Commencement Address
Pennsylvania State University Graduate School
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Dr. Raymond L. Orbach
Director, Office of Science
U.S. Department of Energy

Provost Erickson, Dean Pell, distinguished guests, graduates: I am delighted to be here with you this afternoon to honor the 399 master's and doctoral degree recipients of this distinguished institution.

First of all, let me say congratulations to each and every one of you on a job well done!

I know that there are a lot of you proud mothers out there today. To you, I say, Happy Mother's Day!

I also want to say a word of congratulations to your younger colleagues over at State College Area High School. Two weeks ago, I was with their team in Washington, DC, when they were victorious at the finals of the Department of Energy's National Science Bowl. This was a rigorous science contest involving some 65 high school teams from around the country. In winning the final round of eight, State College Area High School defeated the four-time champion, Thomas Jefferson High School for Science and Technology of Alexandria, VA. You should be proud of your educational environment, and of these remarkable young men and women, who will be your successors.

You are blessed to be receiving your degrees from one of the nation's great research universities. It is also one of the great examples of what federal support for education and for research and development can achieve. Penn State was one of the first federally supported institutions of higher learning, when it became a land grant college under President Abraham Lincoln during the Civil War. You have a strong engineering tradition that reaches back to the nineteenth century. You were first university to offer a bachelor's degree in "fuel science" as long ago the 1930s – long before there was a U.S. Department of Energy! Back in the 1950s, Penn State was also the first university to own and operate a nuclear reactor, which is still operational today. You are the heirs to an impressive tradition.

For as long as Penn State has been training engineers and scientists, research and development in science and technology have been driving U.S. economic growth and prosperity. Nobel Laureate Robert Solow found that as much as seven-eighths of our growth in per capita income in the United States between 1909 and 1987 was caused by technological innovation.

There is every reason to believe this relationship will define the 21st century.

On January 31st of this year, the President of the United States announced his American Competitiveness Initiative in a remarkable State of the Union Address. The President has committed to a doubling of federal funding for basic research in the physical sciences over the next ten years. The President's budget also includes millions more for support of science, technology, math, and engineering education. Under this initiative, the budget request for the Department of Energy's Office of Science, the office I direct, increases by over half a billion dollars to $4.1 billion in FY 2007. That's an increase of 14%.

At the same time that the President announced his Competitiveness Initiative, he announced the Advanced Energy Initiative, providing still more funding for accelerated research in the field of energy.

Today's problem, our problem, is energy. Once thought to be cheap, unlimited, and freely available to our nation, today, all three aspects are in trouble. And so is our globe. Availability of sufficient environmentally friendly energy sources to meet the needs not only of our country, but also of a rapidly growing and developing world population, is the most pressing problem our civilization has ever faced.

The world's energy appetite will at least double, if not triple, by the end of this century. The environmental consequences can be catastrophic. Greenhouse gases are accumulating in our atmosphere at an alarming rate. For CO_2 alone, the atmospheric concentration is approaching 400 parts per million (ppm), 40% higher than when fossil fuels began to be burned, and may exceed 1,000 ppm by the end of this century if no limiting measures are taken. To give you an idea of how difficult a problem this is, pick a value for an acceptable CO_2 concentration: 550 ppm, 650 ppm, 750 ppm. . . . It really doesn't matter. To stabilize at even these very high (and alarming) concentrations, and not go higher, the amount of carbon-*free* energy required at the end of this century will more or less equal the earth's total energy consumption at the beginning of this century.

A global search for massive amounts of carbon-free energy will require transformational changes and disruptive technologies in order to provide clean reliable economic solutions. We cannot fulfill the world's energy appetite with current prospects or incremental improvement to existing technologies. The transistor was not discovered by perfecting the vacuum tube.

There are three points of departure:

1. Increase conservation, largely through increased efficiency.
2. Greatly diversify energy sources and create infrastructures for them.
3. Create and implement long-term (decades to century) energy visions and strategies.

More simply, increase conservation/efficiency and increase production. We must use less energy and produce more of it.

1. Increase conservation, largely through increased efficiency.

The United States is a prime example. Electricity production uses about 40% of primary energy, and of this amount, about 70% is waste or rejected energy. Overall, about 60% of United States primary energy is lost in waste or rejected heat. With less than 5% of the world's population, the United States consumes about 25% of the world's energy (but produces only about 18%). Even if the United States were to be 100% efficient in the use of energy, this would amount to but 15% of the world energy consumption, not negligible, but far less than the doubling to tripling of the world's energy generation required by the end of this century. Nevertheless, when amplified globally, more efficient use of energy will play a major role.

2. Greatly diversifying energy sources and create infrastructures for them.

There are at least four transformational technologies that possess the potential for significant amounts of clean reliable economic energy: a) solar energy utilization; b) advanced proliferation-resistant nuclear energy systems; c) fusion power; and d) biologically derived fuels.

<u>a. solar energy utilization:</u> i. Solar-to-electric, ii. Solar-to-fuels, iii. Solar-to-thermal conversions. Sunlight provides by far the largest of all carbon-neutral energy sources. More energy from sunlight strikes the earth in one hour than all the energy consumed on our planet in a year. Yet solar electricity provides less than 0.1% of the total electricity supply, and renewable biomass (sustainably grown) provides less than 0.1% of all total energy consumed.

i. For solar-to-electric conversion, novel approaches to exploiting new technologies (thin films, organic semiconductors, dye sensitization, and quantum dots) offer fascinating opportunities for cheaper, more efficient, longer lasting systems.

ii. With respect to solar-to-fuels, application of revolutionary advances in biotechnology to the design of plants and organisms can lead to more efficient energy conversion "machines." Designs of highly efficient, artificial, molecular-level energy conversion machines, exploiting the principles of natural photosynthesis, promise substantial energy production opportunities.

iii. In the area of solar-to-thermal conversion, solar radiation as a source of heat, using high-efficiency thermoelectric and thermal photovoltaic converters coupled to solar concentrators, have the potential to generate electricity at converter efficiencies of 25% to 35%. Chemical conversion sequences can convert focused solar thermal energy into chemical fuel.

<u>b. advanced proliferation-resistant nuclear energy systems.</u> Current "once-through" nuclear reactor policy leaves spent fuel rods with long-term heat loads and radioactive decay. Disposal of light water reactor waste must be included as a cost of energy generation from nuclear fission. Once-through spent fuel, subjected to chemical separation, offers many potential options for managing its constituent parts: transmutation of transuranics in fast-spectrum reactors; reducing heat load, toxicity, and

long decay times by two orders of magnitude; and the stabilization of fission products in robust waste forms. These reductions sharply reduce repository requirements, allowing expansion of nuclear energy generation sufficient to meet a significant percentage of carbon-free world energy requirements.

<u>c. fusion power.</u> In less than two weeks, I shall initial an international agreement in Brussels to build and operate the International Thermonuclear Experimental Experimental Reactor, or ITER. This is the first self-standing, truly international, large-scale scientific research effort in the history of the world. The seven parties to the agreement represent more than half of the world's population. Fusion energy uses deuterium from water, and lithium to create tritium, fusing deuterium and tritium into helium and a fast (14 MeV) neutron. Deuterium and lithium are abundant and cheap, the helium will escape from the earth's gravity, and the energy of the neutron will generate electricity or produce hydrogen.

This process is the same as that which powers our sun, and promises unlimited safe clean energy for the world. In a conservative estimate, about a third of today's global energy usage can be generated with fusion power reactors by the end of this century.

<u>d. biologically derived fuels.</u> Two examples are: i. Biofuels derived from plant cell walls, otherwise knows as cellulose ethanol; and ii. hydrogen produced from water using energy from the sun, known as biophotolytic hydrogen.

i. The long-term goal of cellulose ethanol would integrate bioprocessing, now three steps (breakdown of raw biomass using heat and chemicals, use of enzymes to break down plant cell wall materials into simple sugars, and fermentations of the sugars into ethanol using microbes), into one. This requires the development of genetically modified, multidimensional microbes or a stable mixed culture of microbes capable of carrying out all biologically mediated transformation needed for complete conversion of biomass to ethanol.

ii. Under certain conditions, green algae and cyanobacteria can use energy from the sun to split water and generate hydrogen. Research to understand and develop predictive models of hydrogenase (the enzyme that cleaves water to produce hydrogen) structure and function, genetic regulatory and biochemical networks, and eventually entire microbes, can lead to an "ideal" microbe to use in hydrogen bioreactors, or the "ideal" enzyme-catalyst to use in bio-inspired nanostructures for hydrogen production.

If we can meet the technological challenge of producing biofuels from biomass cost-effectively on a large scale, a competition for which we shall announce this summer, we will stand on the threshold of a whole new agriculturally based fuel economy in the United States. We have enormous expanses of arable and potentially arable land in this country. A new fuel economy based on biomass would mean millions of American farmers growing crops for fuel feedstock. The billions of dollars that we now send out of the country to buy imported oil would be recycled at home, creating new jobs and opportunities for our own citizens. This is the way that science can transform a great problem into a great opportunity and provide new capacities to generate wealth that raise our citizens' standard of living.

These four examples of transformational change and disruptive technologies, if successful, will reduce the gap between energy demand and production, while at the same time stabilizing atmospheric CO_2 at levels the earth can live with. The combination of conservation and clean reliable energy production can lead to a sustainable, abundant energy future for our world.

Some of you will have the opportunity to work on these new technologies and contribute directly to the scientific and engineering and agricultural breakthroughs that will make renewable energy sources cost-effective. Others of you will have the opportunity to work in the private sector to bring these new sources of energy to market. All of you--all of us--will have the chance as citizens to participate in the great ongoing decision-making process that will help guide our nation, and our world, toward a more secure energy future. The cause of finding new ways to produce energy, while protecting our environment, is a great cause with the capacity to unite us as a nation. It also is a cause that will call forth the best from us, imaginatively and intellectually. Let us embrace this new challenge. You are blessed with many talents. Let us use our talents together to help create a more secure world for ourselves, our children, and our grandchildren.

Thank you, congratulations, and Godspeed.