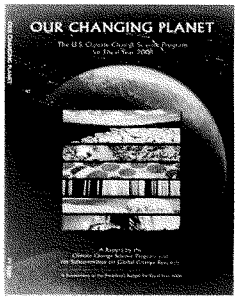
**Budget Estimates.** Below you will find our best estimate and explanations for what it will cost to implement our recommendations. These estimates are based on several key community documents:

1. The Decadal Study and Ground-based Study mentioned above,
2. The US Climate Change Science Program's FY 2008 report entitled *Our Changing Planet* (www.usgcrp.gov/usgcrp/Library/ocp2008), and
3. The *Ocean Blueprint for the 21st Century* (www.oceancommission.gov).

Implementing these recommendations over the next five years will cost roughly $9 billion beyond what our nation is planning to invest in this area between 2010 and 2014. Given the substantial impact severe weather and climate change are projected to have on our nation, we believe these are critical investments toward better local and regional information and a nation that is more resilient to severe weather and climate change impacts. Some of these investments could be paid for by the "climate funds" being created in various climate and energy policy legislation (e.g., from the auction of carbon offsets) and some of them can be supported by reprioritizing efforts in the U.S. Climate Change Science Program. New leaders will need to review these estimates and determine the next level of needed detail and prioritizing. We can provide additional details on any of these estimates.

| Weather & Climate Transition Budget ($ in Millions) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2010-2014 Totals |
|---|---|---|---|---|---|---|---|---|---|---|
| Continue CCSP Base Funding | 1,692 | 1,822 | 1,837 | 1,910 | 1,910 | 1,910 | 1,910 | 1,910 | 1,910 | 9,550 |
| Provide Critical CCSP Increment | 0 | 0 | 0 | 0 | 143 | 267 | 397 | 536 | 682 | 2,026 |
| Fund the NRC Decadal Survey | 0 | 0 | 0 | 0 | 272 | 596 | 975 | 1,038 | 803 | 3,684 |
| Fund the NRC Ground-based Study | 0 | 0 | 0 | 0 | TBD | TBD | TBD | TBD | TBD | TBD |
| Restore Climate Sensors to NPOESS/GOES-R | 0 | 0 | 0 | 74 | 92 | 181 | 227 | 258 | 333 | 1,091 |
| Upgrade Climate/Weather Supercomputing | 0 | 0 | 0 | 0 | 75 | 100 | 150 | 200 | 200 | 725 |
| Fund the NOAA Integrated Ocean Observing System | 0 | 0 | 0 | 21 | 138 | 260 | 385 | 480 | 500 | 1,763 |
| Fund the NSF Ocean Observation Initiative | 0 | 0 | 0 | 0 | 31 | 80 | 90 | 95 | 30 | 326 |
| Restore National Flood Warning/Forecasting Capabilities | 0 | 0 | 0 | 20 | 25 | 35 | 40 | 55 | 80 | 255 |
| Subtotal | 1,692 | 1,822 | 1,837 | 2,025 | 2,686 | 3,428 | 4,175 | 4,572 | 4,538 | 19,400 |
| 2010-2014 Needed Increment | 0 | 0 | 0 | 0 | 661 | 1,403 | 2,150 | 2,547 | 2,513 | 9,275 |

Our estimates are based on the following imperatives:

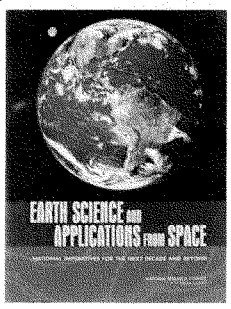



1. **Operational Weather Budgets.** Agency funds that aren't traditionally part of the CCSP, but are critical to weather and climate research and operations, must be continued (e.g., much of NOAA's operational weather budget is not part of the CCSP).

2. **Continue CCSP Base Funding and Provide Critical CCSP Increments.** The CCSP (which was built upon the USGCRP) has been a critically important interagency research and assessment program since the early 1990s, and *Our Changing Planet* provides budget estimates for the 13 federal agencies involved in the CCSP. We expect the funding for the CCSP to be roughly $1,910 million in 2009. This base funding must be continued, but the increments are

needed to undertake a broad range of unfunded activities, including the development of a national climate service, critical national weather and climate modeling efforts, moving toward helping local and regional decision makers, and much more. We also believe that an enhanced CCSP interagency management process as mentioned above is critical. These investments are needed to implement Recommendations 3, 4, and 5. The CCSP goals during this period are:

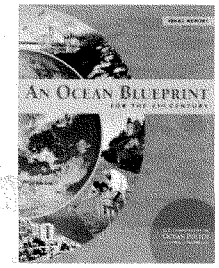
a. Improve knowledge of the Earth past/present climate.
b. Improve quantification of climate forces.
c. Reduce uncertainty in climate projections.
d. Understand the sensitivity and adaptability of different natural/managed/human systems to climate change.
e. Explore abilities to manage risk and opportunities of climate change.




3. **Fund the Decadal Survey and Ground-based Study Recommendations.** The Decadal Survey recommends and prioritizes 17 satellite missions that need to be flown in the 2009–2020 timeframe to adequately capture our planet's vital signs. Our budget estimates include the missions proposed for the 2010–2014 time period that are not included in the CCSP. The Ground-based Study will be released in September–October 2008. Our document will be updated to reflect those key recommendations and budget estimates once they are available. While we can't predict the study's recommendations, we anticipate that they will include new radar and other technologies that are critical to severe weather and climate monitoring. These investments are needed to implement Recommendation 1.

4. **Restore the climate related sensors on NPOESS and GOES-R satellites.** The climate-related sensors were dropped from the NPOESS and GOES-R operational satellites due to budget overruns and were not part of the CCSP funding. These estimates include the resources to put these sensors back on these important operational satellites. These investments are needed to implement Recommendation 1.

5. **Upgrade Climate and Weather Supercomputing.** One of the biggest constraints to providing local and regional decision makers with critical information to make our nation more resilient to the impacts of severe weather and climate has been the lack of dedicated supercomputers to run finer-resolution weather and climate models. These are our best estimates of what could be responsibly spent given expected constraints in computing technologies, software tools, and human resources. These funds should be invested in NSF, NOAA, NASA, and DOE; should be reviewed in the CCSP Version 2.0 interagency process to ensure they are focused on key research and operational areas; and be consistent with the climate modeling management recommendations mentioned above. These investments are needed to implement Recommendation 2.




6. **Fund the NOAA Integrated Ocean Observing System and NSF Ocean Observatories Initiative.** These two important initiatives are not included in the current CCSP and are highly recommended by the *Ocean Blueprint for the 21st Century* to make progress on ocean observations that are key to both weather and climate. These investments are needed to

implement Recommendation 1.

7. **Restore the National Flood Warning/Forecasting Capabilities.** Our nation's water programs have been underfunded for years, which has undermined our ability to issue flood and water quality warnings. Water will be a critical issue in the future as ecosystems are stressed by population growth, economic fluctuations, land use changes, and the impact of climate change. These issues were highlighted recently in a letter from over 30 public and private water associations (http://www.icwp.org/cms/gages/StreamgageLtr2HouseFeb2008.pdf). These investments are needed to implement Recommendation 1.

**Sponsoring Organizations**

This document was developed by the organizations below and we welcome others to join in this effort. This document can be found at: www.ucar.edu/td

- **University Corporation for Atmospheric Research** is a consortium of 71 universities located in Boulder, Colorado. http://www.ucar.edu/td Contact: Jack Fellows jfellows@ucar.edu
- **Weather Coalition** is an industry and academia group involved in advancing U.S. weather observation, prediction, and warning capabilities. www.weathercoalition.org. Contact: John Snow jsnow@ou.edu or Ray Ban RBan@weather.com
- **American Meteorological Society** is a scientific and professional organization dedicated to advancing the atmospheric and related sciences, technologies, applications, and services for the benefit of society. www.ametsoc.org Contact: Keith Seitter kseitter@ametsoc.org
- **American Geophysical Union** is a geophysical scientific association. www.agu.org Contact: Eugene Bierly EBierly@agu.org
- **Consortium of Universities for the Advancement of Hydrologic Science** is a consortium of over 100 universities involved in hydrologic sciences. http://www.cuahsi.org Contact: Richard Hooper rhooper@cuahsi.org
- **National Association of State Universities and Land-Grant Colleges** is nonprofit association of public research universities with member campuses in all 50 states and the U.S. territories. http://www.nasulgc.org Contact: Wendy Fink WFink@nasulgc.org
- **Consortium for Ocean Leadership** is a nonprofit consortium of 95 public and private ocean research education institutions, aquaria and industry with the mission to advance research, education and sound ocean policy. http://oceanleadership.org Contact: Kevin Wheeler kwheeler@oceanleadership.org
- **Alliance for Earth Observations** includes industry, academic, and non-governmental organizations working together to promote the understanding and use of Earth observations of societal and economic benefit. www.strategies.org. Contact: Nancy Colleton nancy_colleton@strategies.org

The CHAIRMAN. The Chair will now recognize himself for a round of questions.

Dr. Kammen, do you believe that we have adequate technologies to begin reducing global warming pollution now even as we increase our investment in R&D in the years ahead?

Mr. KAMMEN. I do very strongly believe that we have an adequate base to begin. We clearly have areas where we need research, a number of individual technologies on the balance between investing in efficiency now and some of the low-carbon technologies in the long run. But as a platform to begin that process today in the economy that base exists, and yet we need to bring much, much more of it to market than has been the case in the past.

The CHAIRMAN. Dr. Hockfield, could you respond to the same question? Do we have adequate technologies today to make a significant beginning?

Ms. HOCKFIELD. We have adequate technologies to make a significant beginning. What we feel is that we have important things we can do in the near term. But in the mid term and the long term, we have got to invest aggressively to improve those technologies to make them more economic and more efficient. But we certainly can begin today, and I think we have to start today.

The CHAIRMAN. Let me ask you this, Dr. Hockfield. What is the interest level of students at MIT with this issue?

Ms. HOCKFIELD. The interest level is deafening. Just as one example, our students are wildly enthusiastic about it. We can't give them enough. We have a student-led energy club that was established just 3 years ago, and now it is over 700 members. This is largely a graduate student organization, and it was established by graduate students across all of the different schools at MIT who recognize that, in their desire to be energy professionals, they are committed to working in the field, that their educations that they were receiving in the department of mechanical engineering or in their MBA program at the Sloan School of Management was insufficient to make them well-educated energy professionals. And so they have linked resources across the entire Institute to educate one another about all of the things they will need to be powerful advocates and powerful facilitators of a bright energy future.

The students' interest is absolutely deafening, and one of my fears is that if we don't fund the kind of research that will fuel innovation, these very brilliant students will see that a bright future actually lies elsewhere, even despite their passion for solving what I believe is the greatest challenge of our era.

The CHAIRMAN. Thank you, Dr. Hockfield.

Let's talk a little bit about the R&D budget in terms of how it compares to past R&D budgets and just kind of get your sense across the board of what needs to happen. Does it need to be increased from a doubling to a tenfold increase in order to deal with the magnitude of this challenge? Could each of you give us a sense of what you believe is the most appropriate?

Mr. FORREST. If I can jump in, I would like to go back one step and talk about climate change and energy and then get—and, if I may, then go to that other question.

But the issue of do we have enough tools for climate change and pursue energy at the same time I think is a vital one. It is not an

either/or proposition. We have to take them both on. We do have the tools. And the best analogy I can give was in the Second World War. We didn't have a choice to say will we go after Germany or Japan? It was both. And that is the same situation we have today.

In terms of the budget, I think the overwhelming opinion of this panel—I can certainly speak for myself—is that we are woefully underfunded. So if we talk about a 10 times increase, yes, but we also have to also build the capacity. So you can't do it overnight.

We have a very large reservoir of student interest, as President Hockfield has mentioned; and I think that we just have to really get on with it right away and start to fund some of these institutes, ARPA–E, for example, and just start moving up that chain as rapidly as we can. But certainly I think the numbers would justify a tenfold increase.

The CHAIRMAN. So the NIH budget is approximately $30 billion a year?

Mr. FORREST. Yes.

The CHAIRMAN. Research on health problems. Is that the scale that you think we should be talking about, Dr. Hockfield?

Mr. FORREST. Yes. Certainly the level of intensity of the problem is every bit as much as what we are tackling with health; and when we really cut the numbers for the DOE right down to what is going into science, it is about $1.5 billion.

The CHAIRMAN. Dr. Hockfield, do you agree?

Ms. HOCKFIELD. Whether it is $1.5 or $4.5 billion, it is vastly insufficient. And I think you have drawn the comparison that I immediately go to as a life scientist, which is a comparison with the NIH budget. The NIH budget is close to $30 billion, and that is a lot of money. But we have gotten a huge bang for that buck.

Just think about it. I gave the example of heart disease and stroke. Look at AIDS. In the beginning of the 1980s, this was a disease that had no cure. It was a death sentence, and we projected that every hospital bed in America was going to have an AIDS patient in it. This was a very tough problem. A new disease. We didn't understand anything about it. We have turned it, through investments, into a chronic manageable disease. The costs to health care savings are 140 times the investment in research dollars, and that doesn't even begin to account for the economic benefit of these people being in the workplace.

We can do the same thing around energy, and it will fuel—you know, Federal investments can fuel an innovation economy that will be good for everyone.

Now we talk about how much money. You know, I say three times right now. Let's do that immediately. And whether it is 10 times, you know, over a 10-year period or it gets to the NIH budget level, I think it has to. These are problems that we can solve, and we know how to solve them.

And it will have the added benefit of, you know, fueling the young people of America. Right now, we kind of wring our hands over our young people's lack of interest in science and engineering and mathematics. Well, when I was growing up, it wasn't that I had an abstract interest in these things. I had a real interest in these things. Because we are going to win the race to the moon.

And I think we could power up our young people today with the same kind of enthusiasm for solving these energy and climate challenges. Not to mention the building of new industries that would come out of it, as we have demonstrated so many times in the past. This is America's gain. We should be able to win it this time.

The CHAIRMAN. Thank you, Dr. Hockfield.

My time is going to expire. I apologize to you, Dr. Kammen.

But there has been, unfortunately, a 16 percent reduction in the NIH budget over the last 4 years as well. So we really do have to change the whole approach that America is taking not only to energy but health and other issues, because these are the real threats to ordinary American families, much greater, actually, than the likelihood that a terrorist will come to their hometown. These are the issues that are actually going to impact their families' futures.

My time has expired. The Chair recognizes the gentleman from Washington State, Mr. Inslee.

Mr. INSLEE. Thank you.

I would like to ask about how to structure this imminent exponential increase in R&D that we will imminently obtain maybe in March next year, I hope. One of the concerns I have is structuring it so that R&D goes into stovepipes, into favorite programs, which is a thing I think we want to resist. And I would just like your comments. Maybe I can start with Dr. Kammen about that.

Would it be an issue right now, frankly, about whether to create a revenue stream that would fund just R&D just in coal sequestration, which I have heartburn about because I don't think we should limit R&D to any one particular technology. We should have a broad-based recognition that some of these technologies will succeed and some of them will fail, and we should not put our eggs in any one basket. Dr. Kammen, any comments?

Mr. KAMMEN. I very much appreciate the chance to address that, because this is a critical issue. The lessons from the NIH budget increase were that you did need to ramp it up in a way that industry and universities could absorb it. Our time constant in academia is actually about 4 to 5 years for a doctoral student to come to fruition. And then in the industry side it is actually often another 4 or 5 years for them to become technologies in the market. So this tripling is a good starting point. In our papers, we actually advocate a 5 to 10 percent increase based on the climate challenge.

But this issue of stovepiping is a vital one; and, in fact, we have had a series of interesting individual program areas in the Department of Energy, at EPA, et cetera, but we have not had the kind of cross-technology comparisons that you are speaking towards. And by far the most effective tool we have now is to examine technologies in batches. There are things that are nearer term, where a carbon cost effectiveness can be performed. But there are also areas which are further off, higher payoff, high risk, where we are going to need to have some areas where we look at with longer-term missions.

The most important lesson we have seen from past efforts is that, for both the near term and for the longer term ones, stability and a plan is the most important future. The private sector cannot ramp up in the broad set of areas we need if we don't see that stability. So the long-term budget increase is part of the story. And

targeting individual ones early on, especially those already have a large market share, has not proven to be an effective use of money in the past. And so targeting money in the coal area is a concern, as it would be in targeting a number of others.

So I urge the committee to look at this broad portfolio approach and to use that to evaluate not only individual technologies but those that have critical synergies. We have seen efforts where wind and natural gas can work well together, and so structuring incentives on the deployment side to draw those technologies into the market is critical as well.

So, again, pushing on the policy and it is research-based at the same time is the best way to bring these technologies broadly into the market and to re-energize a number of U.S. firms to become leaders in these areas.

Mr. INSLEE. Dr. Hockfield.

Ms. HOCKFIELD. I want to emphasize this idea of approaching a portfolio of technologies. We can't choose winners now. We don't know what they are going to be; and we have to invest money, you know, in a number of technologies.

One of the problems is this kind of research is done across a number of Federal agencies. So how can we bring them together to get appropriate synergies and reduce unnecessary redundancy?

I think it is important to enter into a very rapid strategic planning energize that pulls in government, industry and universities to set out a game plan; and I hope that there will be some kind of Federal counsel around these energy issues bringing in the relevant agencies, not just DOE but DOD, NIH, NSF, EPA HUD, you know, around building standards. And I don't know who might chair this council of secretaries, but perhaps it could be co-chaired by the President's science advisor and the Secretary of Energy. But some way of integrating approaches not just within a single agency but across agencies.

Mr. INSLEE. I think that is an important way to think about it.

One quick question: To get to this plateau where we need to do this major ramp-up of R&D, it takes some political throwaway. We have got some great ideas floating around. We need some political throwaway, frankly, to get Congress and the executive branch—we need a combination of—a new Vannevar Bush having these conversations with the next President and Members of Congress. But we need a lot of people around here.

I just wonder, maybe Dr. Fellows, do you have any thoughts about how to develop a real consortium, you know, nationally between academia and the industry? How do we build a real movement to get this job done, as happened in the health care industry that really developed a uniform, you know, strategy to get this job done.

Mr. FELLOWS. Well, you know, it is happening at various scales. The rest of my day I am spending up here on the Hill with the American Geophysical Union on a congressional visit today to talk about these various issues.

But the document I mentioned in my testimony was written by these eight organizations that represents thousands of experts in both the public, private and academic sectors of the weather and climate community. So it is starting to happen, and we are writing

these documents and providing them to leaders like yourselves to try to build these coalitions. In our community, we have about 20 years of multiple agencies working together; and there is some good history here on how these kind of integrated programs can be done. But leadership is key, and getting the right leaders and the right kind of political focus on here is step one.

Mr. INSLEE. Thank you.

The CHAIRMAN. The gentleman's time has expired.

Unlike President Kennedy, who had Jerome Wiesner, became president of MIT, or President Roosevelt, who had Professor Bush come in, it is unclear that this President Bush knows the name of—much less has ever met with—his own science advisors. So there is a stark difference historically in terms of the relationship with this subject.

Let me turn now and recognize the gentleman from Missouri, Mr. Cleaver.

Mr. CLEAVER. Thank you, Mr. Chairman.

Dr. Hockfield, you may have already at least partially answered this question. But I am wondering what are the most important emerging technologies of which we should be aware and what are ways in which we can best support these efforts?

Ms. HOCKFIELD. The incredibly accelerating demand for energy—it is great now. It will probably double by 2050—demands that we pursue a portfolio of technologies. The current technologies that we are using are not going to, you know, go out of phase tomorrow, and we have to work very hard to increase their efficiency and their economy while we can develop the technologies of the future.

We have work going on at MIT across a range of technologies. We believe that nuclear is going to be an important piece of the energy equation in the future. We are very, very excited about the opportunities around solar, wind. Geothermal, a technology that was about to be put to bed except for the MIT geothermal report came out about a year and a half ago and happily rescued that at the last moment.

There are a number of technologies; and, frankly, I believe there are technologies we don't know about today because we haven't unleashed that engine of innovation that comes out of basic research. So I don't think we can make that step yet.

There are enormously exciting things right on the horizon. There are exciting things in hand that just need further development. But it would be desperately premature to pick any one or a small set of them for development. We are going to need everything we can get our hands on. The current technologies have to be improved, and then we have to innovate around the technologies of the future.

Mr. FORREST. If I could jump in on that, if you look at what is price competitive today with fossil fuel in the renewable sphere, the most competitive is wind. But the source of energy which is unlimited out there is solar, and the thing that is holding us back from solar right now is cost. It is the cost per watt that you pay, which is—depends on how you do it—it is between double and triple that of fossil fuel today. But it is marching down at an extraordinary rate.

So if you look at solar, you look at biomass, you look at energy storage which will transform the automotive industry, you have several really strong incumbents that we can move forward with. It is really just a matter of hitting price points at this point.

Ms. HOCKFIELD. Can I just add in the thing about storage? Storage is absolutely critical for all energy technologies. Solar, the price of photovoltaics may come down. But if we don't have our hands around storage, that is going to be problem. And one of the most exciting areas that I see going on is new battery technologies. And it will be the cars of the future. Actually, not such distant future. But it is going to be critical to make solar and wind viable technologies.

Mr. CLEAVER. Dr. Kammen.

Mr. KAMMEN. There are also technology areas that bring in other areas of expertise. There is no question storage that is important. There are some interesting efforts going on in this area. But the basic backbone of this whole system is going to be our transmission distribution system, and many universities have allowed this area to lapse so there are in fact no power electronics professors at a number of leading engineering universities. That is a huge oversight, and it is a huge mistake, because our renewable energy resources are not always coincident with what exists today.

Mr. CLEAVER. What can Congress do?

Mr. KAMMEN. There is a range of things. One is we need better regulation with what the Federal Energy Regulatory Commission does. We also need ties into what the National Academy of Engineering does. Because the advances in power electronics come in from work in a variety of areas, from everything from what is going on with our cell phones to power management issues, need to be applied to make the new grid that we are going to build in some form anyway as flexible and as smart as possible so it really becomes the clean energy superhighway and not yet just another build-out of what we have as —right now, we have quite an antiquated system. That one requires an integration with people who think of themselves as energy researchers and those people who think of themselves as electrical engineering and controls folks.

Thankfully, this country has a large resource there, few of which, however, have been applied right now to working on that new grid. So this is again an area where basic research and the application deployment are taught.

Texas had a historic recent vote to permit and to fund a $5 billion superhighway for wind power, essentially from west Texas and eastern New Mexico into the population centers. And that sends a strong signal. We need to get the basic research so that the new version of the grid is up to the task.

Mr. CLEAVER. So it would help probably if we had an Environmental Protection Agency.

Mr. KAMMEN. It would definitely help if we were protecting the environment and coordinating those efforts in what we do in terms of land, in terms of Department of Energy, in terms of a lot of the basic infrastructure. Even building and housing is going to be tied in, because many of our homes and businesses can, in fact, be power plants.

Mr. CLEAVER. I am going to introduce a bill to create an EPA because I think this country has long needed an Environmental Protection Agency, and I think such legislation should come forth in this Congress.

Dr. Fellows.

Mr. FELLOWS. Well, I wanted to add a perspective from the climate community on priorities.

Our current climate models reproduce a history of the climate quite well, and we can tell you whether a continent is warmer or wetter. But I recently had the executive director of the Colorado Public Health and Environment Department come and visit. And he asked me for the precipitation and temperature trends long-term in the Denver area. And our models are operating on a grid cell size of 100 kilometers; at that level you can't even see the Rocky Mountains, so I can't provide him those kind of long-term precipitation and temperature trends in such a small area.

One of our highest priority areas is to drive down that modeling to a level that local and regional decision makers can actually get the information they need to have to make plans about water, food, transportation system, things like that.

Mr. CLEAVER. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. The gentleman's time has expired.

The Chair recognizes the gentleman from California, Mr. McNerney.

Mr. MCNERNEY. Thank you, Mr. Chairman.

Dr. Hockfield, I would like to get an idea—you are asking for a fairly large amount of money—how you see that money being allocated. One of the reasons I ask is because a concern I have is, young students that want to go to graduate school have to spend 5, 6 years after getting a degree, and they are living at fairly low wages during this period. And even when they graduate with a Ph.D., they are still facing years of substandard wages compared to someone who just went for a bachelor's degree into finance, for example.

One of the experiences I had lately was, a math professor said there are plenty of math students now, there are more than you can imagine. And that was the good news. But then he said, they are all going to finance, which is not bad news, but it is not what we need in this area.

So could you give me some idea of how you think we could address that and similar problems?

Ms. HOCKFIELD. I hate that we all sound like a broken record, research dollars, research dollars, research dollars. But one of the geniuses of the Vannevar Bush appeal to President Roosevelt, and it was then articulated in Science: The Endless Frontier, which set out the blueprint for the American research enterprise, was that we created these magnificent research universities that, at their best, really do integrate research and education together. And frankly, most of my faculty—not all of them, but most of them—could have jobs in industry and be making twice, three times, in some cases ten times what they are making. But they are so motivated by this marvelous draw of invention-innovation, and being

around young people we really do put research and education together.

So by investing in research, we are talking about investing in graduate students, we are talking about investing in postdocs. The reason that the students in mathematics and in electrical engineering and computer science are going to Wall Street when they come out of MIT is because that is where the jobs are. When they look at their faculty who—Empower Electronics is a great, I am so happy you brought that up, a great—we have a couple faculty who are working in it, but miserably funded.

So a smart young person is looking forward to a life of what? There isn't a career track that they can proceed because frankly there has been a roller coaster of energy research over the last several years. It is funded, it goes away; it is funded, it goes away. These people want a career where they can—frankly, they will accept lower salaries.

Mr. MCNERNEY. I heard some very bad news about the University of California, in particular the math department there. One of the finest math institutions in the world is saying that next year they may not be able to accept new graduate students unless they get additional funding. This is a terrific tragedy for our country.

Ms. HOCKFIELD. So part of the government's abdication from the commitment that was set out in the Science: The Endless Frontier blueprint was a real partnership between the research university and government; and the government has abdicated that through these reductions in research funding. And one of the places where it hurt the most is in funding for mathematics graduate education. It has become very, very difficult to fund graduate students at a level that is commensurate with what late-20-year-olds need simply to live at a reasonable level in a place like Cambridge or New York City or in the Bay Area.

Mr. MCNERNEY. One thing that might help is specific academic programs that entice students in energy fields.

Could you address that, Dr. Kammen.

Mr. KAMMEN. Certainly.

Actually, we had a spate of developing these programs in the 1970s during the last time we had this ramp-up of energy funding. My program, the Energy and Resources Group, program at MIT, Carnegie Mellon, Penn, or a number of the beneficiaries of that, a number of these died out or withered away because of this true desert of funding.

We now see students back in droves. When I came to Berkeley from Princeton in 1998 there were 45 students in the graduate-level energy class. We capped the class this semester of 320. And to let you know, I have a huge problem finding qualified teaching assistants because we have so swamped the potential spaces.

So there is good news in the pipeline as referred to at MIT as well; at Michigan and Texas it is all going on. But we really do need to build out this business side, this opportunity for them to go into, as a number of people have mentioned and Congressman Inslee mentioned, the need for a compact and the bones that could be offered out in the political dialogue in D.C. And there is no question that one of the advantages this field is showing right now is

dramatically higher job creation numbers than the same amount of investment in fossil fuels.

Now, this is a transitory effect; it will not go on forever. But at the moment we are trying to dramatically increase the budget. The fact that we see three to five times more jobs per dollar invested in the clean tech energy area—and I am including energy efficiency that we have not mentioned explicitly here, but it is vital to the equation, this job dividend, green collar jobs, inner city jobs, as well as the high-end jobs—is a critical benefit that we can capture. And right now many of those jobs are going to Germany, Norway, Portugal. So we are losing out. In fact, little Portugal just set up a clean energy research investment fund larger than the entire U.S. investment in this area.

Mr. MCNERNEY. I see that my time has expired.

The CHAIRMAN. The gentleman's time has expired.

The Chair recognizes the gentleman from New York, Mr. Hall.

Mr. HALL. Thank you, Mr. Chairman.

And without giving away our ages, I would say Dr. Hockfield has probably already acknowledged being in the same group that I am in, which grew up during the Space Race. My father was head of the design team that built a camera that took the first live pictures from the moon when Neil Armstrong walked on the moon. And my brothers and I got used to having a blackboard over the breakfast table and solving equations that he would scribble out for us while we were downing our cereal. We benefited from a generation that pulled us out of the Depression. The Greatest Generation, the end of the American century that—the second half of which I lived through, the generation that won World War II.

It took great determination and vision and hard work and investment for that generation to win a war and for us to put a man on the moon. But that wasn't all. Their effort was backed up by the resources that put into place an incredible investment at the time in pure research.

I just came back a couple weeks ago from Denver, and one of the most exciting things that—maybe the most exciting thing for me was not the political goings-on, although those were for somebody who had never attended a convention before very exciting, but I got to go to NREL, the Renewable Energy Laboratories, to ENCAR, the Atmospheric Research Center, and to NOAA's research center in Boulder. And in the space of 2 days I saw the latest plug in hybrids, the latest solar, thin-film photovoltaics that are 23 percent efficiency, which is the high point they have achieved so far to my knowledge, and biofuels that are being created from nonfuel sources like wood chips and cornstalks and husks, not the corn kernels that are the food everybody is worried about.

And then the next day, after seeing the good news, I got to go to NCAR and NOAA and see what would happen to the planet if we don't do anything. And to anybody who hasn't been there and seen this, I highly recommend it, because I have already read the statistics and I am a believer. And I have been working on renewable energy issues for 30 years, and it was like being hit over the head with a 2x4 to see the graphic demonstration of what happens when the growing latitudes for food move into the alluvial plain of Canada where there is no soil.

And I said to the director of NOAA, I guess we will go from being a net exporter of food to being a net importer of food. And his answer was "Yes, but from where?" And he pushed the remote control to revolve that big globe they had up there and showed that all continents are the same color red, all the continents will be, if we do nothing, will be pushing the growing latitudes toward the poles at the same time that we are projected to have 12 billion people on the face of this Earth.

So we are looking at a situation that cannot be dismissed. But the good news is that, at the same time, we do have the technologies and we need to make the right choices.

Mr. Inslee covered some of the ground that I was going to ask about in terms of making choices and stovepiping, and I am particularly interested that we not favor some industries, as we do. I mean, there are costs that are not included in the kilowatt hour price that are charged for electricity generated from nuclear and from fossil fuels, whether they be the cost of wars in unstable areas of the world that have oil or the fact that the taxpayer has subsidized the insuring of all nuclear plants since the Price-Anderson Act.

And so I would prefer to see either a level playing field or some kind of equal subsidies for renewables, but that is just my opinion.

I am also concerned that I have been buying wind power in my home at Dover Plains, New York, for several years. The company that—the wind firm that I am buying it from was just bought by a Spanish conglomerate, Iberdrola, a good company but not an American company. So now my dollars are going for the profit of a foreign-owned corporation.

And when I was in Colorado, I saw one of the largest new photovoltaic installations there, built and installed by American workers, but the solar cells were made in China. So if we go from buying fuel from overseas to buying solar cells from overseas, we are really out of the frying pan and into the fire economically. And we are also not putting our brainpower to work in the way that we should.

That is enough rambling from me, but I just wanted to ask in terms of funding climate observation, to the degree that we have a shortage of funds here, we will be looking at trying to make a choice between preventing climate change or focusing on mitigation to some extent, and also prioritizing renewables and noncarbon-based sources of energy versus funding of further climate investigation and focusing on localities and regions as opposed to the bigger picture.

So perhaps, Dr. Fellows, maybe you would like to start answering how you would prioritize those things.

Mr. FELLOWS. Well, in terms of observations, whether you are doing mitigation or adaptation, you need observations. For mitigation, you will be monitoring the carbon levels to see if you are achieving them. For adaptation, it is more about what are the processes that we need to understand to adapt to.

So it was—last year, in 2007, the National Research Council actually produced a study that laid out all the missions that—observational missions you need to take all the vital signs of the United States. There are 17 of them. And even in the document that I provided in my testimony, out of the $9 billion those that fall in the

next 5 years are funded. So we have a very good road map of what kind of observations we need for both mitigation and adaptation.

Mr. HALL. Mr. Chairman, if you would allow the other witnesses to answer the same question, if they wish.

Mr. FORREST. One of the issues that I would like to bring forward is that we are talking an awful lot about energy generation. But there is a tremendous amount we can do with conservation as well. And that also—and we can do that immediately. Interior lighting takes up 20 percent of electricity that is in the grid today. And we are still using an incandescent bulb which is basically a heater that gives off light as a byproduct.

There are other sources. In the automotive domain, we can do hugely better.

So these are very quick responses that we can actually implement within a matter of a few years, and that will really, I think, change also the growth of carbon in the atmosphere at a real rate. We should never take our eye off the ball of conservation. There are a lot of solutions there.

Ms. HOCKFIELD. Can I just add a little bit of reflection about energy research?

We are talking about funding energy research and ramping it up very rapidly. I would just add caution that it should not be too clever. There are a lot of technologies that are almost in reach. And we very much want to move those along and get them implemented. But I believe that one of our government's major responsibilities and one of the important reasons why we have done so well in so many new industries is that we have invested in basic research, the kind of research where, when you embark on it, you don't know what is going to come out of it. There will be new technologies coming along in the future only if we invest in basic research today.

So let us—I am very enthusiastic about funding research that will deliver technologies for tomorrow and 5 years and 10 years from now. We have got to be thinking about what we need to put in place that we are funding the technologies 50 years from now. And that has been the brilliance of, frankly, DARPA, the NIH, in funding early research that nobody could have predicted exactly where it was going to come out, but has been so, so important for the Nation's success.

Mr. KAMMEN. A critical part of the story that we have to come back to again and again is that even if we get to this ten times increase in the Federal money, which is certainly the goal that the papers in my lab have cited, it is going to be the private sector investment far—many times that that we are going to need. To do that we need to send a number of signals that this area is both stable, as we have described, but also we have opportunities now to help balance this field out.

A number of States have adopted so-called loading orders benefiting clean energy, energy efficiency and the low carbon sources before they would authorize new fossil fuel production. That sends a strong signal.

A number of other utility areas have engaged in a process of decoupling the revenues from more electricity sales with their overall profit based on a mechanism that allows a forecast of sales and the

amount you get paid per kilowatt hour to vary to that target. That encourages conservation, it encourages low-carbon forms of energy.

So we have a number of mechanisms that aren't going to be seen as strictly research spending that can dramatically expand the industry's interest, ability and rewards for going to the clean area. That is really why at the legislation level we critically need to tie these at all points, back and forth.

One last point on this is that we have effectively frittered away the last 20 years or so of knowledge of the climate change story. The details are still coming in, but the basic story has been known for some time. And many of these technologies have been ready together.

We need to pull on the market as well as pushing on the research side. And many of those market pulls do not require dramatic amounts of added money. Some do, like a better grid. But coupling clever policy tools and this much expanded R&D base really does send the signal that industry needs to make this a new national priority.

Mr. HALL. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you. The gentleman's time has expired.

What I am going to ask now is for each you to give us your best minute and a half summary of what you want the Congress to remember about this issue as we move forward in putting solutions in place. And we will go in reverse order.

We will begin with you, Dr. Fellows.

Mr. FELLOWS. Thank you, Chairman.

Well, from our perspective, we really see this as civilization standing at a serious crossroads. We have a lot of uncertainties that we are facing.

Mr. Hall, I have sat with Sandy McDonald before and looked at that large globe in NOAA. One of the big concerns we have is helping local and regional decision makers deal with energy issues, with water, with food issues to reduce some of the uncertainties.

Another really scary one is, civilization has been putting about 6 or 7 gigatons of carbon into the atmosphere. There are thousands of gigatons of carbon frozen in the Arctic. As the Arctic heats up—and it will heat up quite a bit more than the rest of the world—how quickly would that be released. If it is released quickly, it could be the end of civilization.

That is a kind of uncertainty that we don't fully understand. I am not saying it will happen, but we don't understand it.

So the kind of research investments that we are talking about in this community document addresses those type of issues.

The CHAIRMAN. Thank you, Dr. Fellows.

Dr. Kammen.

Mr. KAMMEN. First, energy is a $1 trillion industry in this country. We import $700 billion of that. And so what we are calling for here is a very small down payment, a very small brain trust to manage that huge industry.

It is exactly in keeping with the amount of effort we would need in this area. And the fact that we do have such an important diversity of energy research topics and researchers ready to go should give every Member of Congress and the Senate the motivation to

stick with the plan to develop these carbon and energy plans and to bring them forth and to recognize that poll after poll of Americans says that clean energy and secure low-carbon power is something that people want. They need the political leadership and they need the vision that this is going to be a plan.

We lack that plan, we lack that go-to-the-moon sort of mentality right now. That is the vital lesson that will bring all of the science technology base broadly into the market.

The CHAIRMAN. Thank you, Dr. Kammen.

Dr. Forrest.

Mr. FORREST. To me, it is really just simply a matter of priorities. As a Nation, we have great wealth and we can set our priorities almost at will if we choose to. And I can't think of a higher priority. Everything is at stake here. Our national security, we are currently buying our energy from our least best friends in the world, primarily. It is a question of a clean environment. What are we leaving for our children? What are we leaving for generations to come? And finally it is an issue of economic leadership in our standard of living.

Really it is the issue of the 21st century. If America does not seize this as a top priority, as perhaps the top priority, we will lose our position inevitably in the world; and it is going to happen very quickly. So I don't think that we have time to lose. I think that, responding just a wee bit to Mr. Inslee's question of where do we get the political heft to throw this forward, I think there is a rising chorus of voices. It may not hit today in full, or even tomorrow, but it has got to hit within the next year or two, because if we don't set this as the priority—I can give you one example.

Germany has set this as a national priority to get off of the foreign oil addiction and so on, and they have invested through their tax structures and so on in large growth in their solar industry. It is just one example, but they have set the priorities, and they are on their way. We need to get on our way.

The CHAIRMAN. Thank you, Dr. Forrest.

And Dr. Hockfield you are cleanup.

Ms. HOCKFIELD. So we have all articulated the deeply linked challenges of economic insecurity, energy insecurity and global climate change. What we have been advocating for is a massive powerful important investment in research universities. These kinds of investments have a double return. We produce innovations and innovators. And what we are asking is, please, help us unleash the power of America's innovation economy to turn this global energy challenge into a wonderful energy opportunity.

Thank you so much for holding this hearing.

The CHAIRMAN. Well, thank you. It is our honor to have such a distinguished panel. And this is going to be a very important panel in terms of the information you have given us as we formulate the plan for January and February of 2009. We are clearly at a point where the debate for President is revolving around this issue.

And as I said in my opening, "drill, baby, drill" is not a long-term strategy for the United States with 3 percent of the oil reserves. We need to unleash this technological genius. That is our strength, and that is always what has led to the United States being the dominant power in the world. And if we don't tap it, then we will

become ever more dependent upon those who not only are weak in technology but are strong in our weakness.

And that is something that ultimately, I think, can only be remedied by unleashing all the young people at universities you are finding want to solve this problem.

So we thank each of you for being here today.

The hearing is adjourned. Thank you.

[Whereupon, at 11:35 a.m., the committee was adjourned.]

**Select Committee on Energy Independence and Global Warming**
**Additional Questions for Dr. Stephen Forrest**

*1. Besides additional federal dollars, what is the single greatest action that Congress can take to stimulate additional energy R&D?*

The single greatest action that Congress can take is to make solving our energy crisis an issue in which all members are unified behind in a bipartisan effort. This issue is too critical to be dominated by "red vs. blue" politics. Our nation must reduce its dependence on fossil fuels, which is draining our nation's wealth, creating a significant security risk and damaging our environment. If we are going to truly meet the challenge of transforming our energy economy together, the government needs to be unified in this goal and be more active than ever. In our nation's past, we were able to unite to address certain issues of strategic and economic survival without reducing them to political gamesmanship. In the Second World War, the nation came together to solve a problem of grave national consequence without basing actions on pure politics. Arguing about the reality of global warming or the stability of our energy supply from (mostly unfriendly) foreign government misses the point. the issues that confront us as a nation are serious and the consequences for inaction are irreversible.

*2. With Congress facing a tight budget outlook, where do you propose Congress cuts current spending or raises additional revenue to fund additional research and development?*

With the upcoming new Administration and a new Congress, policy makers will encounter many new challenges. But with them will come new perspectives and options for consideration. Of these, one option on the table is a Cap-and-Trade system. During the campaign, President-elect Obama offered support for a national carbon dioxide cap-and-trade program. Debate of this proposal is expected during the first few months next year. Such a program, if passed into law, could be a source of additional funding for energy R&D. Further down the road, as our troops begin to be pulled out of Iraq, money previously allocated to military activity in that country could possibly be allocated to other pressing priorities such as energy R&D.

*3. How does the problem of academic research in new energy development correlate to the broader problem of the decline of engineering students in the United States?*

One of the most problematic trends facing academic research in new energy development is the absence of long-term stability in federal funding. In real terms, FY08 Department of Energy (DOE) funding for energy research just equals the FY84 level following a slow climb up from a low level in FY99. In 2007, DOE requested a 14% increase for Science. However, at the end of the annual appropriations negotiations, it received a 5% increase.

In 2008, it asked for a 16% increase and again ended up with a 5% increase. To a great extent, the instability in federal energy research dollars correlates with the decline of engineering students in the United States. As mentioned in my testimony, I have encountered many promising young researchers who are eager to join in and devote their entire careers to developing alternative fuel sources. However, their enthusiasm is tempered by what has been the unpredictable and declining level of support for energy R&D and its possible impacts their future careers. The possibility of an unsteady funding future discourages many talented students from going on to be leaders in their field.

*4. How do you suggest Congress avoids "cherry picking" technology that we think will work, rather letting the market figure out the best direction for technology development?*

Our first focus should be on supporting the basic research that will lead to the most transformative new technologies. By the nature of such exploration, no one can know at the beginning which new research directions will ultimately lead to these new technologies and industries. Therefore, the best approach is to invest in a wide portfolio of research.

One program that would make an immediate difference is the DOE Energy Frontier Research Center (EFRCs) proposed by the Administration and supported in the House Appropriations Subcommittee draft FY09 appropriations bill. These Centers would integrate the talents and expertise of leading scientists to accelerate research in critical areas such as solar energy utilization, superconductivity, and hydrogen production, storage and use. The EFRCs will harness both basic and advanced discovery research to build the foundation for a fundamentally new U.S. energy economy.[1]

Next, we should focus on the means through which we commercially develop nascent technologies. Our focus should be placed on programs that help innovative technologies bridge the well-known "Valley of Death" gap between the laboratory and the marketplace where many promising inventions languish for lack of sufficient funding to move them into commercial development.

The Advanced Research Projects Agency for Energy (ARPA-E), authorized by the America COMPETES Act, is one such initiative. Modeled on the Pentagon's successful Defense Advanced Research Projects Agency, it will connect pioneering experts at universities with large and small companies. With their more practical perspectives, the companies can take university innovations through to commercialization. With ARPA-E as a bridge between the two worlds, the best ideas will rapidly emerge to find their way into the marketplace.

*5. Do you support nuclear energy as a greenhouse gas free energy source? What programs are you working on which would advance nuclear technology?*

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[1] *Energy Frontier Research Centers: Tackling Our Energy Challenges in a New Era of Science*. U.S. Department of Energy, 2008.

Yes, I support nuclear energy as a greenhouse gas free energy source. While my own research focuses on energy devices that harvest energy from the sun and on new white light sources to replace the highly inefficient incandescent bulb, the University of Michigan (U-M) is home to many experts on nuclear energy. In response to the challenges of meeting U.S. energy needs, the university's Michigan Memorial Phoenix Energy (MMPEI) Institute is working to convene world experts in all areas of energy science and technology – including nuclear -- to develop new ways of addressing the challenges facing us as a nation. Beyond science and technology, the Institute has a broad mission to explore the "third dimension" of energy research: public policy, economics and the societal aspects of our energy system. In the area of nuclear energy our experts range from MMPEI Acting Director Gary Was who focuses on radiation materials science and the environmental effects of these materials on metals to Professor Barry Rabe who focuses on policy issues related to the transport and storage of low-level radioactive waste.

*6. You note that currently only 1.6% or all federal R&D goes to DOE research, yet clearly not all energy-related R&D, is restricted to DOE. Do you have any statistics that include energy-related research in other agencies? For example the military is conducting extensive coal-to-liquid research for fuel for their jets. How would the number change if energy-related research for all agencies was included?*

Unfortunately, there is no good government-wide crossing cutting budget analysis of funding for energy research being conducted by agencies other than DOE. According to Kei Koizumi, Director of the R&D Budget and Policy Program at the American Association for the Advancement of Science, while agencies such as the Department of Defense (DOD), USDA, and the National Science Foundation (NSF) do indeed fund some R&D that is classified as energy research R&D, but it is difficult to categorize their spending because these agencies reportedly do not have inventories of their energy work. The only agency whose R&D budget often gets added to DOE for energy R&D is the Nuclear Regulatory Commission, which has a FY08 budget of $71 million for nuclear power R&D.[2]

Non-DOE energy research, however, plays a critical role in addressing America's energy needs. DOD is the largest consumer of energy in the nation. Thus, reducing fuel costs is an imperative to the military. Research conducted by the Pentagon spans the gamut from the coal-to-liquid research mentioned above to research in diesel technology that combines high fuel economy with low emissions. NSF programs range from the Energy for Sustainability program (which supports fundamental research and education in energy production, conversion, and storage with a focus on environmentally friendly and renewable sources) to the Solar Energy Initiative (which supports interdisciplinary efforts to address the scientific challenges of highly efficient harvesting, conversion, and storage of solar energy).

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[2] Kei Koizumi, November 4, 2008, email.

The Select Committee members should consider urging the Obama Administration to conduct better analysis of the investments that are being made by other agencies in energy related R&D and to work to better coordinate such efforts across various research agencies. Given the vital importance of energy R&D, it is very important the we have a clear picture of how much federal agencies are spending for specific energy R&D efforts. Similar cross cutting budget analyses has been done by the Office of Management and Budget in areas such as climate change and nanotechnology.

*7. How much private R&D is currently being directed toward development of new energy projects? If, as you state, oil and natural gas production will peak shortly, won't the price of fossil fuel continue to rise and thus incentivize more research into renewable fuels in the private sector?*

Private R&D in energy was approximately $1 billion in FY04, down from just under $5 billion in 1980. To put this in context, according to Professor Daniel Kammen of the University of California-Berkeley, total private sector energy R&D is less than the R&D budgets of individual biotech companies such as Amgen and Genentech.[3]

There does indeed appear to be a correlation between increases in the price of fossil fuels and increases in energy R&D. In fact, over time, the amount that the United States has spent on energy-related R&D corresponds with the rises and falls in annual oil prices.[4] However, this means that when the price drops, we also see a drop in R&D dollars. A stable funding stream is essential to basic research's long-term planning and the retention of talents undergraduates and graduate students who will then go on to solve the energy challenges of the future.

*8. What steps is the University of Michigan taking to improve corporate partnerships? Are there specific actions Congress can take to encourage the further development of such partnerships?*

The University of Michigan is taking innovative steps to ensure a seamless linkage with industry to spur economic growth in our state and beyond. Last fall, we established the Business Engagement Center (BEC) to step up our ability to collaborate with business and community partners. With the goal of helping to revitalize and diversify Michigan's economy, the BEC serves as a single portal that provides "one-stop shopping" for companies of every size. Entrepreneurs can rapidly be connected with leading faculty members who have expertise that overlaps with the needs of their companies as well as with student talent, professional development for employees and research partnerships. The objective of this new model of corporate relations is to make what can often be a large

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[3] Daniel M. Kammen and Gregory F. Nement. "Reversing the Incredible Shrinking Energy R&D Budget," *Issues in Science and Technology*, Fall, 2005, pp. 88.
[4] Homer A. Neal, Tobin L. Smith and Jennifer B. McCormick. Beyond Sputnik: U.S. Science Policy in the 21st Century, The University of Micghian Press, Ann Arbor, 2008.

and complicated campus more user-friendly. In this way U-M can help the transformation to a knowledge-based economy. Together with our Office of Technology Transfer, the BEC also has been pursuing new ways to reward faculty for building companies from the floor up. An example of U-M's progress is comments made by Ed Krause, Ford's Liaison with U-M:

> "Seven years ago, Michigan was one of the more difficult schools to deal with, even for a company as close as Ford. It's the opposite of an entitlement mentality now ... And this is not lost on industry partners. Now I would say that Michigan is actually very much among the leaders, and has a chance to become the leader, as far as innovative ways of working with industry."

First, basic energy research funding must be strengthened. Increases authorized by the America COMPETES Act have yet to materialize. As you know, universities have traditionally been incubators for long-term out-of-the-box ideas – or basic research -- that the private sector by itself often cannot always afford to undertake because the risks may outweigh potential payoffs. Today, universities are looking for solutions to the energy independence challenge from all vantage points – hydrogen research, improved lighting sources, biofuels, energy storage, urban planning, semiconductors, alternative fuel cars, and solar cells to name a few. Providing adequate funding will ensure that companies have a large pool of ideas to select from.

To support the further development of such partnerships over the long-run, the most important thing that Congress can do is support initiatives that help move innovative ideas from the laboratory into a phase that can attract substantial venture investment for new businesses to be establishes and take the idea to the market. As mentioned in my response to Question # 4, ARPA-E is one such initiative that will do just that.

Finally, Discovery Innovation Institutes (DIIs), recommended by the National Academy of Engineering and highlighted in my testimony, would closely link industry, universities and the National Labs to respond to the unique regional needs and capabilities of our nation. For example, a DII for the Intermountain West could focus on the energy needs of a rapidly growing population and activity dispersed over fragile ecosystems with limited water resources but primary energy resources.[5]

*9. If ARPA-E is fully funded and can provide direction for energy research, what current project or offices can be consolidated into ARPA-E to eliminate disorganization that currently exists?*

ARPA-E will be a brand new research agency at DOE that will operate independent of any current project or office. As an agency that fulfills an unmet need, no consolidation would be necessary. ARPA-E can be a critical bridge between the energy needs of our nation and

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[5] "Creating a National energy Research Network: A Step Toward America's Energy Sustainability" (draft). Next Energy Project Working Group, May 1, 2008.

experts at universities and private corporations who could provide the answers to the public. Thus, it would have the autonomy necessary to encourage flexibility and collaboration to solve the immense problems facing the energy sector.

THE SELECT COMMITTEE ON
**ENERGY INDEPENDENCE AND GLOBAL WARMING**

**13 November 2008**

**MEMORANDUM TO THE SELECT COMMITTEE ON ENERGY INDEPENDENCE AND GLOBAL WARMING**

**FROM:** Dr. Jack D. Fellows, Vice President, University Corporation for Atmospheric Research, 1850 Table Mesa Dr., Boulder, Colorado 80303, 303-497-8655, jfellows@ucar.edu

**SUBJECT:** Responses to Committee questions from the 10 Sept 2008 hearing on *Investing in the Future: R&D needs to meet America's Energy and Climate Challenges*

Below are my responses to the Committee's questions. I'm going to answer all these questions from the climate R&D perspective. That is the perspective of my testimony, as well as the weather and climate transition document (TD - http://www.ucar.edu/td/) that was the focal point of my testimony. Thank you for the opportunity to respond. Please feel free to contact me if you have any additional questions.

1. Besides additional federal dollars, what is the single greatest action that Congress can take to stimulate additional climate ~~energy~~ R&D? **Answer:** More important than even federal climate R&D dollars is having the right of leadership in key federal climate positions and effective management tools. The weather and climate community's transition document (TD - http://www.ucar.edu/td/) has an entire section on leadership and management issues (Recommendation 5) and underscores the importance of having the right people in the right places to ensure that our climate R&D investments have the optimal return for our nation. Strong, qualified leaders must be appointed to top policy positions. Most important, we need an experienced and knowledgeable leader coordinating the overall federal effort and that person should report directly to the President. This leader will need to understand that all sectors of the research and operational weather and climate enterprise (public, private, and academic) are needed to address these issues. The Executive Branch offices and federal agencies must also take more leadership in coordinating weather and climate programs, including OMB, OSTP, NOAA, NASA, NSF, USDA, DOE, DOI, DOT, and EPA. The U.S.Global Change Research Program (USGCRP - www.usgcrp.gov) has existed since the late 1980s and has made substantial progress on understanding Earth processes and coordinating the federal agency efforts in this area. This multi-agency effort worked best in the years when there was a strong partnership between the research agencies and OMB/OSTP that supported an effective, integrated program and budget approval process. The TD recommends that the next Administration and the Congress adopt the very best management tools from the USGCRP and Climate Change Science Program's history and create CCSP Version 2.0. The TD lists the needed interagency tools, including:

a. The leader of this effort should report to the President and at a level equivalent to an economic or national security advisor. The leader must have an effective staff, enough of a budget to influence the agency programs in key priority areas, the ability to get outside advice from the broad weather and climate enterprise, and an open and transparent manner of conducting business.
b. OMB/OSTP and agency leaders should be selected to support this critical interagency process and OMB/OSTP staff should be given the authority, resources, and time to support it. OMB, in particular, should examine how it is structured to ensure that the involved agencies are overseen in an effective, integrated fashion. In the past, differences between key OMB leaders have eroded the effectiveness of this interagency process.
c. OMB/OSTP should implement an annual integrated weather and climate program and budget review and submit an integrated program plan and budget to the Congress as part of the President's budget.
d. These programs should be considered national priorities and protected from internal agency budget cuts and tradeoffs. This should be implemented via the normal OMB budget development and passback process.
e. The U.S. Global Change Research Program Act of 1990 may need to be updated to reflect a greater focus on adaptation and to ensure that the critical management approaches mentioned above are followed.

To help develop this leadership capability, the TD partners have solicited community nomination for key weather and climate positions in the next Administration and provided that list to Obama transition teams.

2. <u>With Congress facing a tight budget outlook, where do you propose Congress cuts current spending or raises additional revenue to fund additional research and development?</u>
**Answer:** This is question about national priorities and well above our ability to look across the $1.6 trillion federal budget and programs to make this kind of trade offs. While I do believe we must have a responsible exit strategy from Iraq, we are now spending roughly $9-10 billion per month in that effort. We also found $700 billion for the recent economic bailout that has done very little to date to help this situation. Those appear to be national priorities and somehow the funds were found for these efforts. With more than a quarter of the U.S. gross national product (over $2 trillion) sensitive to weather and climate, our nation's health, safety, economy, environment, transportation systems, and national security continue to be battered by billions of dollars in weather-related damages and losses each year. Mayors, governors, and local decision makers trying to plan for climate change and related weather changes need help. Implementing carbon emission reductions (e.g., cap-and-trade, carbon tax, etc.) or moving to a prosperous carbon-free economy will be inhibited by the lack of weather and climate tools and information (e.g., carbon monitoring, forecasts for green industries, etc.). Substantial uncertainties remain over climate impacts and adaptation feedbacks—feedbacks that may prove very costly to civilization (e.g., the release of carbon frozen in a warming Arctic that will dwarf the human carbon contribution to the atmosphere). Science is key to understanding these impacts and uncertainties, but funding for weather and climate research and operations has been flat or declining for years

due to the budget debates in Washington. Through NASA, NSF, NOAA, and DOE we get promises for increases, but in the end we get declining budgets through continuing resolutions and omnibus bills that have so dominated the federal budget process over the last 3-4 years. Given all of this, I would think that this issue of making our nation more resilient and prepared to face a new world with a different climate (and associated weather changes) would be a clear national priority. Current cap and trade legislation is largely silent about how this foundational science will exist to actually support and monitor the success of this legislation. It is just assuming the science, modeling, computing, and observation will be there. If the declines continue, it will not. This cap and trade legislation sets aside funds through carbon credit auctions for many things, BUT not for the very science that is needed to support these bills. That must be addressed in future bills. See more about this in my response to question #8 below.

3. How does the problem of academic research in severe weather and climate ~~new energy development~~ correlate to the broader problem of the decline of engineering students here in the United States? **Answer:** Like engineering, getting a degree in the sciences associated with weather and climate is extremely demanding with major emphasis on physics and math. Many students decide to follow a career track that is not so dependent on the sciences. Frankly, weather and climate are topics that actually keep kids engaged in the sciences. But, it continues to be difficult to get weather and climate integrated into the K-12 curriculum, exactly where you want to reach kids before they loose interest in the sciences -- typically between 6-8 eighth grade. My own organization (UCAR) has develop a program that teaches K-12 kids around the world to take environmental measurements, share them over the internet, and apply them to local environmental problems facing their communities. This program is called GLOBE and, in my opinion, is producing the environmental leaders of the future. It has an "olympics" called a GLOBE Learning Expedition (GLE) every four years where kids around the world come together to share how they have addressed environmental challenges in their community. Not only do they have the technical skills, but they have the ability to bridge between different cultures through these GLEs. Yet, we struggle each year to keep this program funded and getting it integrated into the classrooms across our country. We need to reach these kids before they drop out of the sciences and in ways that are relevant to their future. All of this is further compounded by declining weather and climate research budgets. We have postdoc programs that truly create the next generation of climate researchers and modelers, but we only have the funds to support a small fraction of the applicants (1 in 10). We need both a way to keep kids in the science pipeline all the way to supporting the very brightest in their advanced studies. I believe this will become increasingly true as we move into a green economy and face the many challenges ahead of us due to a changing climate.

4. How do you suggest Congress avoids "cherry picking" climate science ~~technology~~ that we think will work, rather letting the market figure out the best climate adaptation and mitigation approaches ~~direction for technology development~~? **Answer:** The Congress should continue to fund the basic science and broad operations associated with severe weather and climate. Over the past ~40 years, the federal government has invested in the weather and climate enterprise and we have made substantial progress. This enterprise (public, private, and academic) has developed an effective path to transitioning basic

research and public operations into both public and private services and information. This has been done through many years of community discussions on how best to balance these potential conflicting, but equally important sectors of our enterprise. Much of what needs to be done is making these existing tools and information more relevant at the scales that local and regional decision makers need to ensure their communities with have access to reliable and sustainable future water, food, and energy supplies.

5. Do you support nuclear energy as a greenhouse gas free energy source? What programs are you working on which would advance nuclear technology? **Answer:** In our weather and climate world, we don't work on nuclear technology. That said, nuclear energy will need to be part of the energy solution. I'd like to refer you to an interesting article written by Cal Tech's Dr. Nathan Lewis (http://eands.caltech.edu/articles/LXX2/powering.pdf). This is one of the better comprehensive looks at our national energy problem that I have seen. According to Dr. Lewis's article, humanity's current energy consumption rate is ~13 terawatts. We have ~400 nuclear power plants in the world today. To get the ~10 terawatts we need to stay on the IPCC "business as usual" curve, we'd need ~10,000 of our current 1 gigawatt reactors. That would require us building one reactor somewhere in the world every day for the next 50 years. Plus, there is a fuel problem. There isn't enough uranium and safe plutonium reactors seem a long-distant gleam in the future. So, nuclear energy is an important component to the energy solution, but it has substantial limitations. Dr. Lewis believes the more viable solutions are renewable energies like wind and solar (in combination with hydro, nuclear, etc) – ones that will rely on critically important weather and climate information for sitting, development, and operations.

6. What is the current timeline to deploy the next generation of Earth system observation satellites? What demands has this deployment made on the budget of climate observation programs? **Answer:** Observations from both space and the ground are key to monitoring climate and weather variables and developing climate and weather models. These observations will be essential in monitoring the progress and success of any carbon emission reduction initiative (e.g., cap-and-trade). The National Research Council has produced two community documents that the Congress should strongly support:
   - **Space.** The study entitled *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (http://books.nap.edu/catalog.php?record_id=11820) recommends that: *"The U.S. government, working in concert with the private sector, academe, the public, and its international partners, should renew its investment in Earth-observing systems and restore its leadership in Earth science and applications."* This report is often referred to as the Earth sciences "Decadal Survey." This community report prioritizes the needed satellite observations for the foreseeable future, including seventeen that must be undertaken if we hope to understand and monitor critical environmental issues related to climate change and severe weather.
   - **Ground.** An NRC study, entitled *Observing Weather and Climate From the Ground Up, A Nationwide Network of Networks* will recommend a national public-private partnership to renew our strategic investment in ground-based, storm-scale observing systems that are crucial to the prediction of extreme weather, the health and safety of our citizenry, and the impacts of local climate and climate variability. This report is

scheduled to be released by the NRC in November-December 2008 and we anticipate it will include ground-based observing systems that are essential to severe weather prediction and modeling (e.g., radar technologies).

With respect to a timeline, the seventeen Decadal Survey missions are deployed over the period 2008-2020. There is flexibility in this overall schedule given budget constraints and technical challenges on some of the missions. However, the deployment has already been threatened by budget constraints. Only a very small fraction of even the mission planned for the 2010-2014 are in any agency budget (roughly ¼ to1/3 of what is needed) and NASA's science budget is already fully stressed by other agency priorities. In addition, even the operational satellite systems like NPOESS and GOES are underfunded or impacted by constrained budgets. The full NPOESS and GOES constellation are not funded and a critical climate sensor (advanced GOES sounder) was eliminated recently in budget drills. The TD recommends (with specific budget amounts) that both the Decadal Survey missions be funded and these NPOESS/GOES cuts restored. The TD recommends that one of the first things the new USGCRP does is to look at this issue of observations and develop an integrated space-based and ground-based federal weather and climate observations strategy that includes both operational and research systems.

For years, the hope has been that NASA and NOAA would develop a comprehensive strategy to transition research satellites into operational NOAA weather and climate satellites. To date, this has not happened effectively for a variety of reasons, including budget constraints and agency mission differences. The issue is too important to leave to chance or agency culture. Leaders must be chosen for these agencies who will support these important transition issues or, perhaps, the functions need to be folded into some kind of Earth System Agency. There have been proposals to create a national climate service or an Earth system science agency (e.g., combining NOAA and the USGS—http://www.sciencemag.org/cgi/content/full/321/5885/44) or make changes to the interagency process (e.g., S.2037, S.2355, H.R.906, etc.). There are many options that should be examined (e.g., run within an agency, led by an agency, led by an interagency federation, run by a non-profit with federal sponsorship, etc.). These are bold and creative ideas that have strong merit and should be seriously considered—provided they don't divert attention from the real problem of consistent underfunding of these weather and climate research and operational programs. Our community has provided feedback on the merits and shortcomings of these proposals and would welcome the opportunity to provide additional insight on this issue to the Congress. The United States has also played a significant leadership role in developing the Global Earth Observing System of Systems though the international Group on Earth Observations or GEO (http://www.earthobservations.org/geoss.shtml). International cooperation on these critical global observations is extremely important, and U.S. leaders must continue to be involved and lead in the GEO process.

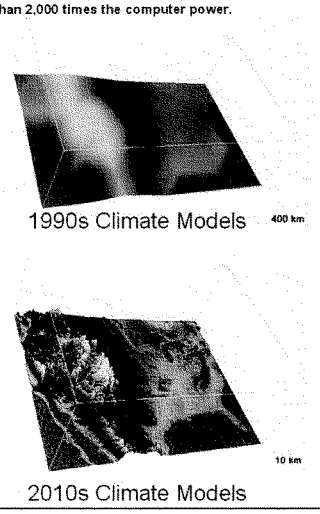
The weather and climate community is also working with NOAA to look at several possible options for a national climate service. I'd like to commend NOAA for bringing this issue up and soliciting external community ideas on how a national climate service should be structured. Perhaps the Committee might ask NOAA about the ideas coming

out of this community exploration.

7. I know that UCAR is working towards refining the computing of systems that run climate modeling. What is the current resolution of climate models that UCAR is simulating and how much extra funding is necessary to acquire computing power for the next step?

**Answer:** Policy debates and emerging legislative initiatives are calling for global change research that is more relevant to decision makers. However, creating integrated atmosphere-ocean-land predictions that are relevant to local and regional decision making is hampered by the lack of key Earth observations, computer resources, and ways to merge science output with management tools in water, agriculture, transportation, and other sectors. There has been an erosion of key observational, computation, and science programs at NASA, NOAA, and NSF at precisely the time when they are most needed. In addition, these science programs will be crucial in developing and monitoring the success of current and proposed climate policy initiatives, such as carbon cap-and-trade systems or a carbon tax. The figure to the right show where we have been and where we need to go in climate modeling. Our models are still functioning with resolutions in the 100s of kilometers when we need to be in the 10s of kilometers to address the needs of local and regional decision maker needs. You can see how these models at the 100s of kilometers don't even resolve critical features as big as the Rocky Mountains. The TD recommends roughly $750 million be invested in climate-related computation over the next five years. We believe this is a realistic investment of what will probably be a total of over $1 billion eventually. We do not support a single climate modeling or climate computation center. Our nation has four key climate modeling groups (NSF's National Center for Atmospheric Research, NOAA's Geophysical Fluid Dynamics Lab, NASA's Goddard Institute for Space Studies, and DOE lab contributions to both climate modeling and computing). These groups serve distinctly different communities and purposes (e.g., NCAR serves the broad university community and GFDL works with NOAA on application activities). Our nation has been well served by having several groups because: (1) history shows that an average across several models outperforms a single model, (2) competition between groups spawns creative innovation, (3) modeling groups can take very different and equally important approaches, and (4) having multiple models and entry points permits more people to participate in model development. Today, it takes roughly $20 million per year to support a cutting-edge climate modeling group (that sum does not include observations or computing). All these groups will need access to computational resources that can be

These two images illustrate the importance of high-resolution models. The top image is an early climate model running at 400 kilometer resolution and the bottom at 10 kilometers. The sharper image produces more accurate analysis, but requires more than 2,000 times the computer power.



"tuned" and dedicated to very specific climate modeling efforts. Some groups will continue to develop critical high-resolution global climate models, while others will work at "nesting" advanced weather models into climate models to provide very specific local and regional information about climate change. Some efforts will be for research and others will have an operational focus. All of these approaches are extremely important, but will have very different computational needs and environments. A general petascale computational center designed for all scientific disciplines will not effectively support a national climate modeling effort. We strongly recommend that the national climate/weather computation and modeling effort be coordinated and managed within a revised USGCRP-like management structure, including a mechanism to provide guidance from the climate modeling and user communities.

8. How would you prioritize the needed investments you outline in response to question two in your testimony? If you were only to get half of your requested additional $9 billion, how would you scale down your request? **Answer:** Our nation is still going to need critical research, modeling, computing, and observational capabilities and advancements if we are going to tackle the challenges laid out in the TD:

    a. A nation's whose health, safety, economy, environment, transportation systems, and national security continues to be battered by billions of dollars in weather-related damages and losses each year,
    b. Mayors, governors, and local decision makers struggling to plan for climate change and related weather changes without key information,
    c. Implementing carbon emission reductions (e.g., cap-and-trade, carbon tax, etc.) or moving to a prosperous carbon-free economy without key weather and climate tools and information (e.g., carbon monitoring, forecasts for green industries, etc.), and
    d. Substantial uncertainties remaining over climate impacts and adaptation feedbacks—feedbacks that may prove very costly to civilization (e.g., the release of carbon frozen in a warming Arctic that will dwarf the human carbon contribution to the atmosphere).

    If we can get some policy direction on which of these the Congress believes we can sacrifice, than the weather and climate enterprise can help restructure the program to fit a budget the Congress feels is appropriate. Perhaps that could be a directive to the new USGCRP-like federal interagency committee. The TD does call for a mechanism to evaluate whether we are making progress toward creating and using knowledge that can help society adapt to climate change and severe weather. One approach to this evaluation mechanism and one that could help on setting priorities would be to establish a committee that will advise, assess, and report on progress toward the recommendations laid out in the TD and on their impacts on national policy. This high-level advisory committee should include representatives from across the weather and climate enterprise, including the public, private, and academic sectors. As mentioned above, some of these investments could be paid for by the "climate funds" being created in various climate and energy policy legislation (e.g., from the auction of carbon offsets).

9. How extensive of a partnership does UCAR currently have with NASA to gather observation data? **Answer:** The UCAR community gets involved in NASA observation programs via the community proposal solicitation process. NASA decides on observational areas they want to pursue and asks for the community ideas through the competitive proposal process. These solicitations are informed by community input like the NRC Decadal Survey mentioned in question #6. These missions are some times mixes between what the community wants and what the NASA science centers want. So, the process involves extensive negotiations and takes quite some time to accomplish. Within NASA, the missions from the various NASA science disciples (earth, heliophysics, planets, and astrophysics) all compete for resources, and they also compete for resources with NASA human space flight and aeronautics programs. So, it is a pretty complicated stage with many different constraints. What is really needed is a much higher examination of what research and operational weather and climate observations are needed and how best to implement them. I believe that can only take place at the White House/OSTP level and with an effective management approach to really oversee its development and implementation. That review would include both space-based and ground-based observation and involve many different agencies, including NASA, NSF, NOAA, DOE, USDA, EPA, and DOI. This is a key recommendation of the TD and is mentioned in question #6 above. UCAR has been involved in several NASA supported missions like HIRDLS (http://www.eos.ucar.edu/hirdls/). It has also initiated high-risk and novel observations systems like COSMIC (http://www.cosmic.ucar.edu/) that had some relatively small NASA support, but were also supported by other agencies like NSF, NOAA, and the Air Force. COSMIC has turned out to be an exceptional data set for weather, space weather, and climate research and operations, but probably would not have happened without UCAR's leadership (and some bold NSF program managers). At the time UCAR began discussing COSMIC, it just didn't seem to fit in any agency's plans and UCAR took enormous financial risks because it thought this observational system was a tremendous value to the federal weather and climate community.

10. What weather and climate programs that currently exist could be merged or abolished with the advent of a "CCSP Version 2.0?" How can you ensure that the fewest cents per dollar is spent on overhead and management and the largest share contributes to actual research? **Answer:** Most of us in the non-federal weather and climate research community don't fully understand what is in the current CCSP. We are not part of the internal federal interagency working groups that develop and coordinate the 13 federal agency programs that make up the CCSP and the detail we see is quite thin. So, it is really hard to say what can be merged or abolished in a CCSP Version 2.0. In addition, the CCSP does not include the weather and climate operational programs, like NOAA weather and climate satellites. So an entirely different look is needed in these programs that I mentioned in my response to question #1. In the early years of the USGCRP (predecessor of the CCSP), it did not focus on adaptation or mitigation oriented research. In recent years, the CCSP started to look at adaptation issues and those are some of the key issue our nation will be facing for the foreseeable future. Regardless of what we do about limiting carbon mission in the next 5-10 years, we are committed to some level of warming that will impact how we plan for water, food, and

energy production and use. The CCSP Version 2.0 must establish the appropriate balance between this adaptation focus and other research needs in the program and it needs a better mechanism to get user inputs. To me, that balance needs to come from the key leaders in the Congress working closely with whom ever becomes the key climate leader in the Obama Administration. With respect to getting the best return on this investment and mentioned in my response to question #8, the TD does call for a mechanism to evaluate whether we are making progress toward creating and using knowledge that can help society adapt to climate change and severe weather, including a committee that could assess whether these investments are being made in the best interest of the nation. Some of the ideas being explored in the national climate service project mentioned in my response to question #6 include putting some of these activities in non-profits outside the government that have more nimble and responsive abilities to develop partnerships and gather advice. Many of the safeguards put into government contracting and advisory mechanisms have created extreme barriers to efficient operations and are wasting millions of taxpayer dollars each year. Our systems now lacks any decent notion of trusting and cooperative partnerships between the federal government and organizations and appears at times to be just fine spending millions of dollars in oversight mechanisms to avoid the possibility of someone stealing $100. In my 11-year tenure at UCAR, we have overseen hundreds of millions of federal research dollars. We have had a few hundred dollars stolen by individuals that were caught by our own internal processes and are now serving time in jail. Yet, a huge amount of our time is devoted to responding to federal oversight requirements. For those of us who are really trying to help our nation, this is very discouraging. So, much more funding could be going to the actual research than into these activities.