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# RENEWABLE ENERGY TECHNOLOGIES—RESEARCH DIRECTIONS, INVESTMENT OPPORTUNITIES, AND CHALLENGES TO COMMERCIAL APPLICATION IN THE UNITED STATES AND THE DEVELOPING WORLD

## FIELD HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED NINTH CONGRESS

SECOND SESSION

AUGUST 2, 2006

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# CONTENTS

**August 2, 2006**


| | Page |
|---|---|
| Witness List | 2 |
| Hearing Charter | 3 |

**Opening Statements**

| | |
|---|---|
| Statement by Representative Judy Biggert, Chairman, Subcommittee on Energy, Committee on Science, U.S. House of Representatives | 10 |
| Written Statement | 11 |
| Statement by Representative Michael M. Honda, Ranking Minority Member, Subcommittee on Energy, Committee on Science, U.S. House of Representatives | 12 |
| Written Statement | 14 |

**Witnesses:**

| | |
|---|---|
| Dr. Steven Chu, Director, Lawrence Berkeley National Laboratory; 1997 Nobel Prize in Physics | |
| Oral Statement | 16 |
| Written Statement | 19 |
| Biography | 23 |
| Dr. Arno A. Penzias, Venture Partner, New Enterprise Associates, Palo Alto, California; 1978 Nobel Prize in Physics | |
| Oral Statement | 24 |
| Written Statement | 26 |
| Biography | 28 |
| Mr. Christian B. Larsen, Vice President for Generation, Electric Power Research Institute, Palo Alto, California | |
| Oral Statement | 29 |
| Written Statement | 30 |
| Biography | 40 |
| Financial Disclosure | 41 |
| Mr. David Pearce, President and CEO, Miasolé, Santa Clara, California | |
| Oral Statement | 42 |
| Written Statement | 44 |
| Biography | 56 |
| Mr. Ron Swenson, Co-founder, ElectroRoof | |
| Oral Statement | 56 |
| Written Statement | 58 |
| Discussion | 78 |

# RENEWABLE ENERGY TECHNOLOGIES—RESEARCH DIRECTIONS, INVESTMENT OPPORTUNITIES, AND CHALLENGES TO COMMERCIAL APPLICATION IN THE UNITED STATES AND THE DEVELOPING WORLD

**WEDNESDAY, AUGUST 2, 2006**

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
*Washington, DC.*

The Subcommittee met, pursuant to call, at 12:30 p.m., in the Council Chambers, San Jose City Hall, 200 East Santa Clara Street, San Jose, California, Hon. Judy Biggert [Chairman of the Subcommittee] presiding.

**COMMITTEE ON SCIENCE**
**U.S. HOUSE OF REPRESENTATIVES**

***Renewable Energy Technologies – Research Directions, Investment Opportunities, and Challenges to Commercial Application in the United States and the Developing World***

Wednesday August 2, 2006

**12:30pm - 2:30pm**
**San Jose City Hall**
**200 East Santa Clara Street**
**San Jose, CA 95113**

**Witness List**

**Dr. Steven Chu**
Director of the Lawrence Berkeley National Laboratory

**Dr. Arno Penzias**
Venture Partner with New Enterprise Associates in Palo Alto, CA

**Mr. Christian Larsen**
Vice President for Generation for the Electric Power Research Institute in Palo Alto, CA

**Mr. David Pearce**
President and CEO of Miasolé, a Santa Clara, CA

**Mr. Ron Swenson**
co-founder of ElectroRoof, and EcoSage

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FIELD HEARING CHARTER

# SUBCOMMITTEE ENERGY
# COMMITTEE ON SCIENCE
# U.S. HOUSE OF REPRESENTATIVES

# Renewable Energy Technologies—Research Directions, Investment Opportunities, and Challenges to Commercial Application in the United States and the Developing World

WEDNESDAY, AUGUST 2, 2006
12:30 P.M.–2:30 P.M.
SAN JOSE CITY HALL
200 EAST SANTA CLARA STREET
SAN JOSE, CALIFORNIA 95113

**1. Purpose**

On August 2, 2006, the Subcommittee on Energy of the House Committee on Science will hold a field hearing on renewable energy technologies.

**2. Witnesses**

- **Dr. Steven Chu** is the Director of the Lawrence Berkeley National Laboratory and a 1997 Nobel Prize winner in Physics. He is currently spearheading a new Laboratory research initiative focused on solar energy.
- **Dr. Arno Penzias** is a Venture Partner with New Enterprise Associates in Palo Alto, CA. While at Bell Laboratories, he won the Nobel Prize for Physics in 1978. Today he is a venture capitalist with interests in renewable energy technologies.
- **Mr. Christian Larsen** is Vice President for Generation for the Electric Power Research Institute in Palo Alto, CA. His division provides data on cost and performance analyses and for renewable, distributed, and hydropower energy generation technologies to the electricity industry.
- **Mr. David Pearce** is President and CEO of Miasolé, a Santa Clara, CA based company that manufactures industrial-scale solar products using thin film solar cell technology developed in Department of Energy national laboratories.
- **Mr. Ron Swenson** is co-founder of ElectroRoof, a solar equipment installation company, and EcoSage, an educational services company developing a program to build solar-powered satellite teaching centers in remote areas of the world in conjunction with solar education programs in schools.

**3. Overarching Questions**

The hearing will address the following questions:

1. What is the current state of adoption of renewable energy technologies in the United States? What factors are limiting the rate of adoption of renewable energy technologies?
2. What is the outlook for potential improvement in market penetration of renewable energy technologies? What are the main research efforts that could improve that outlook?
3. What should the Federal Government be doing (or not doing) to encourage the commercialization of, and demand for, new renewable energy technologies? How well aligned are the Department of Energy's activities with what the investment community is doing?

4. What opportunities and challenges exist for the sale and use of renewable energy generation in developing countries? How do these opportunities and challenges differ from those in developed countries?

**4. Brief Overview**

Renewable energy could significantly reduce the environmental impact of energy production, and in most cases it is produced domestically (although some of the related technology may be imported). The United States has only two percent of the world's oil reserves and three percent of the world's natural gas reserves, while U.S. renewable energy resources are vast and largely untapped. Renewable energy can reduce the demand for imported energy, reducing costs and decreasing the variability of energy prices.

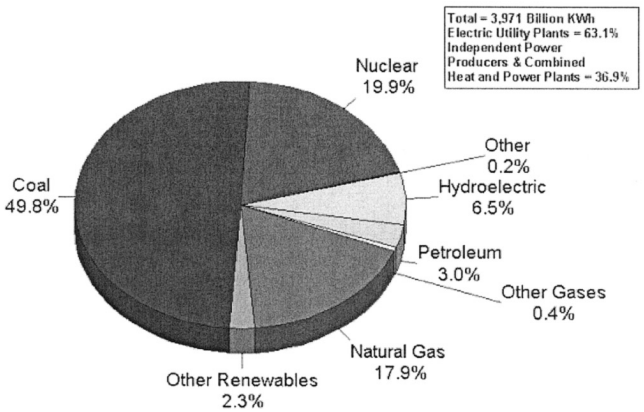
In addition, some renewable energy technologies have other unique advantages. For example, solar energy, while difficult to store, generally follows the changes in demand during the day: its peak output is in the middle of the day, about when air conditioning and other demands also peak. Because utilities tend to use their least efficient (and often most polluting) plants at peak load (they want to run them as little as possible), energy market experts say that small reductions in peak demand can result in very large reductions in price and emissions.

**5. Background**

*Current State of Renewable Energy*

In 2004, the United States consumed nearly four trillion kilowatt hours (KWh) of electricity.[1] Of that total, 6.5 percent came from hydroelectric power plants and only 2.3 percent came from all other renewable energy resources combined, including geothermal, solar thermal, photovoltaic, wind, ethanol and other biomass sources. Given the large number of resources that are added to reach this value of 2.3 percent, the total installation of each type is quite small. The total U.S. installation of solar electric generation, for example, was only 340 MW peak,[2] and the output of that capacity was a negligible fraction of the total electricity consumed nationwide that year. (See Figure 1.)

**Figure 1. U.S. Electric Power Industry Net Generation, 2004**




Note: Conventional hydroelectric power and hydroelectric pumped storage facility production minus energy used for pumping.

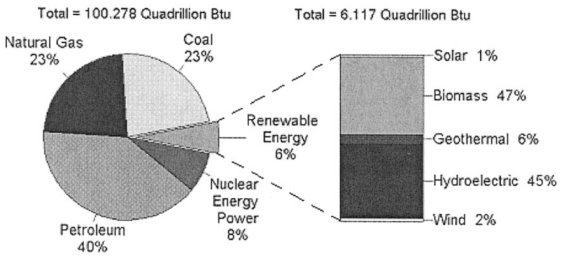
**Source:** Energy Information Administration, Electric Power Annual 2004 Edition

[1] See *http://www.eia.doe.gov/cneaf/electricity/epa/figes2.html*

[2] Solar Energy Industries Association: *Our Solar Power Future—The U.S. Photovoltaics Industry Roadmap Through 2030 and Beyond.* Peak wattage is the output of energy when sunlight conditions are favorable; most solar devices can operate during cloudy conditions at reduced output.

Renewable energy sources also play a small role when compared to the overall U.S. domestic energy consumption, including transportation. Energy from renewable sources constituted six percent of all energy used in the U.S. in 2004, with biomass and hydroelectric power making up the bulk of that total. Wind energy accounted for two percent and solar energy accounted for just one percent of all renewable energy used that year. (See Figure 2.)

**Figure 2. The Role of Renewable Energy Consumption in the Nation's Energy Supply, 2004**




**Source:** Energy Information Administration Renewable Energy Annual 2004 Edition
http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html

*Projected Growth in Total Energy Usage by 2030*

According to the Energy Information Administration (EIA), total U.S. energy use will increase by about 27 percent from 2004 to 2025, or about 1.2 percent per year. Oil demand is projected to grow at about the same rate, by 26 percent, or around 1.1 percent per year; but natural gas use is expected to grow by only 20 percent, or around 0.7 percent per year. Electricity demand is forecast to grow faster than overall energy demand, by 1.6 percent per year, or a growth of 40 percent to 2025. Broken down, electricity demand is expected to grow by 75 percent by 2030 in the commercial sector (due to rapid growth in the service industries), by 47 percent in the residential sector, and by 24 percent in the industrial sector. These growth rates assume that some efficiency gains will be realized in both the residential and commercial sectors as a result of new standards in the Energy Policy Act of 2005 and higher energy prices that prompt more investment in energy-efficient equipment.[3]

In electricity generation, the natural gas share of total production is projected to increase from 18 percent in 2004 to 22 percent around 2020, before falling to 17 percent in 2030. The coal share is projected to decline slightly, from 50 percent in 2004 to 49 percent in 2020, before increasing to 57 percent in 2030. Nuclear electricity is projected go grow by 10 percent over the period, or about one-half percent per year. (Very little oil is used for electricity production.) Under this scenario, emissions of carbon dioxide are projected to rise by 29 percent.

Projected growth rates for renewable energy, in contrast, are relatively high, but because renewable energy is a small part of the mix, the high growth rates projected still result in a relatively small contribution to the mix. Ethanol demand is projected to rise over 300 percent, or about five percent per year; after this increase ethanol will constitute about five percent of the total gasoline demand. Photovoltaic solar generation is projected to rise 26 percent per year in the utility sector, and 10 percent for electricity that is not sold into the grid; however, EIA projects that the percentage of solar photovoltaic power supplied to the grid would still be far less than one percent of the total supply by 2025.

*Potential for Renewable Energy*

Renewable energy industry representatives and other advocates, unsurprisingly, argue that the potential is much greater and the prospects much better for renewable energy than EIA predicts.[4] Critics of EIA forecasts point out that EIA is limited by its assumptions: EIA forecasts assume no changes in current policy and a rate

[3] Energy Information Administration: Annual Energy Outlook 2006

[4] This is true of other industries as well. The nuclear industry also believes that EIA's forecasts do not reflect the prospects for nuclear. However, it is worth noting that EIA has little choice but to assume current policy will continue.

of technological improvement that is unaffected by the level of research and development (R&D) investment. Critics note that changes to these assumptions would produce different results. They also note that EIA's models do not allow for market penetration of technology if its output price is not competitive, even if other attributes are more important in niche markets. For example, solar energy has made inroads in applications where tying to the grid is costly, such as remote or portable power supplies.

Given these limitations and their perspective on the current state of the technology, the Solar Energy Industries Association's U.S. Photovoltaic Industry Roadmap projects that installed peak solar electric generation can increase to 200,000 megawatts (MW) by 2030, up from only 340 MW in 2004, with the industry installing 19,000 MW of new generation per year.[5] In this case, solar power would be a substantial share of U.S. peak generating capacity. (For comparison, 2004 installed capacity for coal was about 335,000 MW; however, solar needs a larger capacity to achieve the same total annual output of kilowatt hours, since its output is only during the day.)

Others analysts depict the need to ramp up solar energy use as a matter of physical necessity if the U.S. is to meet overall demand. For example, Dr. Nathan Lewis, of the California Institute of Technology, has performed an analysis of the potential generating capacity that different renewable energy sources could supply in hopes of meeting the worldwide demand of 28 terawatts (TW) expected by 2050 and 40 TW by the end of the century.[6] (A terawatt equals one billion kilowatts.) According to his findings, hydroelectric power has a technically feasible potential of 1.5 TW, onshore geothermal power could produce approximately 11 TW per year until the wells "run out of steam," (projected to be five years for the average well.) U.S. land-based wind production could produce about 0.5 TW, and biomass may produce five to seven TW. He concludes that solar energy, with a potential of 120,000 TW and a practical capacity of around 600 TW worldwide, is the only renewable resource that could single-handedly meet not just U.S. electricity needs, but could power the entire globe. Lewis emphasizes that his analysis is an accounting of technical potential, not necessarily what is practical based on price without significant breakthroughs in technology and deployment patterns.

*U.S. Actions in International Perspective*

Renewable energy is a growth industry around the world. However, the United States has not been investing as heavily as other countries, and has been losing market share in many renewable industries, especially in the solar power industry. Since 1996, the U.S. market share in the solar industry dropped from 44 percent of the world market to 13 percent in 2003. In 2003, the U.S. Government spent $139 million for research, development, demonstration, and commercial application and other incentives; in the same year Japan spent more than $200 million and Germany provided more than $750 million in low-cost financing for solar photovoltaic projects. Germany and Japan each had domestic photovoltaic industries that employed more than 10,000 people in 2003, while in the same year the United States photovoltaics industry employed only 2,000 people.

*Current Federal Activities in Energy Efficiency and Renewable Energy R&D*

In the State of the Union address, the President announced the Advanced Energy Initiative, which calls for greater federal investment in research on coal, nuclear and renewable energy and in energy efficiency. For renewable energy, the initiative includes increases for R&D on biomass, solar and wind energy, and batteries for energy storage (especially targeted at high-mileage plug-in hybrid electric cars). The President also asked for large increases in hydrogen research, a fuel that must be derived from other sources, including potentially from renewable energy sources.

House and Senate appropriations bills for fiscal year (FY07 have included most of the requested funds for key renewable energy programs, including solar energy and biomass. The House-passed bill includes the requested increases of 65 percent for biomass R&D and 79 percent for solar energy R&D. The full Senate has not yet voted on FY07 appropriations, but the Senate Appropriations Committee also approved large increases for biomass (more than doubling funding to $213 million), and solar energy (up 79 percent to $148 million). In addition, the Senate Committee mark would preserve the geothermal R&D and hydropower R&D programs ($23 million and $4 million, respectively), which the Administration and the House have proposed to eliminate. The Senate mark would also sustain the wind energy program at the FY06 funding level of $39 million. (See table below.)

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[5] Op cit., *Our Solar Power Future*

[6] *http://nsl.caltech.edu/energy.ppt*

**Federal Funding for Energy Efficiency and Renewable Energy R&D**

| | FY 06 Enacted | FY07 Request | FY07 House | House v. Enacted | FY07 Senate Committee Mark | Senate mark v. Enacted |
|---|---|---|---|---|---|---|
| Efficiency and Renewable R&D | 530 | 670 | **730** | *200* | **994** | *464* |
| *- Hydrogen Technology* | *156* | *196* | ***196*** | *40* | ***190*** | *34* |
| *- Biomass and Biorefinery Sys.* | *91* | *150* | ***150*** | *59* | ***213*** | *122* |
| *- Solar Energy* | *83* | *148* | ***148*** | *65* | ***148*** | *65* |
| *- Wind Energy* | *39* | *44* | ***44*** | *5* | ***39*** | *0* |
| *- Geothermal Tech.* | *23* | *0* | ***0*** | *-23* | ***23*** | *0* |
| *- Hydropower* | *0* | *0* | ***0*** | *0* | ***4*** | *4* |
| *- Vehicle Tech.* | *182* | *166* | ***178*** | *-4* | ***180*** | *-2* |
| *- Building Tech.* | *69* | *77* | ***93*** | *24* | ***95*** | *26* |
| *- Industrial Tech.* | *57* | *46* | ***52*** | *-5* | ***48*** | *-9* |
| *- Congressional projects** | *158* | *0* | ***55*** | *-103* | ***54*** | *-104* |

*The treatment of Congressional projects is not comparable from FY06 to FY07.

*How Will Solar Energy Achieve Greater Adoption?*

There are several barriers to the adoption of solar energy systems—primarily cost, efficiency, and the intermittent nature of sunlight. The energy crisis of the 1970's saw the beginning of major interest in using solar cells for power, but prohibitive prices (approximately 30 times current prices) made most applications unfeasible. These prices have declined to the point where electricity from solar energy is about double the cost of retail rates for electricity. For a number of reasons, solar prices are expected to continue to decline. First, manufacturing efficiencies should allow improved prices, that is, as production volume increases, cost will continue to decrease. This economy of scale benefit may be limited periodically by short-term shortages of materials used in photovoltaic technologies. For example, the availability of single-crystal silicon is currently a concern to the industry. Industry projections indicate that market growth coupled with the adoption of favorable public policies could result in electricity costs of 5.7 cents per KWh by 2015, a cost that is lower than current retail rates for many customers.

In addition to driving down costs, advances in materials will increase the efficiency of photovoltaic systems. New technologies such as plastic solar cells, nanostructured materials, and dye-sensitized solar cells offer the potential to move well beyond the efficiency of current materials systems, dramatically lower cost and raise performance. The Photovoltaic Industry Roadmap projects a doubling of conversion efficiency for individual solar cells, of modules made up of multiple cells, and for systems as a whole by 2030.

Improvements in battery technologies for electricity storage are helping to deal with intermittency—an ever present problem for solar energy. Early generation solar systems were only useful during the daytime, but advanced batteries can store electricity generated by the sun for later use, thus making photovoltaics a more reliable energy source.

*The Role Renewable Energy Can Play in the Developing World*

Much of the increased demand for energy worldwide is anticipated to come from developing nations, as economic growth drives energy consumption toward levels in the developed countries. EIA estimates project the developing world's energy consumption to almost double in the next 20 years, driven largely by economic growth in China and India. Cost-effective renewable energy sources such as solar and wind may present a cleaner way to bring electricity to the poorest regions of the world, and meet the demands of rapid economic expansion of others. World Bank figures indicate that approximately 1.6 billion people worldwide are "energy poor," having no access to electricity (70 percent of Sub-Saharan African and 59 percent of South Asian populations are in this category), with hundreds of millions more using only intermittent, unreliable or heavily polluting sources of energy.

Greater adoption of renewable energy technology in the developing world can benefit developed countries as well. U.S. companies can reap the rewards of manufacturing and exporting technologies. If rapidly growing economies can offset growing thirst for fossil fuels with renewable technologies, they will help to reduce global competition for-and therefore prices of-fossil fuels. Furthermore, renewable technology adoption in developing countries can avoid increases in carbon dioxide emissions.

**6. Witness Questions**

*Dr. Steven Chu*

1. What are the limitations of current renewable energy technologies? Are these limitations inherent to the kind of technologies that are being used? What types of technologies can overcome these limitations?
2. What is the long-term potential for renewable energy technologies? What research and development work needs to be performed to lay the groundwork for the commercial application of a new generation of renewable energy sources?
3. What is the appropriate division of labor for this work among government, industry, and academia? How much money do you estimate these efforts will cost?
4. What steps is your lab taking to improve its ability to move technologies from concept through development and to the marketplace?

*Dr. Arno Penzias*

1. Are companies that are developing advanced renewable energy technologies generally viewed as good investment opportunities by the venture capital community?
2. What kinds of technologies are seen as good short-term investments and as good long-term investments by venture investors?
3. What role do you think the Federal Government can play to encourage growth in this sector?

*Mr. Christian Larsen*

1. What is the electric utility industry's perspective on renewable energy generation? Which renewable technologies have been most widely adopted by the industry to date?
2. What is the utility industry's plan for the future adoption of renewable energy sources? Does that plan depend on any changes in current policies, perhaps such as the regulation of greenhouse gas emissions? If it does, please explain the policy changes you are taking into consideration in your planning.
3. What is the electric utility industry's view of distributed generation, either as a business model or as a means to provide stability to the grid and avoid transmission bottlenecks?

*Mr. David Pearce*

1. What are the limitations of today's renewable energy technologies? Are these limitations inherent to the kind of technologies that are being used?
2. What types of technologies can overcome these limitations? How soon do you expect to see the widespread commercial application of the next generation of renewable energy technologies?
3. What challenges do companies like yours face in bringing a new technology from the laboratory stage to manufacturing? Are there particular challenges inherent in locating your manufacturing in the United States, specifically the Bay Area?
4. Is there additional research and development work that should be performed to expand the range of technology options for renewable energy sources? What is the appropriate division of labor for this work among government, industry, and academia? How much money do you estimate these efforts will cost?

*Mr. Ron Swenson*

1. What kinds of projects have you been involved with to deploy renewable energy in developing economies? Which renewable energy technologies did these projects use?
2. Are there challenges to widespread application of renewable energy technologies in developing economies that do not exist in the U.S.? How have government agencies, non-governmental organizations, industry, and academia here and abroad been involved in these projects? What role do you feel

these sectors have to play in encouraging the greater use of renewable energy sources?

3. How important is education in expanding the use of renewable energy? How do you think these efforts should be structured and undertaken?
4. Does the distributed nature of renewable energy electricity technology have any particular advantage in developing economies? What impact might this have on the political and socioeconomic systems of those countries? How might this affect the willingness of governments and industry to encourage the use of renewable energy? How might this affect export opportunities?

Chairwoman BIGGERT. The hearing of the Energy Subcommittee of the Science Committee will come to order. I'll recognize myself for five minutes for an opening statement.

I want to welcome everybody here to this hearing of the Energy Subcommittee, the House Science Committee, on the status of efforts to develop renewable energy technologies and expand their use in the United States and around the world.

It's an honor for me to be here in California, in the district of my friend and colleague, and the Ranking Member of this subcommittee, Mr. Honda, and I hope we make life a little easier by bringing this hearing across the continent to you, rather than making you come to Washington today where the temperature is expected to be 102.

There's no better place to explore the contributions of renewable energy research than here in the Golden State of California. California has made extensive use of hydro, geothermal, solar and wind resources, which supply over 10 percent of the state's electricity, compared to just two percent nationally. In other words, we still have a long way to go. But, California is fortunate to have an abundance of each of these renewable resources. I can't say that the same is true in my home State of Illinois. It's too flat to make significant use of hydro power. It has no geothermal resources, unless you count some of the steam tunnels that run under the City of Chicago, and the sun when it shines just doesn't shine enough; and while the windy city has one renewable resource that is its namesake only recently has technology enabled us to capture the strong and volatile winds in Chicago and in other parts of the state.

When you say renewable energy in Illinois, most people think of corn, and ethanol, and soy beans, and biodiesel. Renewable energy is a growing global industry, and our international competitors are taking renewable energy R&D very seriously. Government investments in renewable energy in Europe and Japan have meant growing market shares for the world and solar generation equipment for those countries, while the U.S. market share is declining. As a nation, we can't afford to sit on the sidelines.

That's why I introduced H.R. 5656, a bill that focuses federal research efforts on some of the greatest challenges to expand our use of renewable energy. Among other things, the bill directs researchers to focus their efforts on making solar electricity cost competitive by 2015. In addition, the bill would establish a program to demonstrate advanced solar technologies in every state. In this way, we may actually learn to capture the power of the sun, even in places like Illinois in the wintertime.

In addition to targeting federal research efforts at improving the efficiency of turbines and the cost-effectiveness of wind power, the bill also supports the development of the genetic and biological technologies to make ethanol from feedstock other than corn.

I'm happy to say that the Science Committee approved the bill unanimously, and it now awaits action in the Full House when we go back in September.

As we discuss our investments in this kind of renewable energy research, the challenge is to ensure that we not forget the demand side of the equation. Energy use of all kinds has environmental consequences. We should be aware of them, understand the trade-

offs and make decisions that are fully informed by the facts. That is why renewable energy R&D, the topic of our hearing today, is so timely.

Americans want affordable energy and a clean and safe environment, and yet, because we've under valued renewable energy research we act as the two are mutually exclusive. This is not true of the witnesses we will hear from today. They understand the potential of renewable energy technologies. They invested in the necessary renewable energy R&D, some independently and some in partnership with the Federal Government. But, in all cases they have success stories. I want to thank this remarkably accomplished panel for sharing their insights with us as we assess the challenges and opportunities associated with the development of renewable energy generation both domestically and in developing countries.

Before I introduce our panel, I'd like to turn to the Subcommittee's distinguished Ranking Member, Mr. Honda, for his opening statement.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

I want to welcome everyone to this hearing of the Energy Subcommittee of the House Science Committee on the status of efforts to develop renewable energy technologies and expand their use in the United States and around the world.

It's an honor for me to be here in California today in the district of my friend, colleague, and the Ranking Member of this subcommittee, Mr. Honda. I hope we made life a little easier by bringing this hearing across the continent to you, rather than making you come to us in Washington, where the temperature is expected to top 102 today.

There's no better place to explore the contributions of renewable energy research than here in the Golden State. California has made extensive use of hydro, geothermal, solar and wind resources, which supply over ten percent of the state's electricity compared to just two percent nationally. In other words, we still have a long way to go.

California is fortunate to have an abundance of each of these renewable resources. I can't say that the same is true of my home State of Illinois. It's too flat to make significant use of hydro power. It has no geothermal resources unless you count some of the steam tunnels that run under the city of Chicago. And the sun, when it shines, just doesn't shine enough. And while the Windy City has one renewable resource that is its namesake, only recently has technology enabled us to capture the strong yet volatile winds in Chicago and in other parts of the State. When you say "renewable energy" in Illinois, most people think of corn and ethanol and soybeans and biodiesel.

Renewable energy is a growing, global industry, and our international competitors are taking renewable energy R&D very seriously. Government investments in renewable energy technologies in Europe and Japan have meant growing market shares for wind and solar power generation equipment for those countries, while the U.S. market share is declining. As a nation, we can't afford to sit on the sidelines.

That's why I introduced H.R. 5656, a bill that focuses federal research efforts on some of the greatest challenges to expanding our use of renewable energy. Among other things, the bill directs researchers to focus their efforts on making solar electricity cost competitive by 2015. In addition, the bill would establish a program to demonstrate advanced solar technologies in every state. In this way, we may actually learn to capture the power of the sun even in places like Illinois in the wintertime.

In addition to targeting federal research efforts at improving the efficiency turbines and the cost competitiveness of wind power, the bill also supports the development of the genetic and biological technologies to make ethanol from feedstocks other than corn. I'm happy to say that the Science Committee approved the bill unanimously, and it now awaits action in the full House.

As we discuss our investments in this kind of renewable energy research, the challenge is to ensure that we not forget the demand side of the equation. Energy use of all kinds has environmental consequences. We should be aware of them, understand the tradeoffs, and make decisions that are fully informed by the facts.

That is why renewable energy R&D, the topic of our hearing today, is so timely. If we are to be successful in addressing the threat of climate change, we have to reduce emissions of greenhouse gases. That means not only improving energy efficiency, but also greatly expanding our use of renewable and non-greenhouse gas-emitting energy technologies such as nuclear power. And because of population growth and economic expansion, we must expand our use of renewable energy and energy efficiency technologies faster than the growth in our consumption of energy. As you can see, making progress on the development of renewable energy is every bit as important as making progress in increasing energy efficiency.

We also should keep in mind that energy efficiency improvements do not automatically lead to reduced energy use. In 1900, a light bulb cost roughly $20 in today's money; today it costs 40 cents, lasts at least 10 times longer and uses a fraction of the electricity to generate the same amount of candlepower.

As the price of light—that is fixtures, the bulbs and the power to operate them dropped—over time, we have figured out ways to use more light—and more energy. Think of just how many new sources of lights there are in the home: recess lighting, task lighting, lighting in and under cabinets in the kitchen, lights on appliances, lights in the yard. You should see Chicago from the top of the Sears Tower: there are lights as far as the eye can see in every direction except Lake Michigan. Only a century ago, the term "light pollution" would have been laughed at.

That brings us back to why we are here today. Americans want affordable energy and a clean and safe environment, and yet, because we've undervalued renewable energy research, we act as though the two are mutually exclusive. That's not true of the witnesses we will hear from today. They understand the potential of renewable energy technologies. They invested in the necessary renewable energy R&D—some independently, and some in partnership with the Federal Government. But in all cases, they have success stories. I want to thank this remarkably accomplished panel for sharing their insights with us as we assess the challenges and opportunities associated with the deployment of renewable energy generation both domestically and in developing countries.

But before I introduce our panel, I'd like to turn to the Subcommittee's distinguished Ranking Member, Mr. Honda, for his opening statement.

Chairwoman BIGGERT. The gentleman is recognized for five minutes.

Mr. HONDA. Thank you, Madam Chair, and welcome to San Jose, and also welcome back to close to the site of your alma mater, Stanford University. And, I know that you are enjoying our wonderful weather, and maybe we can talk a little bit more about that as we listen to our witnesses.

I'd like to thank everyone in attendance for being here today for this hearing about a topic that I believe is essential to the future of our nation, our world, which is renewable energy.

Chairwoman Biggert, I thank you for traveling out to Silicon Valley to join us and to hear what folks from this region have to contribute to this important endeavor.

I extend my warmest thanks and welcome to Cindy Chavez, Vice Mayor of the city of San Jose, who made it possible for us to hold this hearing in this wonderful space today. Cindy, would you stand up and please be recognized, and I want to thank you and your Council for receiving us here today. It's a wonderful, friendly, natural lit chamber.

I also wanted to thank all the witnesses for agreeing to testify before us today. I think that we have assembled an eminently qualified panel that represents the spirit and breadth of expertise and experience that makes Silicon Valley and the whole Bay area the special place that it is.

I'm the kind of person who drives a hybrid car and wants to keep the battery charged with a solar cell when I don't drive it for a while. I'm also in the process of doing some work on my house, and my plans involve installing solar photovoltaics on the roof. Sadly,

the rest of the Nation is not doing the same. The United States was once leader in solar technologies. The first solar cell that produced a useful amount of electricity was invented here, but last year only 11 percent of the photovoltaic generating capacity was manufactured here.

Our track record at installing solar generation is equally poor. By the end of 2004, the United States' total installed photovoltaic generating capacity was only about equal to what a standard coal-fired power plant produces, or approximately 400ths of one percent of U.S. electricity produced. We have fallen behind other nations, such as Germany and Japan, which saw solar installation increase as a result of meaningful government incentive programs. But, all is not lost, because nature gives us an advantage. The United States has far greater potential for solar power than Germany, and this means that the U.S. has tremendous growth potential for solar energy.

Here in California, we are taking a lead with over 100 megawatts of installed grid capacity to date. It took a commitment to get to this point; and because a typical home photovoltaic system is not cheap to purchase and install, to succeed and advance in solar technology cost must be reduced.

Fortunately, as more cells are manufactured, the cost has decreased five to seven percent per year. As more consumers install these systems, with the help of federal and State incentives, prices will continue to fall and the cost of power will become comparable to other sources.

Research and development can help to increase the efficiency and decrease the cost of renewable energy. For example, in the areas of biofuels, research can help develop dedicated energy crops that are cost effective, easy to sustain, and produce greater energy yields.

In the area of photovoltaics, new fields such as nano technology offer the opportunity to develop solar cells that can generate electricity using more wave lengths of the sun's light and collect all light more efficiently.

With the right resources, the global scientific and engineering community can continue down the path to progress. It needs to be a global effort, because developing countries don't have the luxury of thinking about expensive energy solutions. For the poorest countries, energy is a source of their poverty. Thirty eight of the poorest countries are net importers of oil, and 25 of them import all of their oil. At oil prices at over $70 per barrel, these countries are being disproportionately impacted.

Renewable energy in its various forms has many characteristics that make it particularly useful in the developing world, as well here in the U.S. Using the distributed renewable resources of electricity that generate power where it is needed means that large investments in infrastructure can be avoided. In developing countries, this distributed generation is essential to rapid success, and that's where infrastructure links between rural communities or remote settlements are not well developed.

Photovoltaics and small wind generation are well suited to the distributed generation approach, because they can be installed sim-

ply and unobtrusively in remote locations, and they can be scaled to whatever the local energy needs are.

Biofuels can capitalize on agricultural strengths of developing countries, providing a cleaner, more sustainable alternative to oil, while improving the situation of small farmers who cannot compete in the global market as it exists today.

Brazil is a great example of how nations can use our approach to make energy a source of opportunity, rather than a source of oppression.

When I was there last year, I learned how Brazilian Government has provided the necessary support to make ethanol, derived from sugar cane, a common source of fuel. By the end of last year, 70 percent of new cars sold in Brazil were flexfuel vehicles, like the ones that the Chairwoman and I saw in her field hearing in Naperville, Illinois in June, that vehicle can use ethanol as well as gasoline.

In our job, one of the things that we have to worry about is international relations. Both energy and climate change are pieces of this bigger picture. Fortunately, renewable energy offers opportunities to make the big picture a little bit less complicated. When developing nations depend on other countries' natural resources, they are unable to invest in improvements within, leading to humanitarian crisis which require international responses and human suffering. Using renewable energy, developing countries could instead use their own live-in resources to power their development and enhance their economies.

Throughout history, wars have been fought over non-renewable natural resources. In a world focused on using renewable energy, these conflicts could be avoided and greater stability achieved. But, we need to convince consumers here and in developing countries to choose to adopt renewable energy, and to do so we need to make renewables cost effective and improve their performance.

So, I look forward to hearing the insights our witnesses will provide today, about what the future holds for renewable energy, and to a lively discussion following their testimony.

Thanks again to everyone who is here today, and I yield back my time.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

I'd like to everyone in attendance for being here today for this hearing about a topic that I believe is essential to the future of our nation and our world, renewable energy. Chairwoman Biggert, I thank you traveling out to Silicon Valley to join us and to hear what folks from this region have to contribute to this important endeavor.

I extend my warmest thanks and welcome to Cindy Chavez, Vice Mayor of the City of San Jose, who made it possible for us to hold this hearing in this wonderful space today. Cindy, please stand up and be recognized. Thank you so much for reserving the Council Chambers for us.

I also want to thank all of the witnesses for agreeing to testify before us today. I think we have assembled an eminently qualified panel that represents the spirit and breadth of expertise and experience that makes Silicon Valley and the whole Bay Area the special place that it is.

I'm the kind of person who drives a hybrid car and wants to keep the battery charged with a solar cell when I don't drive it for a while. I'm also in the process of doing some work on my house, and my plans involve installing solar photovoltaics on the roof. Sadly, the rest of the Nation is not doing the same. The United States was once the leader in solar technologies. The first solar cell that produced a useful

amount of electricity was invented here, but last year, only 11 percent of the photovoltaic generating capacity was manufactured here.

Our track record at installing solar generation is equally poor. By the end of 2004, the United States installed photovoltaic generating capacity was only about equal to what a standard coal-fired power plant produces, or approximately 0.04 percent of U.S. electricity production. We have fallen behind other nations, such as Germany and Japan, which saw solar installation increase as a result of meaningful incentive programs.

But all is not lost, because nature gives us an advantage—the United States has far greater potential for solar power than Germany. This means that the U.S. has tremendous growth potential for solar energy. Here in California, we are taking the lead, with over 100 megawatts of installed grid capacity to date. It has taken a commitment to get to this point, because a typical home photovoltaic system is not cheap to purchase and install.

To succeed in advancing solar technology, cost must be reduced. Fortunately, as more cells are manufactured, the cost has decreased five to seven percent per year. As more consumers install these systems with the help of federal and State incentives, prices will continue to fall and the cost of power will become comparable to other sources.

Research and development can help to increase the efficiency and decrease the cost of renewable energy. For example, in the area of biofuels, research can help develop dedicated energy crops that are cost-effective, easy to sustain, and produce greater energy yields. In the area of photovoltaics, new fields such as nanotechnology offer the opportunity to develop solar cells that can generate electricity using more wavelengths of the sun's light and collect all light more efficiently. With the right resources, the global scientific and engineering community can continue down the path to progress.

It needs to be a global effort, because developing countries don't have the luxury of thinking about expensive energy solutions. For the poorest countries, energy is a source of their poverty. Thirty-eight of the poorest countries are net importers of oil, and 25 of them import all of their oil. At oil prices of over $70 per barrel, these countries are being disproportionately impacted.

Renewable energy in its various forms has many characteristics that make it particularly useful in the developing world, as well as here in the U.S. Using distributed renewable sources of electricity that generate power where it is needed means that large investments in infrastructure can be avoided. In developing nations, where infrastructure links between rural communities or remote settlements are not well developed, this is essential to rapid success.

Photovoltaics and small wind generation are well suited to the distributed generation approach, because they can be installed simply and unobtrusively in remote locations, and they can be scaled to whatever the local energy needs are. Biofuels can capitalize on the agricultural strengths of developing countries, providing a cleaner, more sustainable alternative to oil while improving the situation of small farmers who cannot compete in the global market as it exists today.

Brazil is a great example of how nations can use agriculture to make energy a source of opportunity rather than a source of oppression. When I was there last year, I learned how the Brazilian government has provided the necessary support to make ethanol derived from sugar cane a common source of fuel. By the end of last year, 70 percent of the new cars sold in Brazil were Flex Fuel Vehicles like the one that the Chairwoman and I saw at her field hearing in Naperville, Illinois in June that can use ethanol as well as gasoline.

In our job, one of the things that we have to worry about is international relations. Both energy and climate change are pieces of this bigger picture. Fortunately, renewable energy offers opportunities to make this big picture a little bit less complicated. When developing nations depend on other countries' natural resources, they are unable to invest in improvements within, leading to humanitarian crises which require international responses and human suffering. Using renewable energy, developing countries could instead use their own living resources to power their development and enhance their economies.

Throughout history, wars have been fought over non-renewable natural resources. In a world focused on using renewable energy, these conflicts could be avoided and greater stability achieved. But we need to convince consumers here and in developing countries to choose to adopt renewable energy, and to do so, we need to make renewables cost effective and improve their performance.

So I look forward to hearing the insights our witnesses will provide today about what the future holds for renewable energy and to a lively discussion following the testimony. Thanks again to everyone for being here today.

Chairwoman BIGGERT. Thank you very much, Mr. Honda. Any extension of remarks may be added to the record.

At this time I'd like to introduce all of our witnesses. Thank you for coming to join us today. Let's start with Dr. Steven Chu, who is the Director of Lawrence Berkeley National Laboratory and a 1997 Nobel Prize winner in Physics. He is currently spearheading a new laboratory research initiative focused on solar energy. We have Dr. Arno Penzias, who is a Venture Partner with New Enterprise Associates in Palo Alto. While at Bell Laboratories, he won the Nobel Prize for Physics in 1978. Today, he's a venture capitalist with interests in renewable energy technology. Mr. Christian Larsen is Vice President for Generation for the Electric Power Research Institute in Palo Alto. His division provides data on cost and performance analyses for renewable distributed and hydro power energy generation technologies to the electricity industry. Mr. David Pierce is President and CEO of Miasolé, I hope I'm close, a Santa Clara-based company that manufactures industrial scale solar products using thin film solar cell technology developed in the Department of Energy National Laboratories. And finally, Mr. Ron Swenson is co-owner of ElectroRoof, a solar equipment installation company, and EcoSage, an educational service company developing a program to build solar-powered satellite teaching centers in remote areas of the world in conjunction with solar education programs in schools.

And, with that, I would turn over to our Ranking Member, Mr. Honda, for introductions.

Mr. HONDA. Thank you, Madam Chair.

Just very quickly I'd like to acknowledge that we have Scarlett Li Lam; Forrest Williams, who is a Council Member for the city of San Jose; a Council Member from Sunnyvale, Chris Moylan, who is also a high-tech guy; and we have Bern Beecham from the Palo Alto City Council, the home site of Stanford University; and we have our Vice Chair, Cindy Chavez, who secured this place for us.

Thank you, Madam Chair.

Chairwoman BIGGERT. Thank you.

Spoken testimony of the witnesses will be limited to five minutes each, after which the Members will have five minutes each to ask questions in rotation, and we will begin with Dr. Chu.

**STATEMENT OF DR. STEVEN CHU, DIRECTOR, LAWRENCE BERKELEY NATIONAL LABORATORY; ACCOMPANIED BY DR. ARNO PENZIAS, VENTURE PARTNER, NEW ENTERPRISE ASSOCIATES, PALO ALTO, CALIFORNIA**

Dr. CHU. Thank you, Chairman Biggert, thank you, Member Honda, and Members of the Committee. It's a great pleasure that I'm here again to testify before the House Science Committee on this issue of critical importance. The last time I was here, I was testifying on behalf of the National Academy of Sciences Report, chaired by Norm Augustine that's known as *"Rising Above the Gathering Storm,"* and in that hearing I was advocating that we consider very seriously starting an energy initiative research program.

You should also know that, because it does have some bearing on this hearing, that I'm also currently co-chairing an Inter-

Academy Council study on, the title is, "Transitions to Sustainable Energy." The InterAcademy Council represents over 60 national academies around the world. The other co-chair is Jose Goldemberg, who was formerly the Secretary of Science and Technology of Brazil, and is currently now the Secretary of Environment for the State of Sao Paulo. He was a major architect in the Brazilian cane story pertaining to the '85 ethanol for Brazil that is now selling for less than commercial gasoline without any subsidy.

It is also important I should point out that that event happened in an environmentally responsible way, so that these are really truly long-term sustainable sugar cane plantations. They are not in there for ten years and the soil is depleted.

In my remaining few minutes I would want to race through the slides, and so if I could first have the second slide, oh, I have total control, good, I'm the Director of Lawrence Berkeley Lab, which is a national laboratory adjacent to U.C.'s Berkeley Campus, and it's—I don't have total control, okay, there's a next—good enough, it's, okay, let me—although this isn't about this I just wanted to remind us why we are here. There are some dire predictions of climate change that could have very serious consequences, not only to the health of the Nation but the health of the world. The probability that these predictions are, is it a certainty, no, is it half, two-thirds, three-fourths, we can debate that, but the predictions are so serious that if someone told you there is an 80 percent chance you will die in 10 years if you didn't stop smoking you might think about stopping smoking. So, whether it's an 80 percent, or 90 percent, or 60 percent, these are the questions.

So, going to that, I think that a dual strategy has to be adopted very aggressively by the United States, by both conserving and also developing new sources of clean energy.

On the conservation side, that is energy efficiency, the Lawrence Berkeley Lab has really led the way, starting with the movement of a high-energy physicist named Art Rosenfeld, and in the middle of 1970 he gave up his career in high energy physics to devote to energy efficiency. He did a number of things that really dramatically turned around, first the State of California, and the United States, but to remind you, the State of California, since the middle 1970s, has been held constant in terms of the average amounts of electricity used per citizen in California, while the rest of the United States went up by six percent.

One of the things that Rosenfeld did was, he instituted refrigerator standards. That brown curve is the size of refrigerators that went from 18 to 22 cubic feet. The standards marked the way of increasing efficiencies by four and a half times. During that time, the inflation adjusted cost of refrigerators had gone down by more than a factor of two. How much electricity did this save? Well, if you look at this bar, we would have used close to three billion kilowatts per year, and we are using about one-fourth of that. That compares to all the conventional hydro in the United States and about a third of the nuclear power which is 20 percent of all electrical generation.

But, this is actually misleading. It's better than that. If you consider what is delivered in value to the home, the end-user, and you look in terms of money, the dollars saved from just refrigerators

was nearly double all of the U.S. hydro, and is now becoming comparable to all of U.S. nuclear, just refrigerators.

And so, efficiency remains the lowest hanging fruit. This is the stuff we can do best and we should aggressively do this.

Now, on the supply side, I want to focus on what we at Berkeley Lab think we can do, and it lends to our expertise, and it has to do with harnessing solar energy in various forms. So, we started this program called Helios, which includes several pathways, and I'm just going to talk about two. One is plants to cellulose, and then cellulose to chemical fuels that can replace oil. I'm going back and talking about the management.

So, the idea here is that in the last several billion years nature has found a way to convert sunlight, carbon dioxide, water and nutrients into chemical energy. When you take that closed synthetic product, turn it into a chemical fuel and burn it, you then release the carbon dioxide, but in principle it can be as good as 95 percent $CO_2$ neutral, in the sense that if you include all the energy you need to invest in terms of distribution, transportation, the growing of the crop, and what you then release as $CO_2$, it will be at least 90 percent, probably 95 percent, $CO_2$. So, that's the idea.

Is there enough land in the world to do this, because, after all, we have to feed people. So, between 1950 and 1995, the world went from about two billion to six billion people. Had there not been any agricultural improvements we would have followed that red line, but instead we followed the blue line. The amount of land put under agriculture production to increase the number—feeding the number of people by a factor of three, was only 10 percent.

So, there are further agricultural things. We haven't really worked at all at raising crops to produce energy, and so there now lies within rapidly developing science the ability to transfer a set of genes to make plants self-fertilizing, which is very energy intensive to make fertilizer, drought-resistant pest-resistant, and then once you have those plants how do you convert it much more efficiently into chemical fuels for transportation.

If you—here is an estimate, you can argue by about a factor of two, but let's take a certain plant, miscanthus, the record is 45 dried tons per acre in Nebraska, in a field test, so we can take 30, you can be very conservative and take 15, 100 gallons of ethanol per dried ton is what is commercially available today. If you take 100 million acres out of the roughly 400 to 450 million acres that we either have under cultivation or we pay farmers not to plant, that corresponds to 300 billion gallons of ethanol a year, which when compared to the total U.S. gasoline consumption is actually more than that.

So, there is the potential for replacing minimally half of the gasoline, and all of the gasoline imports, with biomass. And, as said, you can be very conservative, divide by a factor of two, it's still a very compelling number.

Where are the great gains? Well, one of the biggest gains is that right now the conversion of cellulose material into biofuels is very energy intensive, and one can do much better. There is a new field called synthetic biology, which imports a whole set of genes. One of the poster examples, poster child examples of this synthetic biology, was something one of our laboratory scientists did, Jay

Keasling, he took an active ingredient of a plant, which was a miracle malaria cure, and he's taught e. coli bacteria how to make this plant. It's been very successful. It's now being commercialized and it will soon be distributed to Third World countries at a cost of .20 cents a cure.

That same technology can be used to engineer organisms to produce ethanol, methanol, butanol, or other hydrocarbon fuels.

There are other technologies, micro interface technologies, where you can use these to have, essentially, an accelerated directed evolution for the microbes and for the genetic plants, but mostly for the microbes, so again, this is a very rapidly changing area of technology.

And finally, one can think of, and we are, and others are beginning to think about, algaes that naturally occur, but to engineer them so that they grow suitable biofuels at much higher efficiency than we think—that we know are possible today, and we think compares by a factor of ten.

So, let me close and say that national and international concerns, as we all know, national security ranks very high, but national security is intimately tied to energy security. There is the economic prosperity of getting out of our dependency on foreign oil, but also having energy that's affordable, and finally, environmental issues, local and global.

[The prepared statement of Dr. Chu follows:]

PREPARED STATEMENT OF STEVEN CHU

Chairman Biggert, Ranking Member Honda, and Members of the Committee,

I am Steve Chu, Director of Lawrence Berkeley National Laboratory, and it is again my pleasure to testify before the House Science Committee on an issue of such critical importance to the United States and to the world. The last time I appeared before your committee I was privileged to represent the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine's Committee on Prospering in the 21st Century and to discuss the recommendations of the committee's report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.*

Because of its direct bearing on this Hearing, I wanted to let you know that I am currently serving as Co-Chair of the InterAcademy Council's study panel on Transitions to Sustainable Energy. The InterAcademy Council was created by the world's academies of sciences to bring together the best scientists and engineers worldwide to provide high quality advice to international governmental and non-governmental organizations. It is the charge of the Transitions to Sustainable Energy panel to provide scientific advice to policy-makers on moving toward adequately affordable, sustainable and clean energy supplies. My Co-Chair is Jose Goldemberg, formerly the Secretary of Science and Technology and the Secretary of the Environment for Brazil, and an expert in sustainable energy technologies who helped to shepherd Brazil's sugar cane-based energy phenomenon. The panel has given me a broad and varied view of the many energy challenges and opportunities facing our world. Our final report should be completed by early 2007 and I will make sure that a copy is transmitted to the Committee once available.

Today, I'm excited to share with you developments in science, particularly at Berkeley Lab, that I believe hold great promise for addressing the world's energy and environmental challenges. My comments or written testimony are not intended to represent the policies or positions of the Department of Energy.

**The Challenge and the Opportunity**

There is now general consensus that humanity faces an energy and environmental crisis. Global energy use has grown to the point where the by-products of man's energy consumption are significantly influencing the atmosphere and climate, with costly and potentially disastrous consequences. Experts forecast that the ability to locate viable sources of energy will increasingly determine the degree of economic

and technological development. Motivated by a strong desire to provide solutions to these problems, and encouraged by the findings of the *Gathering Storm* report, the President's American Competitiveness and Advanced Energy Initiatives, and new research funding opportunities within the Department of Energy, concerned scientists and engineers from across a diverse range of disciplines and institutions are developing new and innovative approaches to energy research. This is what we are also doing at Berkeley Lab.

There has been an ongoing effort for decades on the part of the scientific community to find a solution to the renewable energy problem. So is there any reason to believe that the problem is more amenable to solution now? The answer is yes. Major recent advances in science and technology have dramatically improved the prospects for finding a technical solution. The multi-billion dollar investment in the National Nanotechnology Initiative that was so ardently proposed and supported by Congressman Honda and this committee has led to dramatic advances in the synthesis and control of materials that are crucial to the problem. Large scale advances in genomics have led to whole genome sequencing, as well as to the new field of synthetic biology, a new scientific discipline in which Berkeley Lab is a pioneer.

**The Helios Project**

Answering the call of the Congress and the Administration to discover new and cleaner energy sources, we at Berkeley Lab are embarking on an exciting new initiative called the Helios Project. Hoping to do for the supply-side of the equation what we've done at Berkeley Lab on the demand-side, the objective of Helios is to accelerate the development of renewable and sustainable sources of energy using sunlight. We are approaching this goal with a clear commitment, intent on developing solutions from basic science through to practical uses.

Although there is currently no "magic bullet" to solve the energy problem, we believe that utilization of the sun holds significant untapped promise for reducing the need for fossil fuels. Using Helios as an example, my testimony will describe exciting new scientific and technological opportunities that are available to researchers to address the fundamental barriers to developing sustainable energy alternatives.

The ultimate goal of Helios, simply stated, is to use sunlight to manufacture a transportation fuel. Transportation fuels would be the most costly form, but the most valuable form, of solar energy. Helios recognizes that there are several routes to accomplish this goal, and various approaches require materials and techniques that will have significant impact in other solar applications. For example, one approach is to use photovoltaics to capture sunlight that then can be used with photoelectric cells to convert carbon dioxide and water into liquid fuels or hydrogen. Scientists and engineers will collaborate to make more efficient and less-costly photovoltaic systems and electrochemical systems. Either of these new systems will have vast implications for other clean energy routes and stand-alone processes.

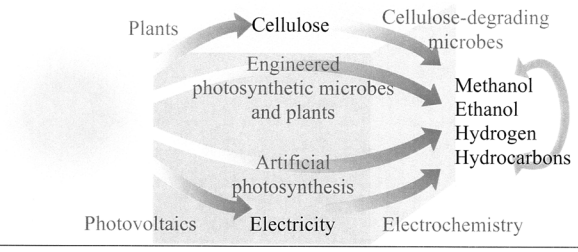
A comprehensive and accelerated program of basic science and technology development, such as Helios, can make great strides. Much like the development of the transistor at Bell Laboratories, Helios will be managed in a way that ensures progress toward its applied technology goals. Because of the ability to marshal resources, focus scientific research and build broad teams of multi-disciplinary expertise, a national laboratory is uniquely organized to attack big scientific challenges like the present energy crisis. Berkeley Lab is well suited for this task because of our long history in biological and chemical systems research such as photosynthesis, as well as our world-leading and pioneering work in nanotechnology and synthetic biology.

Even so, the scientific problems to solve and the technological barriers to overcome are huge and other Labs and research universities, along with an engaged and proactive commercial sector, will be required to ensure the successful translation of science and technological achievement into the marketplace.

**The Four Pathways**

The overarching goal of the Helios Project is to revolutionize the means by which we harvest the energy of sunlight, so that this source will satisfy a majority of our energy needs. Figure 1 illustrates the four major pathways for going from sunlight to fuel that Helios will explore: two based on living systems, and two based on artificial systems. A great advantage of the Helios Project is that all programs and research pathways will be closely integrated. We have analyzed each of the four pathways, to determine the present status, the requirements, the major roadblocks, and the benefits that may arise as each roadblock in each path is solved.

Fig. 1. Helios research will break down roadblocks on four routes to solar fuels development




**Path I: Sunlight to Fuel via Biomass**

Biomass is the most abundant renewable carbon source on the planet and has long been a major combustible fuel for mankind. While biomass has the potential to meet most, if not all, of the transportation fuel needs, there are several difficulties in using biomass for production of fuels. The first problem is that current biomass crops are far from optimal for energy- and water-efficient production. The second problem is the expense and inefficiency of the process for converting biomass to fuels. Helios will address both problems.

Currently ethanol for transportation is produced primarily from sugar cane and corn. Possibly we can find a way to create new plants that will "grow energy" by incorporating genes that will make the plants self-fertilizing, and drought- and pest-resistant. The creation of crops efficiently raised for energy will also take full advantage of our great American agricultural capacity. Also, by designing microbes which will behave in new ways, our scientists hope to convert cellulose into chemical fuel more efficiently, so that biomass fuel can be obtained at a cost-effective price, and to keep the overall cycle as carbon-neutral as possible.

**Path II: Microbial synthesis of biofuels using photosynthesis**

Another approach is to skip production of the intermediate biomass and produce the fuels directly from sunlight using photosynthetic microorganisms. This model will use nature's mechanism as the refinery. While there are microbes and plants that utilize sunlight directly to produce oils and alcohols, they are not efficient enough to supply a significant fraction of U.S. energy need. They need to be optimized for their fuel production role. Berkeley Lab's strengths in photosynthesis since the early discoveries by Nobel Laureate Chemist Melvin Calvin will be put to use to increase photosynthetic efficiencies. DOE's Joint Genome Institute (JGI) and the Berkeley Lab Genomics Division will also play integral roles in this endeavor.

**Path III: Sunlight to Electricity: Nanotechnology enabled solar cells**

There are many possible routes to achieve solar energy utilization. However, all known potential routes are limited now by two types of serious roadblocks: one is the need for fundamentally new and optimized materials for use in solar collectors, efficient processing steps, and energy handling. The other is that because of daily, seasonal, and other variations, the use of solar energy must involve the development of efficient storage strategies. The Helios Project is devoted to developing the basic science needed to overcome these roadblocks.

Because the elementary steps of conversion of sunlight to electricity in either biological or non-biological pathways takes place on the nanometer scale, the advent of new methods to control and pattern matter on the nanoscale has created tremendous new opportunities for solar cell design. Two broad areas of activity will be pursued: with new nanotechnology based solar cells, it is possible to explore concepts for how to dramatically increase the power efficiency of solar cells; second, low cost high volume solar cell fabrication techniques will be enabled. By controlling the size, shape, dimensions, and connectivity of nanoscale building blocks, it is possible to control the basic energy levels of a system, allowing for the design a new type of solar cell.

**Path IV: Direct Photochemical or Photoelectrochemical Solar to Fuel Conversion**

Finally, nature's photosynthetic machinery constitutes proof of principle that solar fuels can be generated by direct chemical conversion in a single device. However, there are energy costs in the production and handling of huge amounts of biomass. The goal of this research is to develop single devices that mimic the pathways of natural plants in producing fuel from water and sunlight but which are stable and have significantly greater efficiency. The recent progress in the understanding of the design principles of natural photosynthesis coupled with the rapid emergence of new nanostructured inorganic, organic and biological/non-biological hybrid materials has opened up opportunities to develop engineered solar to fuel systems that will meet the efficiency and durability requirements of a practical system. In many ways this path may hold the greatest long term promise, but is consequently probably the most difficult research objective.

**Cross-Cutting Areas**

In addition to the four pathways, we have identified cross-cutting areas of fundamental science and engineering which will be further developed for the Helios Project to succeed. Breakthroughs in these crosscutting areas will have a positive impact on more than one of the four paths. The cross-cutting areas are: Catalysis, Separations, Theory, Synthetic Biology, and Manufacturing.

As an example, synthetic biology is an emerging field that will play a tremendous role in the success of the Helios Project and other alternative fuel research initiatives. In July 2003, Berkeley Lab established the world's first Synthetic Biology Department, which seeks to understand and design biological systems and their components to address a host of problems that cannot be solved using naturally-occurring entities. University of California at Berkeley Professor and Lab Scientist Jay Keasling heads this department and is one of the pioneers of synthetic biology. He is also one of the leaders of the Helios Project.

The overarching role of the cross-cutting synthetic biology component of Helios is to create biological components that can be used across the whole spectrum of Helios activities. For example, this approach will enable us to rapidly and reproducibly engineer cells to convert renewable resources (sunlight, cellulose, starch, and lignin) into fuels.

The discipline's specific aims are 1) to develop the foundational understanding and standard, interchangeable, biological components (parts, devices, and chassis) that will allow us to routinely build large numbers of useful biological systems; 2) to develop mathematical models and computing methods to organize and analyze data, predict the behavior of biological components, and design new biological components and large integrated systems; and 3) to utilize state-of-the-art molecular profiling technologies to better understand biological systems and to optimize their function.

**When will the Helios Project produce results?**

Helios is focused on revolutionary research to accomplish significant advances. The risk for any individual project is substantial, but with all approaches taken together the probability of making significant advances in the overall goal of developing sustainable energy alternatives is high. We cannot know in advance which approach or research area will be most valuable, and which will pay off earliest. So we have given great thought to our management plan, and have built in the flexibility to respond to new results and the freedom to veer toward something new, away from the current approach, if that seems to be the more promising route.

We realize that timeliness is essential. To ensure the timely success of the Helios Project, we have adopted an active management strategy. The technical requirements for each path have been clearly defined, as are the known major bottlenecks. These will be re-examined twice yearly. Helios investigators will be required to develop core research areas but also to directly contribute to advancing at least one of the four paths. As the project advances, it will be necessary to focus the effort into those directions that appear most promising. With a tightly managed program, the Helios Project will produce a range of advances in specific sectors (like improved photovoltaics or a better way to break down cellulose) within five years, with the goal of a major breakthrough within ten years.

**Conclusion**

The mission of the Department of Energy is to advance basic science and to explore energy solutions and promote environmental stewardship. Because of increased funding scheduled for basic sciences and energy research at DOE and with

the public's growing awareness of the energy crisis and the environmental consequences of inaction, we believe that now is the right time for Helios.

Over the past three decades, Berkeley Lab has been a leader in developing energy efficient technologies, standards and practices that have a significant impact on the demand side of the energy equation. Technologies developed at Berkeley Lab have saved the U.S. economy tens of billions of dollars in energy costs—these technologies include the development of dual-paned, gas-filled energy-efficient windows; the now ubiquitous energy-efficient electronic ballasts for lighting; software tools for better building design; and the development of appliance standards to save energy and water.

I strongly believe that the most immediate and substantive gains in addressing the energy challenge are available through energy efficiency and conservation.

However, addressing the demand side alone will not fully provide the solutions necessary to address the energy and environmental crisis we face today. You must also address the supply side.

It has been my pleasure to describe our initiative to you today, and I look forward to keeping you updated as we work to build a systematic and well-focused program of transformational energy technologies development.

Chairman Biggert, Ranking Member Honda, and Members of the Committee, thank you for the opportunity to provide testimony on this critical topic.

I would be glad to respond to any questions.

BIOGRAPHY FOR STEVEN CHU

Steve Chu, 57, became Berkeley Lab's sixth Director on August 1, 2004. A Nobel Prizewinning scholar and international expert in atomic physics, laser spectroscopy, biophysics and polymer physics, Dr. Chu oversees the oldest and most varied of the Department of Energy's multi-program research laboratories. Berkeley Lab has an annual budget of more than $520 million and a workforce of about 4,000.

His distinguished career in laboratory research began as a postdoctoral fellow in physics at the University of California's Berkeley campus from 1976–78, during which time he also utilized the facilities of Berkeley Lab. His first career appointment was as a member of the technical staff at AT&T Bell Laboratories in Murray Hill, N.J. where, from 1978–87, his achievements with laser spectroscopy and quantum physics became widely recognized. During the last four years there he was Head of the Quantum Electronics Research Department, during which time he began his ground-breaking work in cooling and trapping atoms by using laser light. In 1987, he became a Professor in the Physics and Applied Physics Departments at Stanford University, where he continued his laser cooling and trapping work.

This work eventually led to the Nobel Prize in Physics in 1997, an honor he shared with Claude Cohen-Tannoudji of France and United States colleague William D. Phillips. Their discoveries, focusing on the so-called "optical tweezers" laser trap, were instrumental in the study of fundamental phenomena and in measuring important physical quantities with unprecedented precision.

At the time, Dr. Chu was the Theodore and Francis Geballe Professor of Physics and Applied Physics at Stanford University, where he remained for 17 years as highly decorated scientist, teacher and administrator. While at Stanford, he chaired the Physics Department from 1990–93 and from 1999–2001.

He is a member of the National Academy of Sciences, American Philosophical Society, American Academy of Arts and Sciences, Academia Sinica, and Honorary Lifetime member, Optical Society of America. He is also a foreign member of the Chinese Academy of Sciences and the Korean Academy of Sciences and Technology.

Dr. Chu has won dozens of awards in addition to the Nobel Prize, including the Science for Art Prize, Herbert Broida Prize for Spectroscopy, Richtmeyer Memorial Prize Lecturer, King Faisal International Prize for Science, Arthur Schawlow Prize for Laser Science, and William Meggers Award for Laser Spectroscopy. He was a Humboldt Senior Scientist and a Guggenheim Fellow and has received six honorary degrees.

Born in St. Louis and raised in New York, Dr. Chu earned an A.B. in mathematics and a B.S. in physics at the University of Rochester, and a Ph.D in physics at UC–Berkeley. He maintains a vigorous research program and directly supervises a team of graduate students and postdoctoral fellows. He is author or co-author of more than 160 articles and professional papers, and over two dozen former members of his group are now professors at leading research universities around the world.

Chairwoman BIGGERT. Thank you very much.

Dr. Penzias, you are recognized for five minutes.

**DR. ARNO A. PENZIAS, VENTURE PARTNER, NEW ENTERPRISE ASSOCIATES, PALO ALTO, CALIFORNIA**

Dr. PENZIAS. Thank you for allowing me to speak today. Again, I'm going to leap on the side of shortness, so I keep in the five minutes, and then it can be added into the stuff I gave you.

I framed my testimony in response to the questions that were sent the witnesses. The first question, what is the current state of adoption of renewable energy in the United States? And, what's limiting that rate of adoption?

Right now, I think it's high cost and limited supply. High cost, and to me dollars—this is why I have mixed feelings about subsidies, they were right as an interim step, but dollars are probably the best test of whether something works or not. And so, you don't have to do any calculations to know that there's less energy going into the ethanol in Brazil, because it costs less. You know that nobody is wasting energy there, there's no subsidy, so it's a great thing. We don't always want to do that, but that's what happens in that case.

And, I think right now it's fair to say that that really is the problem. But, what's the outlook, and what research or innovation could prove that outlook? For me, I think the outlook is extraordinarily positive. I have been an alternative energy skeptic for decades. I started in alternative energy some 30 years ago, about the same time as that same little hook with the first Arab oil boycott in the early 1970s. That's just about 30 years ago. And, during that time, that period, I was frustrated by the lack of progress, and not for want of resource, not for want of will, not for want of bright people, it just takes time, the surprises come, in my experience, from other areas. It isn't the people that are looking at alternative energy.

The thing I will show you later is made from an automobile headlight, and nobody would have thought that that was going to be a way of cutting the price of silicon, not by five or seven percent, but by 70 percent. That's dramatic, and that's the kind of thing that happens when creative people get together. It's what we do here in Silicon Valley wonderfully; and this is, you know, I'm a zeal of a convert. I worked for the largest corporation in the world, and the world's best research laboratory for 37 years, and when I got out here, one reason I came was because I knew too many things that didn't work. And, boy, have I been surprised since I've been here.

Now, so let me move on to some examples of where I think these opportunities are. Silicon was the one I spoke about, silicon I just mentioned, and here by the way is the automobile headlight. This is one piece of a much larger solar concentrator. At the back of it, and we can look at that later, at the back of it there is a very small, very efficient, extremely expensive, solar cell, smaller than the tip of my finger. On an area basis, there would be no way of using it. This thing, for a tiny area you have to pay $6. But, because you are able to use this automobile headlight shaped glass technology, you get a 500 to one improvement. So, it looks to the sun as if it's 500 times bigger.

So, it's private enterprise together with the folks that built this, which by the way was a government laboratory, NREL, this triple

junction solar cell, which is by the way fueling a whole new generation of solar concentrators, not just the company.

And then, there is a research component as well, as I find in almost every company, which comes from the university, Professor Roland Winston at the University of California at Merced, who invented something called non-imaging optics. As a physicist, I was shocked that you really can fool Mother Nature into collecting more light than I would have expected as an astronomer. You can have both broad field of view and enormous magnification, as long as you don't have to see what's there. The solar cell doesn't care what it sees, it doesn't matter where the light is coming from, it still converts it. So, this thing here by the way has only eight parts, which is only one more than the .89 cent nail clippers you can buy on a key chain at WalMart.

So, the cost would be $6 on here, which works out to about .50 cents a watt, is the biggest single cost, and I need hardly remind you, silicon is like $4 or $5 a watt, if you can get it. So, this is a big advance, this is a big advance, and it's coming, just a simple example at Silicon Valley. There are lots of other examples, I can give you examples in fuel cells, you know about some of those and others, but I thought that was one example, we are not talking about details here today.

So finally, what should the government do? First and foremost in my judgment, and I can't mention this strongly enough, and that is to continue the tradition of supporting our country's research universities. I'm old enough to have benefitted from the Korean War GI Bill, and that started the whole post war boom, from which the United States had an acceleration which has kept us way ahead of the rest of the world. The universities are at the heart of all this, and just as mentioned, Stanford, they mention Berkeley as well, everybody wants a Silicon Valley, and every Silicon Valley, wherever they are in the world, has a great university at heart.

Another thing, the subsidies, there's a wide variety of them. I really like variety. Some come from the states, some come from all sorts of other places. They spur demand. They get people interested, but the interesting thing, while some people think that is needless duplication, what it does is it encourages exactly the kind of exploration and opportunistic advances that have made our country's venture a buzzword, you know, essentially, the unmatched model for progress in the entire world.

I've gone to many countries. Everybody says, how do we get our own Silicon Valley, or how do we make ours like the one there? And, one size fits all buzzwords are great, because they lead people into the future, but you don't want to lead people too fast unless you really know where you are going, things like hydrogen economy for example, you know, I think we ought to be moving past some of those things, and I think we are.

Now, another thing, there's the vast and diverse needs of the Federal Government, those triple junction solar cells were spurred by the high prices of them. They are used for aerospace, for defense, other purposes, they weren't ready for commercialization, but they are available now, because all this stuff from the Federal Government that comes, those needs generate a very important demand. And, some of that demand is going to renewable energy, for

more efficient, lighter weight, lower consumption, even for diverse sources of diesel oil for the U.S. Navy through, perhaps, biodiesel—all sorts of things that are moving this ahead.

And then, so it's great that federally-funded sales sometimes showcase energetic products as well.

And so, the last thing is the partnering between the federal labs and the private industry. I think in some cases it's very good. One of my companies, for example, has a very nice CRADA, and I now understand what Cooperative Research and Development Agreement, you know, what it stands for, with the National Renewable Energy Laboratory; and that's worked wonderfully to get this company jump started. So, that's a nice thing.

And finally, you mentioned the developing countries, there are opportunities and challenges there, and for me the opportunities in developing countries for us to sell to them, we have the inter-company partnering. We have local manufacturing, local distribution, local support, and as those—and as unit costs drop, because they can't afford subsidies for that stuff, that will continue.

But, it isn't just colonialism, it is the other side of that. Because other countries have lower levels of infrastructure, it may not be that the centralized manufacturing and distribution models, I mean, Dr. Chu showed this fantastic ethanol plant, you know, cellulosic ethanol plant, in other places you may want to go with something which is more labor intensive and could be done locally.

By example, in a country like India, the southern half, which has heavy rainfall, would be very good to produce ethanol through sugar cane. You don't need a microbe, you just have local people cut it up, because ethanol can be made very quickly from sugar in local areas, transportation costs are saved, and there is labor for the farmers who then make their own fuel on the spot. And so, there's a lot of opportunity there. The transportation cost is terrible in some of these remote areas, so, it helps.

In the northern area, you probably would go with Jatropha, one of the species in the Genus Jatropha, which makes an inedible nut, which can be squeezed and used directly as biodiesel, and so you would find on that end the local—just a simple calculation that shows that a farmer, an unusable acre can give a farmer about $1,000 a year of cash income in a Third World area for a part-time job, just harvesting nuts, hiring somebody in a pick-up truck to take them to the local little processing plant, which doesn't have to be much bigger than something that can be fit in a container. So, that kind of thing is wonderful in the Third World, not something we are going to use here, but we can export that technology and folks in India are really moving very fast with it anyway, we don't have to teach—they have places like IIT, you don't have to worry that they understand those things.

Chairwoman BIGGERT. Doctor, would you sum up, please?

Dr. PENZIAS. I'm done. Thank you.

[The prepared statement of Dr. Penzias follows:]

PREPARED STATEMENT OF ARNO A. PENZIAS

Thank you for allowing me to contribute to this important hearing. I have framed my prepared testimony to respond to the four questions posed in the Charter for this hearing.

**1. What is the current state of adoption of renewable energy sources in the United States? What factors are limiting the rate of adoption of renewable energy technologies?**

Right now, I think it's fair to say that relatively high cost and current supply constraints associated with currently-available renewable energy technologies are limiting adoption.

**2. What is the outlook for potential improvement in market penetration of renewable energy technologies? What are the main research efforts that could improve that outlook?**

Based upon what is currently happening in this technology area, I see the outlook for dramatic improvements in market penetration as being very positive. As an active venture investor and advisor for the past ten years, I can recall few investment areas which have engendered a degree of investment interest comparable to what we now see in the renewable energy arena. Speaking personally, I very much share this point of view, so much so, that I now devote the major portion of my efforts to investments in this area.

I have been concerned about energy issues for some thirty years, and have worked to seek and perfect alternatives to our country's dependence upon fossil fuels, but felt frustrated by the lack of viable alternative approaches to this vexing problem. It wasn't a question of resources or interest. Even given the best intentions, talent and resources, program after program yielded little in the way of concrete results. In the last few years, however, this situation has taken a dramatic turn for the better, thanks to a growing array of novel ways is which advances in a wide variety of seemingly-unrelated technology areas—as well as in several areas of applied science—are being employed to overcome my earlier concerns about conventional approaches to green energy.

Silicon solar cells, for example, work well but cost too much to produce and install. Despite some incremental progress in silicon device costs, I see other photovoltaic technologies poised to grow far more rapidly—notably large-area PV modules based upon thin crystalline films and organic materials, as well as novel approaches to even higher efficiencies through a combination of emerging advances in sunlight concentration, with small but extremely efficient multi-junction devices.

I can illustrate this last point in detail, by citing three key elements of a solar concentrator recently completed by SolFocus—our firm's most recent energy investment. These innovations should give you the flavor of what went into their design. First: the use of an innovative imaging geometry called non-imaging optics (created and perfected by Professor Roland Winston of the University of California, Merced) allows each module to capture more solar energy per square inch of area than the most perfect conventional magnifier one can buy. Second: the precision optics necessary to implement this minor miracle can be formed and assembled out of a total of only eight parts per module, including the detector, at a manufacturing cost comparable to that achieved by the makers of today's sealed automotive headlights (the enabling technology in this instance). Third: The concentrated light is converted into electricity with unsurpassed efficiency by a unique triple-junction solar cell invented at the National Renewable Energy Laboratory (far more expensive per unit area than other types of solar cells, a tiny device serves a surface area some five hundred times larger).

**3. What should the Federal Government be doing (or not doing) to encourage the commercialization of, and demand for, new renewable energy technologies? How well aligned are the Department of Energy's activities with what the investment community is doing?**

First and most important, in my judgment, the Federal Government can encourage the commercialization of new renewable technologies through continued support for our country's universities, the source of America's innovation edge, a tradition of support that traces back to the land grant colleges of the 19th century and the GI Bill that fueled our country's emergence as the world's unquestioned leader in science and technology. There is hardly a place on the face of this Earth that doesn't hope to have its own "Silicon Valley," rooted in the presence of a great university. With the demise of vertical integration as the economic base for corporately supported long-term applied research, the task of fueling continued innovation has fallen upon our university system.

The wide variety of mandates, subsidies and other incentives for the creation and use of alternative energy, enacted at the federal and State level, serve to spur demand for new technologies of various kinds, thereby spurring innovation, investment, market testing and further innovation, in virtuous circles. The great virtue

of what some might see as needless duplication encourages exactly the kind of exploration and opportunistic advances that has made our country's venture capital system the unmatched model for progress in the global economy. One-size-fits-all buzzwords, such as "hydrogen economy" can help focus attention, as long as they don't constrain behavior.

The vast and diverse needs of federal agencies and suppliers frequently offer ideal early test beds for new solutions to under-solved problems. Given the necessarily complex nature of federal procurement regulations, I'm pleased that federally-funded sales of innovative products have often proven to be an early means of show-casing new alternative-energy ideas and products.

At Bell Labs, I encouraged active partnerships between efforts in my research organization with those business-oriented organizations, by making sure that both sides had skin in each game. In the same way, I now see successful examples of alignment between DOE Labs and the investment community, in the increasing use of CRADA's, particularly at NREL.

**4. What opportunities and challenges exist for the sale and use of renewable energy generation in developing countries? How do these opportunities and challenges differ from those in developed countries?**

Opportunities include inter-company partnering, particularly in the case of local manufacture, distribution and support, for energy technology developed in the U.S. These opportunities should grow dramatically as unit costs drop to more attractive levels Challenges include difficulty in applying common business practices and the protection of intellectual property.

Given the lower levels of infrastructure in the developing world, the centralized manufacture and distribution models favored in our country may not apply as universally. On the other hand, labor intensive installation costs ought to prove less of a barrier to adoption in developing economies.

In biofuels, for example, short term opportunities in the U.S. would include using existing feed stocks—such as corn for ethanol, and waste grease and edible seed oils for biodiesel, possibly followed later by cellulosic ethanol. In the developing world, we are more likely to see special plants (especially Jatropha) in arid areas such as northern India, and sugar cane in areas of abundant rainfall. These crops appear especially useful in the developing world, where transportation favors local processing on small scales, with the work of harvesting done by local farmers as an additional source of income.

BIOGRAPHY FOR ARNO A. PENZIAS

Arno Penzias is a Venture Partner at New Enterprise Associates. In this role, he prowls Silicon Valley and similar places, seeking out promising technology futures and catalyzing their applications. His present Board memberships include Glacier Bay, Ion America, and Konarka. In addition to helping NEA portfolio companies on an as-needed basis, in areas such as technology, strategy, and intellectual property, Arno serves on—and frequently chairs—Technical Advisory Boards for a number of NEA companies such as Alien Technology, Heliovolt, Hillcrest Labs, Luxtera, Motion Computing, SolFocus, Spreadtrum Communications, Telegent Systems, and Teneros. A long-time skeptic on the commercial viability of "alternative energy" technologies, he now finds his earlier conclusions outdated by the advances made in number of seemingly-unrelated technologies, and their exploitation by a relatively-small handful of entrepreneurs. Having found a few already, he earnestly hopes to find—and help finance—more of them.

Dr. Penzias began his scientific career in 1961 when he joined Bell Laboratories as a Member of Technical Staff. He conducted research in radio communication and took part in the pioneering Echo and Telstar® communications satellite experiments. As a scientist, he is best known for his work in radio astronomy—most notably, the discovery of Cosmic Background Radiation, which earned him the Nobel Prize for Physics, in 1978, together with Robert Wilson—as well as his pioneering work in the detection and study of a rich variety interstellar molecules, thought to be a possible basis for the development of life.

He left Bell Laboratories in 1998, having led its world famous research organization, and then serving as its Chief Scientist.

The author of over one hundred scientific and technical papers, he is also a sought-after speaker on emerging trends, and has written a number of articles on information technology, especially its impact on business and society. His highly acclaimed book on the subject, *"Ideas and Information"* was published by W.W. Norton. A second book, entitled *"Digital Harmony: Business, Technology, and Life After*

*Paperwork"* published by Harper Collins, charts the course of the Information Revolution and its demands for higher levels of system integration.

A member of both The National Academy of Sciences, and The National Academy of Engineering, Dr. Penzias received a Bachelor of Science degree from the City College of New York, after serving in the U.S. Army Signal Corps he attended Columbia University where he received his Master's and doctorate degrees. He has also received a number of honorary degrees, as well as other awards for his contributions to science, R&D management, and public service.

Chairwoman BIGGERT. Okay, thank you.

Mr. Larsen, you are recognized.

**STATEMENT OF MR. CHRISTIAN B. LARSEN, VICE PRESIDENT FOR GENERATION, ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CALIFORNIA**

Mr. LARSEN. Chairman Biggert, Mr. Honda, I represent the Electric Power Research Institute, which is a non-profit collaborative R&D organization conducting electricity-related research in the public interest. Our public and private members account for about 90 percent of the kilowatt-hours sold in the U.S., and we now serve over 1000 electricity and governmental organizations worldwide, in about 40 countries.

EPRI appreciates the opportunity to address the future prospects for renewable energy, and I really appreciate the invite.

I'd like to make several key points. The U.S. must keep all of its energy options open to meet the uncertainties of the future. For electricity, this means improving the economics, the integration and utilization of renewables and energy efficiency as well as building and sustaining a robust portfolio of affordable generating options for the future, and this means also ensuring the continued use of coal, nuclear and natural gas.

EPRI believes that prudent investment decisions for power plants in the future need to include considerations associated with generating power in a carbon constrained future. Whether decision-makers assume the future cost of $CO_2$ to be zero as it is today in the U.S., or $30/ton, or $50/ton, this all dramatically changes the relative cost of the various supply options. A carbon-constrained future could and would make renewable energy more economically competitive and more important.

Currently renewable generation, excluding large hydro, contributes less than two percent of the Nation's electricity supply. Until recently, the expected future role of renewable energy in the U.S., based on projections from the Energy Information Agency using the NEMS model and other models, has not been significant. Long-term estimates for contribution of renewables to total electric energy remain around two percent.

Recently, some new EPRI modeling shows that the role of renewables, as well as other low and non-emitting resources, could be expected to increase substantially. In one base case scenario in an EPRI model, the estimates showed the contribution for renewables by 2050 in the range of five to six percent. Now, this represents 700 to 800 percent increase over today's megawatt hours, and this should be noted that this was not taken into account in the introduction of a disruptive technology that could significantly decrease the cost of these renewables.

Various distributed generation technologies, which include renewable energy sources, such as roof-top solar, are being developed and they will enhance the current distribution system. These will add power system flexibility, increase end-use efficiency. Distributed generation and central station generation are not either/or alternatives; EPRI believes that they will have to complement each other in the future power delivery system.

There also needs to be recognition that future renewable technologies as solar, wind and, eventually, ocean energy are not dispatchable, i.e., controllable, resources and that there will be a cost associated with the integration of these resources into the system. This cost is small today, when the significant portion of available generation, such as nuclear hydro or gas turbines, is dispatchable. However, as the percentage of renewable generation increases, so will the cost of grid integration.

Finally, technology breakthroughs will undoubtedly enable renewable energy to meet the electricity demand in new and better ways. Economic roof-top solar, clean fuels from biomass, effective energy storage with hydrogen, or advanced batteries, would help diversify U.S. energy resources and bring new opportunities to the electricity industry.

In summary, given the expected growth and demand for electricity and the many uncertainties in our energy future, we believe that developing diversity in electric generation is critical as an objective for the country, also striving for cleaner and more sustainable resources will bring more renewable energy into the mix, and future breakthroughs in cleaner fuels, photovoltaics, and energy storage will change the nature of the electric grid. These will not replace the need for the electric grid, but they will increase its flexibility and value to the country.

Thank you for the opportunity to speak today.

[The prepared statement of Mr. Larsen follows:]

PREPARED STATEMENT OF CHRISTIAN B. LARSEN

Chairman Biggert and Members of the Committee:

I represent the Electric Power Research Institute, which is a non-profit collaborative R&D organization conducting electricity-related research in the public interest. EPRI has been supported voluntarily by the electricity industry since our founding in 1973. Our public and private members account for more than 90 percent of the kilowatt-hours sold in the U.S., and we now serve more than 1,000 energy and governmental organizations in more than 40 countries.

EPRI appreciates the opportunity to address the future prospects for renewable energy. I would like to make several key points in my testimony.

**Key Points**

1. The U.S. must keep all of its energy options open to meet the uncertainties of the future. For electricity, this means improving the economics, integration and utilization of renewables and energy efficiency as well as building and sustaining a robust portfolio of clean, affordable generating options for the future—ensuring the continued use of coal, nuclear and natural gas.
2. EPRI believes that prudent investment decisions for power plants in the future need to include considerations of the economies associated with generating power in a carbon constrained future. Whether decision makers assume the future cost of $CO_2$ to be zero as it is today in the U.S., or $30/ton, or $50/ton, dramatically changes the relative cost of the various supply options. A carbon-constrained future could make renewable energy more economically competitive and more important.

3. Currently renewable generation, excluding large hydropower, contributes less than two percent to the Nation's electricity supply. In 2005 the majority of global renewable installed capacity (excluding hydropower) came from wind, biomass combustion, and photovoltaic solar. The remainder of the global renewable installed capacity includes some biomass gasification, thermal solar and ocean energy demonstrations. Until recently the expected future role of renewable energy in the U.S.—based on projections from Energy Information Agency (EIA), the National Energy Modeling System (NEMS), and other models—has not been significant. Long-term estimates for the contribution of renewables to total electric energy have remained around two percent. Even when the current renewable portfolio standards adopted in 23 states are applied through 2017, the contribution of renewable resources would not likely exceed three percent of the total electric energy that will be needed in 2017.

Source EPRI *Renewable Energy Technical Assessment Guide: TAG-RE 2005* (1010407, 12/05)

| Renewable Energy Technology | Status | 2005 World Installed MW | Issues |
|---|---|---|---|
| Wind | Commercial | 52,100 | Integration at large scale |
| Solar PV | Commercial | 3,900 | Conversion Efficiency & Cost |
| Solar Thermal | Demo & Pre-Commercial | 370 | High Capital Cost |
| Biomass Combustion | Commercial | 20,000 | High Fuel Cost |
| Biomass Gasification | Pilot & Demo | <20 | Hot Gas Cleanup |
| Ocean Energy | Pilot & Demo | <20 | Cost and Reliability |

Figure 1. 2005 Global Installed Renewable Capacity

4. However, recent EPRI modeling shows that the role of renewable, as well as all other low and non-emitting resources, could be expected to increase substantially. New renewable energy resources, primarily wind, solar and biomass, are expected to exceed the current portfolio standard requirements. In a base case scenario EPRI estimates renewable contribution to electric energy by 2050 in the range of five to six percent. This represents a 700-800 percent increase over today's contribution of 100 MMW–Hs, reaching roughly 750 MMW–Hs by 2050.
5. Various distributed generation technologies which include renewable energy sources, such as roof-top solar, are being developed that will enhance the current distribution system. These will add power system flexibility, increase end-use efficiency with technologies such as combined heat and power, and reduce power delivery losses. Distributed generation and central station generation are not either/or alternatives; EPRI believes they will complement one another in the future power delivery system.
6. There needs to be recognition that future renewable technologies as solar, wind and, eventually, ocean energy are not dispatchable resources and that there will be a cost to integrate these resources into the electricity system. The cost is for the supporting generation that will be needed to match supply and demand instantaneously, to follow energy demand ramping, and to provide the reserves required to maintain grid reliability. This cost is small when a significant portion of available generation resources are dispatchable,

such as hydro and gas turbines. However, as the percentage of renewable generation increases so will the cost of grid integration.

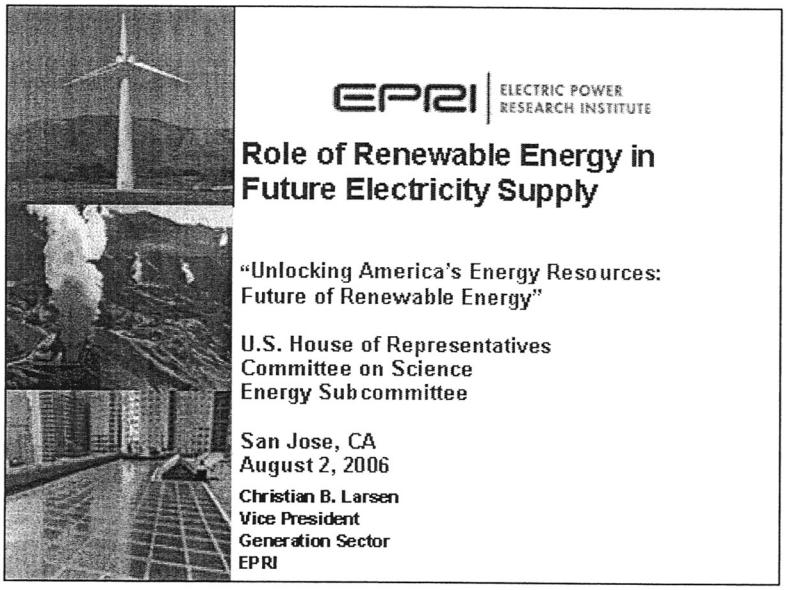
7. Technology breakthroughs will undoubtedly enable renewable energy to meet electricity demand in new and better ways. For example, economic roof top solar, clean fuels from biomass, effective energy storage with hydrogen, or advanced batteries, would help diversify U.S. energy resources and bring new opportunities to the electric industry.

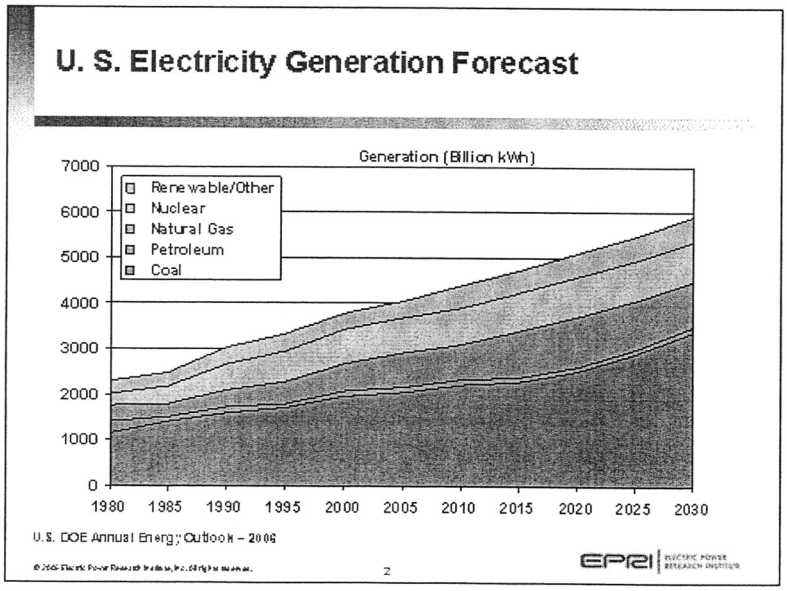
**Summary**

Given expected growth in the demand for electricity and the many uncertainties in our energy future, we believe that developing *diversity* in electric generation is a critical objective for the country. Also, *striving for cleaner and more sustainable* resources will bring more renewable energy into the mix. *Future breakthroughs* in cleaner fuels, photovoltaics, and energy storage will change the nature of the electric grid. These will not replace the need for the electric grid but will increase its flexibility and value to the country.

Thank you for the opportunity to provide these comments to the Subcommittee.

Appendix – Role of Renewable Energy in Future Electricity Supply



## Renewable Energy Technology Overview

Source : EPRI *Renewable Energy Technical Assessment Guide: TAG-RE 2005* (1010408, 12/05)

| Renewable Energy Technology | Status | 2005 World Installed MW | Issues |
|---|---|---|---|
| Wind | Commercial | 52,100 | Integration at large scale |
| Solar PV | Commercial | 3,900 | Conversion Efficiency & Cost |
| Solar Thermal | Demo & Pre-Commercial | 370 | High Capital Cost |
| Biomass Combustion | Commercial | 20,000 | High Fuel Cost |
| Biomass Gasification | Pilot & Demo | <20 | Hot Gas Cleanup |
| Ocean Energy | Pilot & Demo | <20 | Cost and Reliability |

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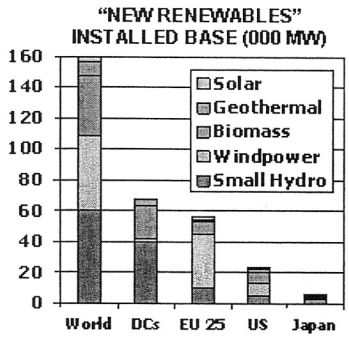
3

EPRI ELECTRIC POWER RESEARCH INSTITUTE

## State of the Global RE Market
## 160,000 MW Installed Growing at 25 GW/Year




**Plus:**

**720,000 MW Large Hydro**

**220,000 MW (th) Biomass Heating**

**28,000 MW (th) Geothermal Heating**

**77,000 MW (th) Solar Heating**

**1,000 MW of off-grid solar PV systems**

Source: Renewables 2005: Global Status Report

Total Renewable Energy = 1,206,000 MW Equivalent for Electricity and Heating Around the World

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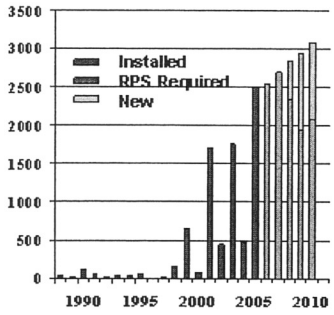
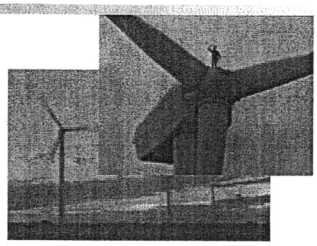
4

EPRI ELECTRIC POWER RESEARCH INSTITUTE

## Wind Power




Sources: AWEA, GE Wind, and ACORE



9,700 MW Installed Base 2005
35,000 MW estimated by 2015
Key Issues:
. Turbine availability
. RPS extension past 2007
. Siting and Transmission

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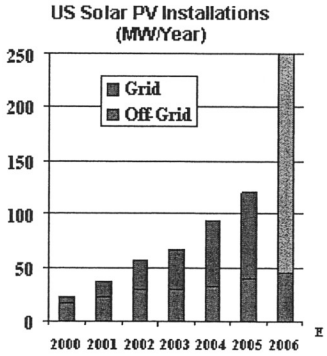
## Solar PV
## $7 Billion/Year Global Industry




Sources: PV News and ACORE

Approximate 5,000 MW in place
Adding 1,500 MW/year globally

Key Issues:
. Global competition
▪ Distribution system impact

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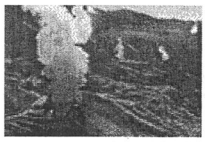
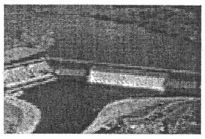
## Geothermal, Hydropower and Solar Thermal-Electric



500 MW contracts

Solar Dish-Sterling: 350 MW Contracts



Incremental hydro

Solar Trough: 50 MW Under Construction

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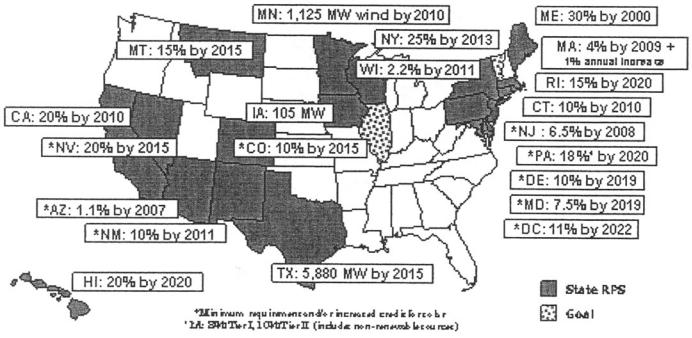
## Renewable Portfolio Standards

January 2006




*Minimum requirements and/or increased credit for solar
'IA: SWTier I, 1GWTier II (includes non-renewable sources)

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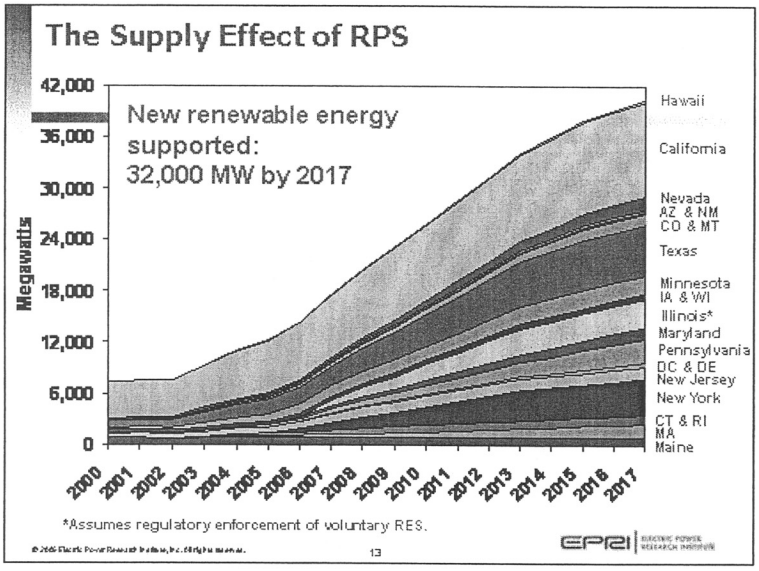
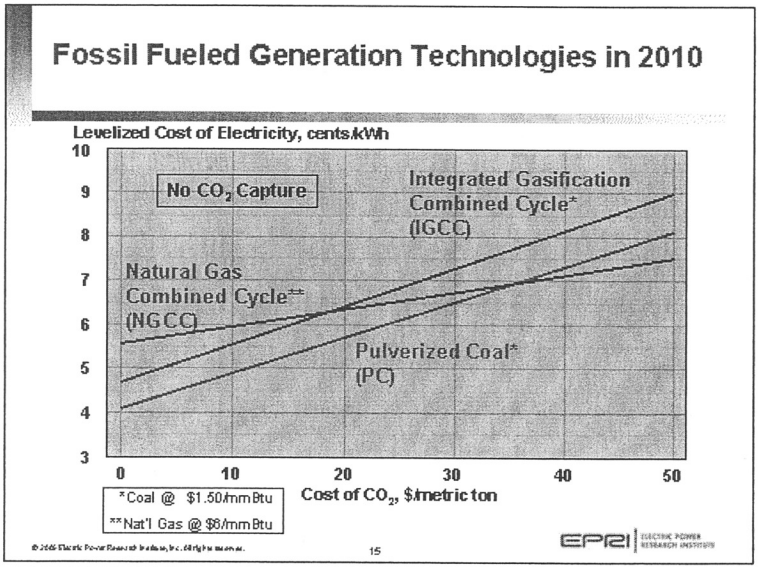
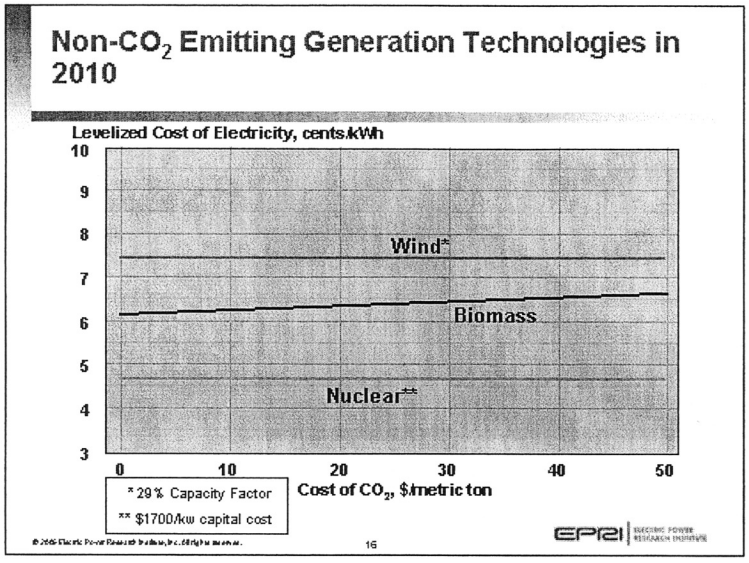
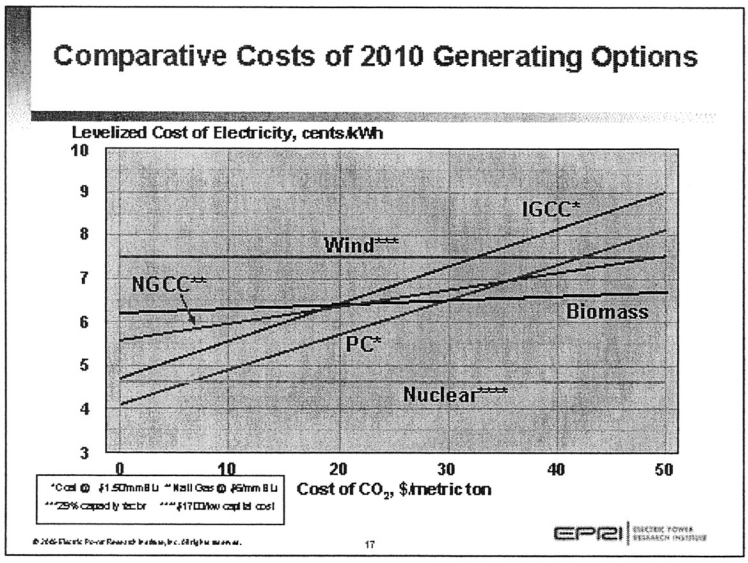
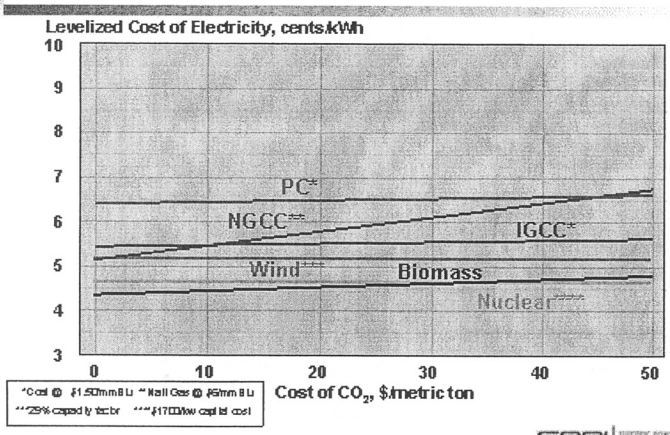

The Supply Effect of RPS
New renewable energy supported:
32,000 MW by 2017
Megawatts
42,000
36,000
30,000
24,000
18,000
12,000
6,000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Hawaii
California
Nevada
AZ & NM
CO & MT
Texas
Minnesota
IA & WI
Illinois*
Maryland
Pennsylvania
DC & DE
New Jersey
New York
CT & RI
MA
Maine
*Assumes regulatory enforcement of voluntary RES.
13


Fossil Fueled Generation Technologies in 2010
Levelized Cost of Electricity, cents/kWh
10
9
8
7
6
5
4
3
No $CO_2$ Capture
Integrated Gasification Combined Cycle* (IGCC)
Natural Gas Combined Cycle** (NGCC)
Pulverized Coal* (PC)
0
10
20
30
40
50
Cost of $CO_2$, $/metric ton
*Coal @ $1.50/mmBtu
**Nat'l Gas @ $6/mmBtu
15


Non-$CO_2$ Emitting Generation Technologies in 2010
Levelized Cost of Electricity, cents/kWh
10
9
8
7
6
5
4
3
Wind*
Biomass
Nuclear**
0
10
20
30
40
50
Cost of $CO_2$, $/metric ton
* 29% Capacity Factor
** $1700/kw capital cost
16


Comparative Costs of 2010 Generating Options
Levelized Cost of Electricity, cents/kWh
10
9
8
7
6
5
4
3
IGCC*
Wind***
NGCC**
Biomass
PC*
Nuclear****
0
10
20
30
40
50
Cost of $CO_2$, $/metric ton
17

## Comparative Costs of 2020 Generating Options




*Cost @ $1.50/mmBtu **Natural Gas @ $5/mmBtu
***25% capacity factor ****$1700/kw capital cost

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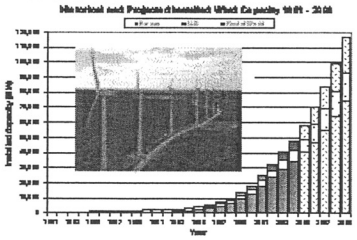
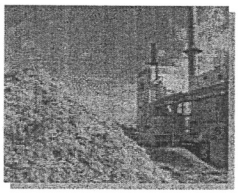
## Wind and Biomass Status and EPRI Program Direction

### Wind

- Maturing technology and significant resources, ~ 50 GW worldwide. Wind will play important role as non-emitting generation of choice.
- Future focus on integration issues on/ off shore, forecasting, condition monitoring, emerging operation and maintenance issues as utility own wind.





### Biomass

- Fits utility's traditional model, central dispatchable, interest has been with co-firing, testing, corrosion assessment, etc
- Direction is to track European experience broaden look to biofuels, gasification, more co-firing tests, develop biomass deposition.

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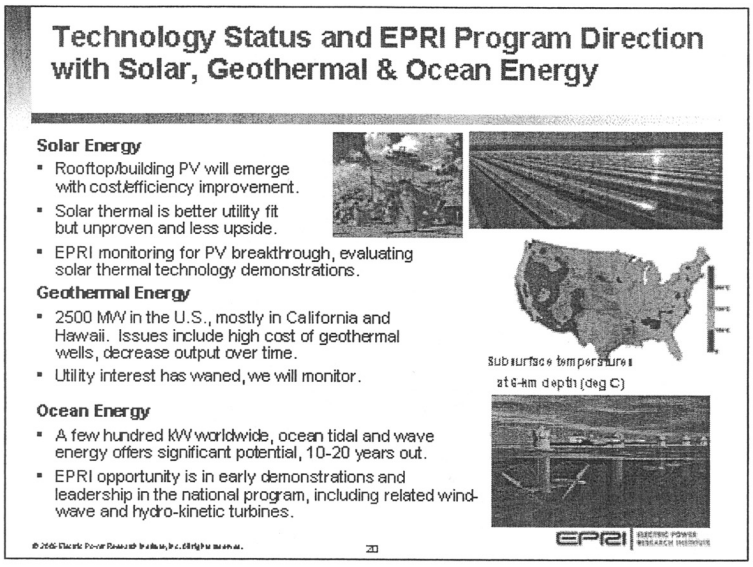


BIOGRAPHY FOR CHRISTIAN B. LARSEN

Chris Larsen is Vice President of Generation at the Electric Power Research Institute. He joined EPRI in November 2004 as President and Managing Director of EPRI International, Inc., a wholly owned subsidiary and transitioned into his current role in January, 2006.

Prior to joining EPRI, Larsen spent the majority of his career with GE Energy working in the nuclear energy division. Larsen started his career as an applications project manager, servicing nuclear power plants at customer sites internationally. Larsen then transitioned into the GE corporate Six Sigma initiative as a Master Black Belt focused on the process improvement for the new and refurbished parts services business. Larsen's last role prior to joining EPRI was General Manager of the Reactor Services business unit which was responsible for providing Inspections, Outage Services and Reactor Modifications for nuclear utilities worldwide.

Larsen received a Bachelor's degree in Mechanical Engineering from Georgia Tech.

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

August 1, 2006

Representative Judy Biggert
Chairwoman, Subcommittee on Energy
House Committee on Science
Suite 2320, Rayburn House Office Building
Washington DC, 20515-6301

Dear Representative Biggert:

This is to provide a record of financial disclosure according to the Rules of the House of Representatives for testimony at your Subcommittee's hearing entitled, "Renewable Energy Technologies - Research Directions, Investment Opportunities, and Challenges to Deployment in the U.S. and the Developing World" on Wednesday, August 2, 2006. I am the Vice President of the Generation Sector at the Electric Power Research Institute, Inc. ("EPRI").

The following are the current federal funding contracts that directly support the subject matter on which I will testify before the Subcommittee:

| Federal Sponsor | Period | Amount |
|---|---|---|
| 1) Natural Resources Conservation Service, U.S. Department of Agriculture | 2004-2006 | $241,933 |
| 2) U.S. Department of Energy | 1994-2006 | $9,350,000 |
| 3) National Renewable Energy Laboratory | 2005 | $20,000 |
| 4) National Renewable Energy Laboratory | 2002-2003 | $150,000 |
| 5) U.S. Department of Energy | 1996-2001 | $6,006,000 |

Please let me know if you require any further information regarding these federally funded contracts.

Sincerely,

Christian Larsen
Vice President

Chairwoman BIGGERT. Thank you very much.

Mr. Pearce, you are recognized for five minutes.

**STATEMENT OF DAVID PEARCE, PRESIDENT AND CEO, MIASOLÉ, SANTA CLARA, CALIFORNIA**

Mr. PEARCE. Thank you for the opportunity to present here today. Madam Chair, you did get the name correct, it's Miasolé, which loosely translates into my sun.

I'm here to talk about solar electricity. If I could have the next slide, please, but just a quick overview on Miasolé, we are a Santa Clara-based California manufacturer of thin-film solar cells, a bit unique in that we are trying to bring manufacturing jobs back to the Silicon Valley, with an 80,000 square foot facility. We expect to be in volume commercial production later this year.

Myself and my team have a very long history of high volume thin-film component manufacturing, going back to the '80s where we made the hard disk drives for data storage applications, more recently, optical components for fiber optic communication, seeing the same core technology to produce thin-film solar cells.

We are backed by several leading venture capitalists, the most significant of which are Kleiner Perkins and VantagePoint Venture Partners.

Next slide, please.

So, a little background on the solar industry. One, the industry has been experiencing a 43 percent compounded growth rate for the last five years, so it's caught a lot of attention of the investment community, and is certainly making great strides. There is increasing adoption worldwide of incentives and subsidies to support the growth of the solar industry. Just last week, the country of France introduced some major incentives, very close to those being implemented right now by Germany. And certainly, the State of California leads in the U.S., in terms of the size of its total electric program.

The very high demand, though, for solar has created shortages for one of the key feedstocks, the basic silicon material that is used to make the dominant form of solar cells, this is based on crystalline silicon technology. This is a 50-year-old technology that today represents 94 percent of the market.

We believe at Miasolé, and as do many of our competitive startups, that there is an emerging class of thin films that hold tremendous potential to dramatically lower the cost of solar. In particular, the thin-film technology allows the capability of building flexible solar cells, flexible modules, opens up the opportunity for a great number of new applications, easing of installation processes, and, basically, opportunities to attack the entire value of solar.

Miasolé's thin-film technology, we believe, will be capable of supporting a 60 to 70 percent reduction in the price of solar, and generating a reasonable profit margin for the company in the process. At that point, solar is competitive with grid generated electricity from conventional sources, in the range of .8 to .10 cents a kilowatt hour, and we believe this goal will be reached well within the time frame of the U.S. Department of Energy's Solar American Initiative, which has set a goal to achieve price parity by 2015.

And, I mentioned we are not alone, we have several, you know, very strong venture-backed entrepreneurial companies that have also entered this market. We think the entire industry is on the cusp of some major changes, and it's exciting to see the investment coming in, it's exciting to see the attraction of very senior management that bring with them a breadth of manufacturing and high-volume experience. So, I think the stage is very much ripe for disruptive change.

So, I'll speak a minute now about thin films. Thin films represent a class of semiconductor material that by its very name it's very thin film, of approximately 1/100th the thickness of standard silicon solar cells. There's no dependence from the silicon feedstock that are currently in limited supply.

In our case, it's a continued deposition process. We literally take a meter-wide coil of stainless steel, about two miles in length, and continuously coat all the solar films on it, at a rate of two linear feet a minute. We are currently building two of these very high-volume roll coaters in Santa Clara, and expect to populate our factory with eight of the systems by the end of 2007. If we achieve those ambitious goals, it would make Miasolé the largest producer of thin film solar cells in the world.

Laboratory efficiencies for the material we are working with, which is, the acronym is CIG, of the elements in the semiconductor, very high efficiency, 19½ percent achieved in the government lab, very close to that of a polycrystalline silicon. The issue has been while the laboratories have done tremendous research work, it hasn't really translated in a significant way into the commercial marketplace. What the commercial market has lacked is high-volume manufacturing technology, and that's what is starting to happen with companies like Miasolé and some of our competitors. We are all taking slightly different angles, but we are trying to leverage other industries to bring high-volume manufacturing technologies to what's been proven in the government lab, and that is a tremendous stepping stone to have all that fundamental research done and behind us.

The flexible solar cell in our case from this very thin stainless coil allows for flexible modules, again, easy to install, lower the cost throughout this valued thing, and I think the most important thing that is going to happen to solar over the next five years is, we are going to see a major move to improve building integrated photovoltaics, where PV becomes the ubiquitous with the installation of a new roof on a new home or a new commercial building. Right now, the vast majority of the market is retrofit, and we need to have a paradigm shift there.

And, here's the final slide, what can Congress do to help? Well, I think already some big steps are being made. There is currently out for solicitation the Solar America Initiative, which is virtually a doubling in funding for solar research, about $148 million a year. A major portion of that would be granted to the most promising private companies to accelerate research activities.

I believe there's an opportunity with the Department of Energy's Building Program. This is a program that to a large extent is focused on efficiency and zero energy homes, with a goal of achieving by 2020 a zero energy new residential construction.

Well, with the shift in population in the U.S., to the south, the west, and the desert southwest, they have tremendous new residential developments. I visited one just a month go in Albuquerque, that's proposing 37,000 new homes. That's a tremendous opportunity to put solar on every one of those roofs, and if we miss that opportunity it's 20 years before we get another shot at it, because that roof is not going to be replaced for 20 years.

So, I think maybe a closer look at the Building Program and how we could marry that up closer with the Solar American Initiative.

Last year, the Energy Bill included a provision for 30 percent investment tax credit for solar installation. It was capped at $2,000 for residential. First, it's very impressive that we got that level of investment tax credit through, but I'd like to see it expanded through 2015 as presently proposed, and also an expansion of the residential credit, because $2,000 is insufficient to cover the typical electrical needs of residential homes.

And finally, at the commercial building level, I think there's opportunities for a federal loan guarantee program. We have such facilities for large power plants, but if we could down size that and make it available to commercial buildings to large-scale distributed solar generation I think there's a significant opportunity.

Right now, as a business owner, and I look at opportunities to spend my capital budget, I, like most of my brethren, look at a two or three-year payback. You just can't get that with solar, because you are really buying an asset that generates free electricity for 25 years. So, if there was some financial facility that made it possible for the commercial building owner, be it the big-box retailer, or the big warehouse, to put solar on in a mechanism to kind of get that off their balance sheet so they could justify the financial investment. I think that would go a long way to making commercial installation much bigger.

Thank you.

[The prepared statement of Mr. Pearce follows:]

PREPARED STATEMENT OF DAVID PEARCE

Thank you for the opportunity to testify before the distinguished Committee on Science. By way of background I am the CEO of Miasolé, a Santa Clara, California based manufacturer of thin-film solar cells. Miasolé has been in operation since late 2001 and exclusively focused on thin-film solar cells since early 2003. Miasolé occupies an 80,000 square foot manufacturing facility in Santa Clara and expects to commence high volume commercial production in the forth quarter of this year. The company's employment has grown from 16 employees this time last year to 58 in Santa Clara today. We expect to have over 100 local employees by year-end.

Miasolé is backed by several leading Bay Area venture capital firms including Kleiner Perkins Caulfield and Byers and VantagePoint Venture Partners, both of whom have a significant focus on alternative energy investments. Floyd Kvamme, a Kleiner partner, serves as co-Chairman of the Presidents Counsel of Advisors for Science and Technology. I have had the honor of speaking before this distinguished group regarding the potential for thin-film solar and have also met with Samuel Bodman, Secretary of Energy and Under Secretary, David Garman. There is wide spread support for Miasolé's activities and for the potential for thin-film technologies to significantly reduce the cost of solar generated electricity.

Miasolé's technology is highly disruptive and is expected to result in a 60–70 percent reduction in the cost of installed PV systems within five years, thus allowing PV to be competitive with conventional fossil fuel sources of electricity without the continuing need for subsidies. Our technology is based on thin-film solar cells incorporating 1/100th the amount of expensive semiconductor material used in conventional crystalline silicon solar cells. Miasolé's PV modules will be made of flexible laminates, eliminating heavy glass encasements and frames required for today's sil-

icon technology. We expect to integrate electronic functions into the PV module, further reducing costs and simplifying installation. Finally the form factor for Miasolé's solar material is highly flexible enabling truly building integrated photovoltaics ranging from residential roofing shingles that have the appearance of composition shingles to membrane roofing systems for commercial applications.

**Solar Industry Background**

The Department of Energy has funded solar research for more than 30 years with a total investment approaching $3 billion. Unfortunately the U.S. does not have much to show for its investment. After discovering the photovoltaic effect at Bell Labs 51 years ago, the U.S. enjoys only limited market penetration and a small share of global production. Last year Japan represented approximately half of all global production and Germany more than half of all PV installations.

The U.S. has the potential to regain manufacturing and market leadership with a new class of photoactive materials characterized as "thin-films." Thin-films have been well researched and have been widely viewed as having the potential for dramatic reductions in costs. What the industry has lacked is high volume manufacturing technology to leverage the achievements of government funded research. Miasolé believes the age of thin-films has arrived and that the industry is on the verge of major disruptive changes. Miasolé is one of several venture capital funded startups that are bringing high volume manufacturing technologies to bear on this market opportunity.

The early days of photovoltaics served primarily off-grid applications. In recent years the on-grid market has dominated driven by high subsidies and favorable legislation such as net metering which provides a credit mechanism for excess electricity fed back into the grid. The on-grid market is dominated by the retrofit market where PV systems are installed on existing roofs. For truly cost effective solar technology PV needs to become ubiquitous with new construction. This will eliminate retrofit labor and materials and a labyrinth of distributor markups while producing an aesthetically pleasing product that can be more easily financed.

Cost effective building integrated photovoltaics (BIPV) is a challenge with conventional crystalline silicon based solar cells since they must be encapsulated with tempered glass to protect the fragile silicon wafer. The resulting PV modules are heavy and therefore limited in size. Thin-films can be manufacturing on thin flexible substrates and encapsulated with flexible materials. Form factors can be easily adapted to different building requirements with the substantially lighter weight allowing for larger modules and simplified installation.

Ninety-four percent (94 percent) of the photovoltaics market is based on crystalline silicon technology, a fifty year old technology. Another five percent is based on amorphous silicon technology, a more than thirty-year-old thin-film technology that suffers from inherently low efficiency. Two emerging classes of thin-film technologies have demonstrated high conversion efficiencies in government labs approaching that of polycrystalline silicon. These are cadmium-telluride and copper-indium-gallium-selenide (CIGS). Of these two technologies CIGS is the most efficient and is the technology of choice for most new entrepreneurial startups.

Compounded PV system growth rates exceeding 40 percent per year for the last five years have resulted in a significant shortage of polysilicon, the basic feedstock for crystalline silicon solar cells. This shortage has resulted in a doubling in feedstock prices and price increases at the PV module level of approximately 50 percent. Subsidies which were intended to stimulate the market by allowing economies of scale are having the opposite effect. The Senate recently requested a study of the impacts of supply constraints in the polysilicon feedstock industry with the understanding that polysilicon availability posed both a limitation to the growth of the PV industry and a floor to how low prices could go. There is growing concern that crystalline silicon based PV technologies will not be able to achieve the Department of Energy's goal for solar generated electricity achieving price parity with the grid by 2015. A disruptive change is required with both the Senate and DOE providing indications that they view thin films as a very strong solution to the polysilicon shortage.

The solar industry has recently attracted substantial private financing. Venture capitalists have been very active financing new management teams and the public financial markets have been quite receptive to initial public offerings and follow-on offerings. Equally important the opportunities in alternative energy and solar in particular are attracting a new class of highly experience management teams, some of which are steeped in high volume, low cost manufacturing. Most of these new entrants are focusing on thin-film technology. With the accomplishments of federally funded thin-film research, significant inflows of private capital and the attraction of experienced management teams, the stage is set for disruptive change.

It is important to note that most major technical innovations or disruptive business models have not come from venerable established corporations, but from entrepreneurial startups. Examples of industry changing startups that displaced mature organizations include Google, Cisco Systems, Apple, Genentech and Southwest Airlines, to name a few.

**What can Congress do?**

Congress should support the Solar America Initiative by fully funding the request of the Department of Energy. The current request for solar research, including funding national laboratories is $148 million per year, a substantial increase from prior funding levels. Awards should be granted to the most promising cost effective high volume technologies. A byproduct of this is expected to be strong support for disruptive thin-film technologies and a favoring of entrepreneurial companies over mature industry incumbents focused on 50-year-old crystalline silicon technology.

Congress should reevaluate the funding level of the Department of Energy's Building Program currently slated to receive $19.7 million of funding in fiscal 2007. This program focuses on energy efficiency with a goal of providing energy and technology programs needed to achieve "Zero Energy Homes" (ZEH) by 2020. With a shift in population to the south, west and desert southwest where solar irradiance is high there is a tremendous opportunity to adapt BIPV in new residential construction, however, there appears to be a disconnect between the technology goals of the Solar America Initiative and the level of emphasis in the Building Program. Every new major residential development without PV represents a lost opportunity as it will be twenty years before a roof replacement is needed. PV retrofits are not nearly as cost effective as new construction. Congress should consider a step increase in the Building Program with the incremental funds dedicated to BIPV applications for new large scale residential development.

Congress should approve the extension of the investment tax credit for PV systems and lift the cap on the size of residential systems which at the current two KW limit is insufficient to meet the electrical needs of most residential housing. Congress should consider a more aggressive funding level in support of solar installations on new residential buildings, perhaps a direct buy down of the builder's cost of PV systems in new construction.

There is a tremendous opportunity to install PV systems on commercial roofs, particularly with new thin-film technology that allows PV modules to be built into membrane roofing systems. Membrane roofs represent a $10 billion a year industry in the U.S. The challenge with commercial roofs is capital. For example consider a big box retailer with acres of roof space. Senior executives of these companies often have a myriad of capital projects and make funding decisions only for projects with two to three years payback. Solar is akin to buying a new car and prepaying the gas for the next ten years even with cost parity to the grid. The PV system goes on to produce essentially free electricity for twenty-five years or more but virtually the entire cost must be paid up front. Businesses would have far more incentive to install PV systems if additional financing options were available such as third party financing backed by federal loan guarantees. The Federal Government already provides loan guarantees for large scale utility plant construction. Congress should give consideration to a financing program that encourages smaller scale distributed PV systems on commercial rooftops. Consideration should also be given to a funding mechanism for manufacturing assets for PV manufacturers that operate in the U.S. This would allow the U.S. to compete for PV manufacturing jobs that are now going to Europe and Asia due to very large capital grants and/or heavily subsidized income tax rates.

Thank you for the opportunity to voice my opinions on behalf of Miasolé and the solar industry.

**Addendum**

## Additional Detail on the Solar Industry and Emerging Thin-film Technologies

### The crystalline silicon PV industry

The photovoltaics industry has grown in excess of 40 percent per year for the past five years, largely stimulated by government incentives. These subsidies were expected to lead to an increase in the rate of market adoption which in turn would lead to economies of scale and lower installed system prices. Unfortunately high demand has had the opposite effect of increasing costs and increasing industry profit margins. During the past two years a significant shortage of polysilicon feedstock, the basic material for making a silicon solar cell, has emerged causing a major run-up in the price of the feedstock, silicon wafers, solar cells and PV modules. A significant reduction in the cost of installed PV systems is required to realize the potential of solar technology and to make significant inroads in reducing our dependence on fossil fuel sources for electricity generation.

Silicon PV suppliers are trying to bring down their costs through several means which include greater economies of scale (plants are already of significant size), reduced wafer thickness to lessen the use of expensive polysilicon feedstock (with increased manufacturing complexity and higher losses due to breakage), improved photovoltaic conversion efficiencies (a relatively mature 50-year-old technology) and more efficient manufacturing processes, offshore manufacturing, etc. Compounding the problem is that the polysilicon feedstock industry, which supports both solar and semiconductor industries, is demanding and getting higher prices while also requiring long term commitments to insure supply. Polysilicon feedstock costs have more than doubled in the last three years and represent a significant portion of the cost of a completed silicon PV module. Polysilicon feedstock shortages are expected to be address by 2008/9 but high costs are being locked in for five years or longer under long-term supply agreements.

Before the advent of the polysilicon feedstock shortage, the solar industry historically realized four to five percent per year price declines. In order for PV systems to be competitive with conventional sources of electricity without subsidies PV modules prices need to decline from the prevailing rate of approximately $4.00 per peak Watt to the range of $1.00–$1.50 per peak Watt. The goal of the Solar America Initiative is to achieve price parity with the grid by 2015. This will require a compounded price decrease of more than 10 percent per year for the next nine years. Many doubt that crystalline silicon technology can reach this goal.

Besides the expense of making crystalline silicon cells there is considerable added expense associated with silicon technology. First, silicon based PV manufacturing plants are staggeringly capital intensive, on the order of $2–$3 million for each megawatt of annual capacity with factories needing several hundred million dollars of fixed assets to achieve scale. Second, the rigid and fragile silicon wafer must be protected with a tempered sheet of glass. This requirement limits module size due to weight considerations, requires aluminum frames for mounting, bulky mounting hardware, poor aesthetics and high installation costs. Thin-films offer a disruptive path to significantly lower manufacturing costs, simplified and light weight module packaging, ease of installation and the potential for truly "building integrated" photovoltaics (BIPV) where solar becomes ubiquitous with installing a roof during new construction.

To summarize:

- Crystalline silicon solar cells are a 50-year-old technology representing 94 percent of solar industry sales
- Crystalline silicon manufacturing processes are relatively mature; significant economies of scale have already been achieved
- Manufacturing costs have been rising due to polysilicon feedstock shortages; new supply is coming on line in two to three years but at high contracted long-term prices
- Market based subsidies have created high demand which in turn have caused escalating costs and have enabled expanding margins
- Crystalline silicon costs aren't likely to decline fast enough to meet the goals of the Solar America Initiative. . .i.e. price parity with the grid by 2015.

**Thin-film photovoltaics**

Thin-film photovoltaics involves the deposition of a thin film of photoactive semiconductor material on a low cost substrate. The amount of semiconductor material in a thin-film solar cell is approximately 1/100th that of a crystalline silicon cell. In addition, thin-film solar cells can be manufactured over large areas, including roll-to-roll continuous deposition processes. To put this in perspective, crystalline silicon cells are nominally six inches by six inches in size and are manufactured in discrete, batch oriented processes. Contrast this to Miasolé's process which continuously deposits thin films on meter wide rolls of stainless steel foil two miles or longer in length moving at two feet per minute.

Thin-film solar materials have been researched for more than 30 years and have been in modest volume production for the past ten years for both commercial and residential use. The most mature thin-film technology is amorphous silicon. The first significant markets for amorphous silicon were hand-held calculators. Today amorphous silicon represents about five percent of the rooftop solar market. The principal draw back to amorphous silicon is its inherently low conversion efficiency equal to about half that of crystalline silicon. Amorphous silicon deposited on thin flexible metal substrates and encapsulated with flexible laminates yields a PV module that is light weight, flexible and easy to install. It is this unique flexible module capability that has generated most of the demand for amorphous silicon rooftop applications.

There are two other classes of thin-film technologies currently in commercial scale production which together represent about one percent of the world market: Cadmium-Telluride and Copper Indium-Gallium di-Selenide (CIGS). The U.S. has long led the world in thin-film solar research holding the world records for high efficiency cad-telluride and CIGS solar cells. What the market has lacked is a high volume manufacturing process to leverage the progress made at the laboratory level for these technologies. Entrepreneurs have seized the opportunity in the past several years with the formation of several new startups funded by the venture capital industry all with the intent of pursuing high volume, low cost manufacturing technologies. The majority of these startups are pursuing CIGS solar cell technology since CIGS has demonstrated the highest conversion efficiencies of any thin-film technology, very close to that of polycrystalline silicon (19.5 percent for CIGS vs. 20.3 percent for polycrystalline silicon).

Production processes for cadmium-telluride and CIGS thin-films remain relatively immature. This situation is expected to change rapidly as volumes increase and manufacturing learning curves improve product performance, production yields and lower costs. Equally important, thin-film processes typically require dramatically lower fixed asset expenditures for a given level of production.

Unisolar, a division of Energy Conversion Devises, is the world leader in amorphous silicon and First Solar is the world leader in Cadmium-Telluride. Miasolé believes it will quickly become the world leader in high volume, low cost CIGS production.

Thin-films represent the opportunity for the U.S. to regain the lead in solar technology, cost competitiveness, volume production and market penetration. With these goals achieved, widespread market adoption becomes possible without the need for continued subsidies.

To summarize:

- Thin-film solar technologies have been widely researched and have achieved laboratory conversion efficiencies closely matching polycrystalline silicon technology
- The industry has lacked a high volume manufacturing platform to leverage the discoveries made in a laboratory environment
- Entrepreneurs and investors are aggressively pursing the high volume manufacturer of thin-film solar with CIGS based solar cells the technology of choice amongst most startups
- Thin-films offer the potential for substantially lower costs per peak Watt, up to a 70 percent cost reduction from crystalline silicon for installed systems.

**Challenges to commercializing thin-film technologies**

*Challenges associated with scaling laboratory technology demonstrations:*

Most government and university thin-film research has focused on optimizing the efficiency of thin-film solar cells and improving the understanding and characterization of these films. Unfortunately most of the laboratory processes are not easily scaled. Little effort has gone into researching large scale production platforms. Miasolé is leveraging the core experience developed by NREL but is using a dif-

ferent vacuum deposition process known as "sputtering." Sputtering is widely used in the architectural glass industry (sheets of glass 12' x 20' in size) and the data storage industry for making hard disks. In Miasolé's case a significant portion of the Company's technical team came from the data storage industry augmented with engineers from the glass coating industry and engineers and scientist with specific CIGS experience.

One of the challenges to the high volume production of thin film solar cells is that commercial production equipment does not exist. The industry is similar to the early days of the semiconductor industry where companies developed their own manufacturing tools. Today there is a discrete and separate semiconductor capital equipment industry. Fortunately Miasolé has years of experience designing and manufacturing high volume vacuum deposition systems with several core patents covering major elements of its technology.

*Challenges associated with the time to develop high volume processes:*

A second challenge is that each high volume process has its unique properties that are different than laboratory processes. It frequently takes several years to develop a production tool and an equal amount of time to perfect a production process. Government funded research offers an excellent platform for getting started, but substantial additional process and system development is required. Historically most of the solar startups were founded by scientist out of government and university research programs. While these scientists had a core understanding of the technology, they lacked volume manufacturing and general business experience. Venture capitalists tend to back experienced management teams and had difficultly backing early scientist turned entrepreneurs. All of this is changing with the advent of a large scale solar industry and more plentiful investment dollars. The industry is now attracting experienced management teams, several of which have deep domain experience in high volume manufacturing, and significant private equity.

*Challenges to locating manufacturing in the U.S.:*

There are challenges to locating factories in the U.S. and California in particular. Silicon based PV cells and modules are relatively labor intensive favoring overseas production in low labor cost countries. Thin-film processes, if properly executed, are less people intensive but labor costs remain an issue in a highly cost sensitive marketplace. Many countries offer significant financial incentives for establishing PV manufacturing plants. Several European countries offer capital grants equal to 50 percent of the cost of a factory. With large scale PV factories costing hundreds of millions of dollars, these subsidies are very substantial from both a unit cost standpoint and the amount of capital required. Asian countries favor tax holidays with some countries offering five year income tax holidays, another five years at 7.5 percent tax rates and permanent long-term income tax rates of 15 percent. Often countries that subsidize factories also offer some of the highest market incentives and thus represent large domestic outlets for production.

At the state level, California not only has inherently high labor, facility and utility costs, but it also is one of only eight states in the U.S. to tax manufacturing assets. Miasolé anticipates spending approximately $30 million for fixed assets next year for installation at its Santa Clara facility plus an additional $2.5 million for use tax that the Company would not incur if operating in most other states. California talks about wanting high paying manufacturing jobs but does little to encourage industry to expand, particularly those that are fixed asset intensive. On the plus side, California's PV market incentives are among the best in the country.

# The Subcommittee on Energy of the Committee on Science

## Limitations and Opportunities for Renewable Energy

August 2, 2006

MIASOLÉ

MAKING AFFORDABLE THIN-FILM SOLAR CELLS A REALITY

## Miasolé Overview

- Santa Clara, California based solar manufacturer
- Focused on thin-film photovoltaics since 2003
- 80,000 sq. ft. Santa Clara manufacturing plant
- Long history of high volume manufacturing of thin-film components
- Backed by leading venture capitalists
- Expect to commence volume production in 2006

MIASOLÉ

MAKING AFFORDABLE THIN-FILM SOLAR CELLS A REALITY

# Background on the Solar Industry

- Recent growth in the solar industry has exceeded 40% per year
- Increasing adoption of solar incentives and Renewable Portfolio Standards (RPS) are creating more demand
- High demand and material shortages have increased prices
- 94% of all PV modules are based on crystalline silicon, a 50 year old technology
- Thin-film is emerging as a disruptive technology with the potential for much lower costs, flexibility and simplified installations (BIPV)
- Miasolé's thin-film technology is expected to reduce installed system costs by 60-70% over today's crystalline silicon costs
- Several venture backed entrepreneurial startups are pursuing thin-film photovoltaics... the industry is on the cusp of disruptive change

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MAKING AFFORDABLE THIN-FILM SOLAR CELLS A REALITY

# Thin-films Represent the Best Opportunity for Significant Cost Reduction

- 1/100% the amount of expensive semiconductor material…No dependence on polysilicon feedstock
- Continuous high volume roll-to-roll processing vs. batch oriented silicon wafer processing
- Laboratory efficiencies approaching polycrystalline silicon (19.5% for CIGS; 20.3% for poly-Si)
- Enables flexible PV laminates for lower costs, simpler installation, and aesthetically more pleasing products
- Enables true Building Integrated Photovoltaics (BIPV)

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MAKING AFFORDABLE THIN-FILM SOLAR CELLS A REALITY

## What Can Congress Due to Help?

- Support the Solar America Initiative
- Greater synergy with DOE's Building Program by promoting PV installations on large scale residential developments
- Extend solar investment tax credit period and increase the cap on residential systems
- Financial assistance via federal loan guarantees for large scale commercial installations

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Thank you for the opportunity to address the Committee!

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BIOGRAPHY FOR DAVID PEARCE

Mr. Pearce serves as President and Chief Executive Officer of Miasolé, a Santa Clara, California venture backed solar photovoltaics company he founded in 2001. Mr. Pearce has served at the President/CEO level of both private and public high-technology companies for the past 20 years. He is a serial entrepreneur, having founded four venture-backed companies and accomplished two IPOs.

Mr. Pearce's accomplishments include major breakthroughs in the production of hard disks for the data storage industry, low cost optical filters for fiber optic communications and now, thin-film solar cells that dramatically lower the cost of solar generated electricity. Mr. Pearce holds a BS in Industrial Management from Georgia Tech and an MBA from the University of Texas.

Mr. Pearce's employment history over the past twenty years is as follows:

2001–present—Founder, President & CEO of Miasolé

1999–2001—Founder, President & CEO of OptCom, an optical components manufacturer of thin-film filters for fiber optic communications

1997–2001—Founder, President & CEO of SciVac, a manufacturer of precision thin-film vacuum deposition equipment

1994–1997—President, Exclusive Design Corporation, a manufacturer of capital equipment serving the hard disk industry

1992–1994—Founder and President of JTS Corporation, a manufacturer of hard disk drives

1990–1992—President & CEO, Kalok Corporation, a manufacturer of hard disk drives

1985–1990—President & CEO, Domain Technology, a manufacturer of thin-film media for the data storage industry

Chairwoman BIGGERT. Thank you very much.

Mr. Swenson.

## STATEMENT OF MR. RON SWENSON, CO-FOUNDER, ELECTROROOF

Mr. SWENSON. Thank you very much. I appreciate the opportunity to speak today about international renewable energy education, and I especially appreciate the thoughtful questions that were raised by yourselves and the staff.

It's appropriate that we are holding this meeting in California. Since the '49ers gold rush mystique spread far and wide, California has changed the world several times. Hollywood and Silicon Valley symbolize these dramatic changes. And, Dr. Rosenfeld, as Dr. Chu showed, is leading in that direction still.

Now, Silicon Valley is rising to a new challenge to save the world from global warming produced by carbon energy to global sustainability produced by silicon energy.

Since 1992, I've been involved in renewable energy education projects, primarily applications of solar electricity, in Mexico, Uganda, Bolivia, South Africa, Ecuador, Butan in the Himalayas and Peru.

Coincidentally, just yesterday in Quito, Ecuador, the United Nations Development Programme announced that SolarQuest, which is our non-profit arm, has been given responsibility for planning a Renewable Energy Applications Laboratory in the Galapagos Islands. We call this the "REAL-Lab" by the acronym. Since 2002, we've been providing human capacity building, that is to say, training with young people and the staff of the electric utility there, in renewable energy, installing wireless internet first of all, then assessing energy conservation options for the community, installing solar with hands-on training, and monitoring the performance of the solar and the diesel generators which were in place before we

arrived. Young people there have jumped on board enthusiastically and intelligently, and we call what we do "productivity-centered service learning," learning by doing in simpler terms.

In the next phase of our work, we are integrating these international initiatives to transform energy in the islands to renewables, in order to reduce the risk of oil spills that would threaten the endemic wildlife there. With guidance from the UNDP, Ecuador's Ministry of Energy, and industry sponsors, we are teaming up with American universities as capacity partners. Each university here in the States brings unique skill-sets to bear on renewable energy research and renewable energy education, and they will in turn partner with the universities in Ecuador, and when we open the lab to broader membership, other nations will also enjoy these benefits.

Renewables face many of the same obstacles in developing countries as we do, but there are some differences. In developing countries, the market is eager but capital is more scarce. In remote parts of the world, modern skills are lacking, and you can't just jump from the three Rs immediately to science and physics.

Another thing is that fossil fuel subsidies penalize the economics of renewable energy there as it does here. In the Galapagos Islands, a National Fairness Doctrine means that electricity is the same price as on the Mainland, and yet, the electricity costs twice as much to produce from diesel there. According to the International Energy Agency, energy subsidies add up to about $200 billion worldwide each year. What if we were to invest that money to build lasting solutions instead of propping up the fossil fuel infrastructure which is failing us?

You've also asked how we structure our renewable energy education programs. I've already hinted at it, but to say a little bit more, just the same way that Apple Computer developed a loyal following by supporting computers in schools, so we are matching up universities in the U.S. with universities in the REAL-Lab countries. Taking this one step further, consider what it might be like if we looked at the 100,000 schools in Latin America that still have no electricity. The U.S. Government could sponsor solar systems installed in every one of these schools. Even $100 million for a small solar system on each of these impoverished schools would be a huge improvement.

Government Industry Education Partnership would bring huge benefits to the U.S. economy and our political welfare.

Renewable energy for developing economies has the advantage of being bite size, ubiquitous and grid independent. Solar can be started on a small scale and grown as resources become available. Coal or nuclear power requires a huge investment, but one family or a village can start with solar on a very modest scale. For example, we installed a two kilowatt system in a village school in Bolivia, only four watts per capita, that's less than a night light per capita, and yet, it made a huge difference in that community.

The political and economic implications for renewable energy in the international arena are enormous. Renewables are carbon neutral, and they are nuclear free. The threats of developing nations from nuclear-based energy are as foreboding as climate change. The day may come when all political regimes are sufficiently or-

derly and stable to control weapons-grade nuclear materials, but humanity has not mastered this talent yet. Small nations use valid concerns for their energy future to justify the nuclear alternative, and they get persistent encouragement from the ambitious nuclear power industry, and if not from the United States, then from Russia, France, or others.

If the U.S. and its responsible G8 partners were to offer these nations a large-scale and lasting renewable energy solution, the energy efficiency argument for nuclear power would fall aside and the world would be a far safer place.

In light of all these concerns, renewable energy is the unique, unifying principle for rational energy export. We have a mandate ourselves to repower the Galapagos with renewables. Through education, we are exploiting bridges of understanding packaged with U.S. energy solutions.

So, imagine a $100 million scholarship from the National Science Foundation to train foreign students in solar energy at U.S. universities. We would create partners in development, not just consumer markets.

Renewable energies are mature. Coal and nuclear power may be valid as measures of last resort, but they are just temporary measures. The sun is delivering 120,000 Terawatts for us as we speak to meet our existing 13 Terrawatts of demand. We have a lot of margin to work with.

So, I would invite you to join us in the Galapagos Islands to see the REAL-Lab and our productivity centered service learning, and I would say further that if people want to look at more detail of some of my comments, you can go to SiliconEnergy.org, where I posted some other remarks.

[The prepared statement of Mr. Swenson follows:]

PREPARED STATEMENT OF RON SWENSON

I appreciate the opportunity to speak today about international renewable energy education. I especially appreciate the thoughtful questions which have been raised by yourselves and your staff.

**1. My Renewable Energy Projects in Developing Countries**

Since 1992, I have been involved in renewable energy education projects, primarily applications of solar electricity, in Mexico, Uganda, Bolivia, Ecuador, Bhutan and Peru. (I am providing a list as Attachment 1.) Coincidentally, just yesterday in Quito, Ecuador, the United Nations Development Programme announced that SolarQuest® (our non-profit arm) has been given responsibility for planning a Renewable Energy Applications Laboratory in the Galapagos Islands. We call it the "REAL-Lab." Since 2002 we have been providing human capacity building for renewable energy in the Islands—installing wireless Internet, working with secondary school students to assess energy conservation, install solar with hands-on training, and monitor the performance of solar and diesel generators there.

In the next phase of our work, we are integrating international initiatives to transform energy in the islands to renewables, reducing the risk of oil spills that threaten the unique endemic wildlife there. With guidance from the UNDP, Ecuador's Ministry of Energy, the Galapagos National Institute, and the e8 Network, we are teaming with universities in the U.S. to serve as our capacity partners. Each university will bring unique skill-sets in renewable energy research and education into partnership with universities in Ecuador. When we open the lab to broader membership, other nations will also enjoy these benefits.

**2. Unique Challenges for Renewable Energy in Developing Countries Renewables face many of the same obstacles in developing countries as in the USA and other OECD countries. Some differences come into play:**

- **Money:** In the USA there is capital but the market has been slow to embrace the technology. In developing countries the market is eager but capital is scarce. Ironies persist in our complex world!
- **Skills:** In all large cities around the world, it is possible to find skilled technicians, engineers and scientists. Cities can't work without commercial forms of energy and personnel trained in the field. Throughout the remote parts of the world, however, understandably there are few people with significant education in modern science or engineering.

  Nor can core competencies (e.g., the three R's) be taken for granted. En route to building capacity in solar energy, a student can't leap from reading simple hand-me-down texts to understanding physics and engineering concepts.

  Blending education in core competencies with specific skill-sets applicable to renewables, our students excel. Not surprisingly, when offered access to tools and tangible opportunities to serve their communities, young people respond intelligently and enthusiastically to our initiatives. We call this *productivity centered service learning.*
- **Subsidies:** Fossil fuel subsidies penalize the economics of renewable energy. In the Galapagos Islands, a national fairness doctrine makes electricity the same price as on the mainland, even though diesel-electric costs twice as much. According to the International Energy Agency, energy subsidies add up to $200 billion per year. What if we invested that much to build lasting solutions instead of propping up the failing fossil fuel infrastructure?

**3. Renewable Energy Education in Developing Economies**

As warnings of global warming are increasingly validated by catastrophic events, human capacity building in the energy sector is becoming essential for the rapid substitution from carbon-based energy to carbon-neutral sources. If banks, industry and governments continue to favor carbon-based energy over carbon-neutral solutions, it may ultimately fall upon youth to educate their elders. It's like, if your computer isn't working, get your teenager to fix it for you!

**How to Structure Renewable Energy Education in Developing Economies**

Structuring renewable energy education in developing countries could make a crucial impact on international relationships for the USA Government.

- **Markets Lost:** The potential for USA industry to capture renewable energy markets worldwide is enormous. But time is against us: even though most renewable technology has been developed in the USA, our advantage has been lost. Europe and Japan took the lead by encouraging commercialization in their own domestic markets, and that prepared them for dominance in the international markets.
- **Creating Market Potential:** Just as Apple Computer developed a loyal following by supporting computers in schools, we are matching up universities in the USA with universities in the REAL-Lab member countries. The member nations joining our Renewable Energy Applications Laboratory will designate their own universities to partner with our U.S. university capacity partners. Markets for U.S. solar energy products will accelerate when ten universities in the USA are matched with ten universities in ten member countries. Their intellectual strengths will be coupled with American strengths to develop robust human capacity.
- **Hands-on:** In the USA, because of liability issues, it has been very difficult for us to provide opportunities for young people to learn by doing. On the other hand, in developing countries we have been able to bring together teams of young people with little experience and teach them the basics of electricity, solar energy, satellites and computers in short order. Hands-on experience has been the key to motivation and knowledge retention.
- **Large-Scale:** Taking this one step further, consider the 100,000 schools in Latin America with no electricity. The U.S. Government could sponsor solar systems to be installed on every one of those schools. Even $100 million for a small solar system on each of these impoverished schools would be a huge improvement over nothing. We would motivate future scientists and engi-

neers who appreciate Americans when we combine this hardware investment with curriculum delivered by our University capacity partners. A government-industry-education partnership would bring huge benefits to the U.S. economy and our political welfare.

**4. Advantages of Distributed Renewable Energy in Developing Economies**

- **Bite-Sized and Ubiquitous:** Solar can be started on a small scale and grown as resources become available. Coal or nuclear power requires a huge investment, but one family or village can start with solar on a very modest scale. We installed two kW at a village school in Bolivia—only four watts per capita for 500 people. It made a huge difference. Anywhere in the world, a family with one solar panel can have basic communications and lighting.
- **Grid Independent:** Renewable energy can be installed where no grid exists. In the USA and other developed economies, copper was mined and laid out in wires across the entire landscape many decades ago. In less developed nations the electricity grid is far weaker—where it even exists. The grid is nonexistent for roughly a third of the human population. With more pressing priorities and limited buying power, less developed nations are unlikely to be able to mimic our sophisticated grid infrastructure in the foreseeable future.

**Political and Economic Impacts**

Political and economic implications for renewable energy in the international arena are enormous.

- **Solar facilitates fairness; Oil breeds conflict:** Coal, oil and natural gas are unevenly distributed but solar energy can be distributed equitably to the entire human population.
- **Carbon Neutral:** As demand for electricity and transport grows around the world, the threats to developing nations from carbon-based energy sources are unfathomable. My flight to Bhutan in 2002 landed in Dhaka, the capital of Bangladesh. I was shocked to find myself in a *Water World.* Already surviving on a thin margin between land and ocean, Bangladesh and many other countries will suffer massive dislocations if the pace of global warming isn't stopped soon. While the USA has so far suffered the highest profile losses from global warming, there are numerous developing countries that have suffered as well. Hurricane Mitch devastated Honduras when the role of global warming was less obvious. Ironically, Chinese and Indian energy policies threaten their own highly developed low-lying coastal regions as they engage in the madness of coal-fired economic growth.
- **Nuclear Free:** The threats to developing nations from nuclear-based energy are as foreboding as climate change. The day may come when political regimes are sufficiently orderly and stable to control weapons-grade nuclear materials, but humanity has not mastered this talent yet. Small nations use valid concern for their energy future to justify nuclear, and they get persistent encouragement from the ambitious nuclear power industry (if not from the U.S., then from Russia, France and others). If the USA and its responsible G8 partners were to offer these nations a large-scale and lasting renewable energy solution, the energy deficiency argument for nuclear would fail and the world would be a far safer place.

**Government and Industry Willingness to Encourage Renewables**

We hear talk of energy independence, and of course people are increasingly concerned about the high price of gasoline. But there are serious implications if responses to these concerns ignore other concurrent challenges.

- **Peak Oil and Carbon Intensive Responses:** Do rising oil prices derive from political instability and economic challenges or do they represent early signs of reaching the intrinsic limits to physical oil supplies? There are ominous signs that natural limits are contributing to the challenge to find more oil. Extraction is declining rapidly from the North Sea and from Cantarell, Mexico's largest field. Indonesia recently became a net importer of oil. New discoveries replace only a fraction of annual consumption. While it is a laudable goal, the quest for energy independence so far has led to policies that encourage carbon-intensive forms of energy, including coal-to-liquids, tar sands, oil shale, corn ethanol and nuclear power. (Some of these energy forms are erroneously represented as carbon-neutral, which further complicates the debate. *www.energycrisis.com/nuclear*)

- **Global Warming:** There are credible warnings that glaciers in Greenland and the Antarctic will continue melting, leading to a significant rise in sea level, even if we act quickly. In the face of this and other climate catastrophes, we can only hope to minimize impacts by immediately exploiting alternatives to carbon-based energy sources. We also need to understand the potential costs and environmental impacts that such catastrophic events may impose on the global economy and to compare those costs against profound investments in carbon-neutral renewable technologies.

  The challenge is acute in China, where coal-fired power plants are coming online at an alarming rate and renewable energy, especially solar water heaters and solar electricity, are also growing rapidly.

**Export Opportunities**

- Exporting bridges of understanding: In light of all these concerns, renewable energy is the unique unifying principle for rational energy exports. We have a mandate to re-power the Galapagos with renewables. Through education, we are exporting bridges of understanding, packaged with energy solutions.
- **Linked to Energy Efficiency:** An integrated approach to energy is a key strategy to differentiate U.S. solar initiatives from those of competing interests. With low energy appliances—skipping light bulbs altogether in villages getting electricity for the first time and going directly to LEDs, for example—literally could make all the difference. Electricity alone doesn't do the job; it's the foundation for services that need to be integrated from the start. We can point to all kinds of failures—tractors that can't be repaired for lack of parts inventories, refrigerators delivered to places with no electricity. Electricity in combination with efficiency can build strong markets for a broad array of American products.
- **Rapid Deployment:** We need rapid deployment of renewables to meet the environmental challenges we face. We need to stimulate the renewable energy business in every sector, from finance to manufacturing to operations and maintenance, to intensive capacity building.

  My team has a mandate to re-power the Galapagos with renewables. What if the National Science Foundation were to invest $100 million in education to re-power developing nations worldwide? The USA would get an enormous return.
- **Renewables are mature:** Coal and nuclear power may be valid as measures of last resort but they are at best temporary measures with potentially dire consequences. The sun is delivering 120,000 Terawatts for us to meet 13 Terawatts of demand. We have a lot of margin to work with.

I invite you to join us in the Galapagos Islands to see the *REAL-Lab and productivity centered service learning* in action.

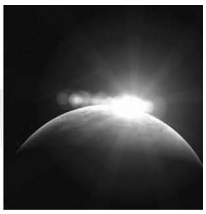
For additional information, visit my website at *http://www.SiliconEnergy.org/us/*
.

**Attachment 1**

**Renewable Energy Projects in Developing Economies**

**R B Swenson**

| Country | Date | Affiliates, Sponsors | | Technologies |
|---|---|---|---|---|
| Mexico | 1992-1996 | MX | Universidad Nacional Autonoma de Mexico | Solar race car (photovoltaics) |
| | | US | USDOE EERE | |
| | | AU | SA Development Authority | |
| Uganda | 1999 | US | White House Millenium Council | 100 small thin film photovoltaic systems |
| | | UG | Office of First Lady | |
| Bolivia | 2000-2001 | US | White House Millenium Council | Crystalline Photovoltaics, Solar-powering satellite-based internet and computer lab, Distance Learning |
| | | US | American Electric Power | |
| | | US | New Mexico State University | |
| | | UK | British Petroleum | |
| | | BO | Fundacion Amigos de la Naturaleza | |
| Bhutan | 2002 | US | American Electric Power | Micro-Hydro, Micro-Solar |
| | | JP | Kansai Electric (Kyoto) | |
| | | BT | Ministry of Energy | |
| Peru | 2004-2005 | US | Private Donor | Thin film Photovoltaics, powering micro- computer lab |
| | | PE | Plan Puyhuan (NGO) | |
| Ecuador | 2002- | US | US Universities | Crystalline Photovoltaics, Satellite remote monitoring of climate, hybrid diesel, wind and solar |
| | | US | American Electric Power, Global 3 E, UN Foundation | |
| | | EC | Ministry of Energy and Mines, Galapagos National Institute ("Ingala") | |
| | | Intl | UN Development Programme | |



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# A WAKE-UP CALL

The sun is the only energy source that can meet the oil depletion challenge. But solar energy ramp-up must be large-scale and immediate.

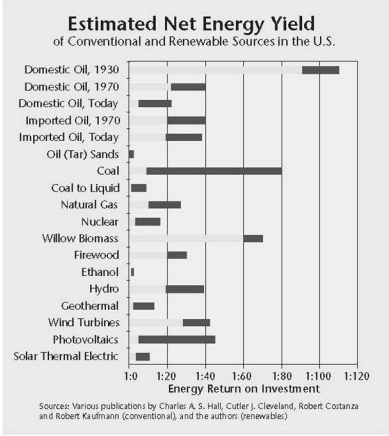
By **Francis de Winter** and **Ronald B. Swenson**

This issue of *SOLAR TODAY* focuses on the Global Hubbert Peak, the point in time when petroleum (and natural gas) will go into unavoidable decline. Here we explore the options available in light of dwindling fossil fuel resources, and we speculate on the scale of solar energy development that will be needed to overcome the expected oil and natural gas shortfall.

Peak oil is an emerging reality. With production already declining in all but a few major oil regions, an energy shortfall is inevitable. As demand for oil continues to grow, this shortfall can only mean disappointment for those around the world who aspire to live more like Americans, consuming their body weight in oil every week (150 pounds on average). Never mind price. Even if price is no object, production will begin to drop and shortages will become increasingly acute. There will be great temptation to exploit high-carbon, non-conventional fossil fuels that could accelerate global warming. To avoid disaster, solar energy must rise, and rapidly, to meet the challenge of oil depletion.

### A Coming Crisis

In 1994 we established contact with leading geologists who were studying oil depletion and created a website, www.oilcrisis.com. Much earlier, one prominent petroleum geophysicist spoke out about the future of oil. In 1956, the late Dr. M. King Hubbert predicted correctly that oil production in the United States would peak around 1970, after which production would decline forever. In the 1960s and 1970s, he predicted that the worldwide "Hubbert Peak" would be reached around the year 2000. The world Hubbert Peak has been postponed a bit because the 1970s energy crisis made us more frugal, but experts agree that it remains imminent. Dr. Farrington Daniels, the founder of our International Solar Energy Society, was associated with Hubbert when he first introduced his peak oil analysis. *(See sidebar, "A Solar Future Long Anticipated.")* Dr. Colin J. Campbell, the most prominent successor of Hubbert, expects the Hubbert Peak in the very near future *(see "The Second Half of the Age of Oil Dawns," page 20)*.




Since the beginning of our short oil era around 1860, world population has increased dramatically. This population growth has been fueled substantially by oil. In the United States, food travels more than 1,000 miles on average, requiring over 10 times the petroleum energy to produce than its solar energy food value (calories). As a practical matter, we are eating mostly petroleum.

Many societies throughout history have faced resource depletion. History tells us that Plato deplored the deforestation in Greece, and that the Greeks started using passive solar orientation in their settlements when they ran out of firewood. Archeologists have found many societies that disintegrated because they depleted their resources with no concern for the future. Some simply abandoned their settlements and moved to fertile land. Others, like the people on Easter Island, could no longer move. They had cut down all their trees and couldn't even make crude boats to fish.

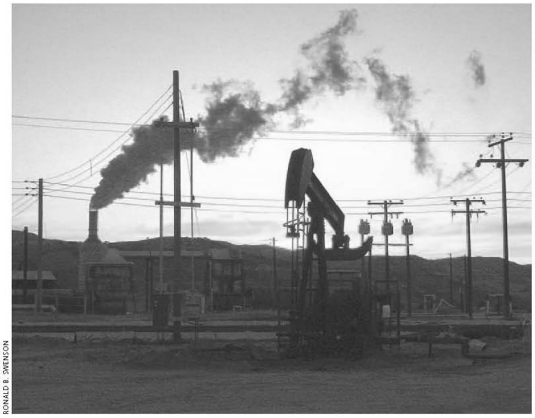
Developed and developing countries alike are addicted to cheap oil. For the United States, depletion is going to be especially difficult. Americans use oil as if it will never run out. The country is designed and built around cars using cheap gasoline. With fossil fuel resources becoming scarce, we have to learn to make do with what we have peacefully or we will have war, depleting humanity's collective resources even further.

What might be the possible early reactions to peak oil?

**Conservation:** Whenever natural disasters or political disruptions shed light on our energy vulnerability, earnest appeals for conservation can be heard. Conservation can be voluntary: I can choose to buy a Toyota Prius and still go to the beach on the weekend. I will use less oil, but my lifestyle will be preserved.

**Deprivation:** As oil supplies continue to dwindle, energy conservation will cease to be voluntary. That may lead to rationing if we make a reasoned response. But if depletion is not managed effectively, *deprivation* will overwhelm efforts to conserve rationally. As shortages impact the industrialized world, trips to the beach will be sparse. Lifestyles will change.

**Conflict:** With oil as an essential foundation of productive modern agriculture and starvation already intense in certain regions, it can be argued that the poor of the world are already deprived, involuntary participants in energy conservation. Energy inequities will continue to grow between the haves and the have-nots, and the struggle over the remaining oil reserves will intensify.



RONALD B. SWENSON

Peak oil is an emerging reality. To avoid disaster, solar energy must rise to meet the oil depletion challenge.

Some say the conflict in Iraq is a grab for oil. Whether true or not, how might we avoid conflicts over energy resources?

**Substitution:** We will inevitably have to find other energy sources, substituting new energy for oil and what oil does. Are there solutions close at hand?

### No Answers in Non-Conventional Oil, Nuclear

One place where the peak oil message is being heard is at the margins of the oil, gas and coal industries. As energy prices rise exponentially, researchers are attempting to exploit carbon-intensive, non-conventional fossil fuels to replace transportation fuels. Massive investments have been made to extract tar sands in Alberta; research is ramping up to find a way to convert oil shale in Wyoming and Colorado; and improved technologies are being developed to convert coal to liquids, using the same process that fueled Hitler's desperate army.

But such attempts have produced inadequate amounts of net energy. For heat to extract oil from tar sands, natural gas equivalent to one-third of a barrel is used per barrel. This natural gas is in addition to the liquid fuels and electricity needed for mining, refining and environmental remediation. Recognizing rising natural gas prices, advocates are even suggesting nuclear power to replace natural gas for heat in the extraction process.

Nuclear power is also being examined for the extraction of oil shale. This misnamed substance (neither shale nor oil but marlstone and kerogen, an immature hydrocarbon) must be heated under pressure to convert it to oil. One proponent in Colorado envisions a nuclear facility generating more power to heat oil shale *in situ* than all electricity now consumed statewide. Water requirements and environmental impacts could be huge.

As the informed public becomes aware of the impact of greenhouse gases, nuclear power is being promoted again, this time as a carbon-free energy source. But the popular notion that nuclear is carbon-neutral is faulty. High-grade uranium ores have already been exploited, and the mining and refining of lower-grade uranium ores are increasingly fossil-fuel intensive.

If all bets are placed on marginal fossil fuels and nuclear power, the consequences for society will be dire. Perpetuating the automotive fleet, for example, may seem laudable. But propping up the fleet with low-grade fuels could be more dangerous than doing nothing because, as U.S. Rep. Roscoe G. Bartlett suggests in his article (page 27), these marginal sources too will run out, and humanity will be left high and dry.

### Only Solar Energy Can Fill the Gap

Meanwhile, renewable energy technologies are being brushed aside by some peak oil "experts" as too intermittent or diffuse to merit serious attention. Let's examine a few of these objections to a full-scale transformation to renewables.

*"Solar energy, plant biomass and other renewable forms of energy are diffuse forms of energy."*

Direct sunlight is indeed diffuse, but *thin* collectors are a perfect match to *diffuse*. Mirrored surfaces on solar concentrators

## How Will We Fill the Fossil Fuel Gap?

***Solar energy far exceeds all other possible forms of substitution, with none of nuclear energy's safety and waste-disposal challenges.***

*The Energy Challenge*

*13 terawatts (TW) continuous world energy consumption in 2005*
*30 TW projected demand in 2050*
*Projected shortfall = 17 to 20 TW**

ALTENERGY POWER

**The Atlantic County Utilities Authority dedicated the Jersey-Atlantic Wind Farm, supported by solar power, in Atlantic City, N.J., in December.**

NONCARBON RESOURCES

***Hydropower***
4.6 TW global theoretical potential
0.7 TW technically feasible
0.5 TW installed capacity

***Tides/Ocean Currents***
< 2 TW cumulative energy globally

***Biomass***
7 to 10 TW global theoretical potential

***Geothermal***
12 TW globally, of which only a small fraction could be practically extracted

***Wind***
50 TW global theoretical potential
2 to 4 TW economically feasible land usage, plus additional offshore potential

***Nuclear***
10 TW, based on construction of a new 1-gigawatt nuclear fission plant per day for the next 50 years

***Solar***
120,000 TW global theoretical potential
600 TW available incident solar power
60 TW technically feasible generated power based on 10 per cent conversion efficiency
20 TW based on usage of just 0.16 percent of global land area and 10 percent conversion efficiency

*1 TW equals 1 million megawatts (MW). For context, if a large electric power plant generates 1,000 MW of power, it would require 1,000 such power plants to produce 1 TW.

Sources: *Energy and Transportation: Challenges for the Chemical Sciences in the 21st Century* (National Academies Press, 2003) and *Basic Research Needs for Solar Energy Utilization* (2005, U.S. Department of Energy Office of Basic Energy Sciences).

## A Solar Future Long Anticipated

***When Hubbert predicted global peak oil, Farrington Daniels focused on the solution.***

The afternoon of Sept. 15, 1948, was an important date for solar energy, the petroleum industry and the International Solar Energy Society (ISES). The American Association for the Advancement of Science (AAAS) was 100 years old, and AAAS President Edmund Sinnott, Ph.D., invited three prominent speakers for a Symposium on Sources of Energy at the Centennial Celebration in Washington, D.C.:

- **Dr. M. King Hubbert**, a geologist working for Shell Oil, addressed ***oil depletion***, as the "Golden Century of Oil" was getting under way.
- **Dr. Farrington Daniels**, a physical chemist who had been in charge of the Chicago branch of the Manhattan Project and later started the organization that would become ISES, addressed the future of ***solar energy***, while solar energy was still a dream.
- **Dr. Eugene P. Wigner** of Princeton, who would receive the 1963 Nobel Prize in Physics and who had worked on the Manhattan Project for Daniels, addressed the future of ***atomic energy***, about eight years before there were any commercial power reactors.

At this symposium, Hubbert presented his first paper on what would become known as the "Hubbert Curve," the brief period in human history during which petroleum was discovered; adopted by society as its principal energy source; extracted in ever greater quantities; burned with no serious concern for the future; fostered affluence, wars and pollution; became ever harder to find and "produce"; and was destined to decline inexorably — leaving us no choice but to switch to sustainable energy sources.

**Getting to know Hubbert made Daniels aware of oil depletion and the energy deficiencies that solar energy would have to address.**

Even in this first paper, Hubbert warned that the post-oil transition process would be extremely difficult. Neither Daniels nor Wigner had much to offer except hope; solar and atomic energy technologies were still primitive. Despite Daniels' experience in the Manhattan Project (or perhaps because of it), he decided to concentrate on solar energy, forming the society now known as ISES and creating a solar energy program at the University of Wisconsin-Madison that remains famous.

Getting to know Hubbert made Daniels aware of oil depletion and the energy deficiencies that solar energy would have to address. In 1964 Daniels wrote that U.S. oil "production" would peak about five years later, as Hubbert had predicted accurately in 1956, and that worldwide oil scarcity would begin shortly after 2010. As humanity now encounters the Hubbert Peak, the man who established ISES to meet the challenge of oil depletion will inspire members of the solar community in the decades ahead.

are thin. Solar cells are thin, and thin-film cells are even thinner. Furthermore, sunlight is far more evenly distributed around the globe than is oil.

*"Photovoltaic electricity is expensive."*

The *profitability test* is often the result of accumulated political decisions favoring special interests. In economics it is formally assumed that oil and other natural resources have no value until they are "produced" (i.e., extracted), and then the only value assigned to the resources is the cost of extracting them. They are free for the taking, and so we have been paying nothing for the inherent value of oil. Lobbying efforts have provided large subsidies for oil. Externalities are not charged at the gas pump. Preferential tax treatments, highway construction and defense budgets underpin the oil economy.

Humanity's "primary energy production," including all fossil fuels, nuclear power, hydroelectric and renewables, is 13 terawatts. Solar energy has 600 terawatts of terrestrial potential.

Renewable energy subsidies are beginning to level the playing field. As fossil fuel costs increase, the economics of renewable energy will transform the market. *(See January/February* SOLAR TODAY *for features on the theme, "Solar Energy Cost Breakthrough Ahead?")*

*"The EROI (energy return on investment, or net yield) for fossil fuels tends to be large, while that for solar tends to be low."*

A hundred years ago, oil gushers yielded high net-energy recovery rates, but today solar, hydroelectric and wind power have net energy yields higher than conventional fuels such as oil, gas and coal, and an order of magnitude better than non-conventional fossil fuels. With their inherently high net-energy yields, renewables can be ramped up rapidly. *(See table, "Estimated Net Energy Yield of Conventional and Renewable Sources in the U.S.," page 16.)*

*"Neither solar nor wind power is an immediate, large-scale solution to the energy problem. … Plants, on average, capture only about 0.1 percent of the solar energy reaching the Earth."*

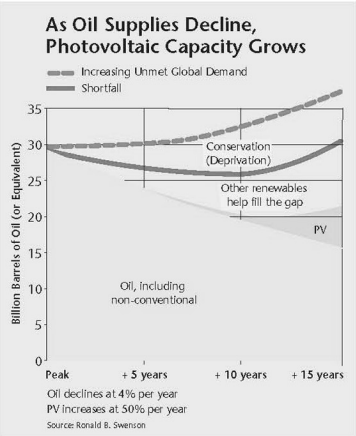
Humanity's "primary energy production," including all fossil fuels, nuclear power, hydroelectric and renewables, is 13 terawatts (equivalent to 13,000 large power plants), less than 1/100 of 1 percent of the 170,000 terawatts continuously delivered to the earth as sunlight. With 600 terawatts of terrestrial potential, solar energy far exceeds all other possible forms of substitution. *(See sidebar, "How Will We Fill the Fossil Fuel Gap?" page 17.)*

Transportation in a post-cheap-oil world poses special challenges. If non-conventional fossil fuels are untenable and

As energy prices rise, researchers attempt to exploit non-conventional fossil fuels to replace transportation fuels. But such attempts have produced inadequate amounts of net energy.

transportation is powered almost exclusively by liquid fuels, it is tempting to propose biomass as a substitute for oil. In the United States, 1 billion tons of biomass are managed each year. To meet all our energy needs, 7 billion tons more would be required. Obviously, electric airplanes or cargo ships are impractical, so biomass will play an important role in our energy future. But liquid fuels exclusively from plant material will be possible for transport at only about one-tenth the present level worldwide. Something has to give.

Considering society's huge investment in the vehicle fleet and these limitations of biofuels, it is difficult to imagine the transformation of transportation to renewable energy sources. To make the shift, the premise that solar energy must be converted




into fuel has to be challenged. A direct path from sunlight to electricity can be 10 times as efficient as photosynthesis. Solar energy can't be touched or put into a bottle. Solar is *radiant energy*, not a solid, liquid or gas.

Electricity from renewables is ideally suited for urban transportation. It is nonpolluting and well-suited for fixed guide rail and automated routing of traffic, and an electric vehicle is at least twice as efficient as a gasoline vehicle. We are ready for a good reason to get rid of the internal combustion engine in dense urban areas, where it is about as practical as a campfire in the kitchen. Efficiency in the face of oil depletion is that compelling reason.

Solar technologies continue to improve, and so do electric vehicles. A battery with three times the energy density of lead-acid and a charging time under two minutes is scheduled for introduction in 2007 or 2008. Shanghai has an electromagnetic propulsion maglev train that travels at 270 miles per hour.

### Getting Up to Speed: Think Terawatts

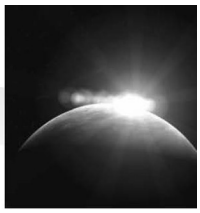
According to Campbell and other leading peak oil experts, permanent oil decline will begin during this decade and will likely proceed initially at 2 to 8 percent per year. If oil declines at 4 percent and photovoltaic manufacturing grows at 40 percent per year until 2020, PV would meet less than 20 percent of the oil shortfall without meeting any demand growth. If the PV industry sustains growth averaging 50 percent or more per year, it will contribute significantly. Though such growth is an aggressive goal, it is realistic under a scenario slightly more ambitious than the two-year doubling time projection that Ron Larson presents in this issue's "Chair's Corner" (page 4). As nonsilicon-based solar products quickly become commercialized, this goal is even more feasible. *(See graphic, "As Oil Supplies Decline, Photovoltaic Capacity Grows," left.)* Developing similar growth rates for all renewables, it will be possible for sustainable solutions to realize their potential for oil, gas and coal substitution. The sidebar, "Making the Transition," (page 29), samples some industry proposals.

France converted from zero to nearly 100 percent nuclear power in less than 20 years. Renewable energy technologies have higher net-energy yield than nuclear by far and are faster to install, so it will be possible to ramp up in even less time. If others continue to insist that nuclear power, tar sands or coal-to-liquids are options, the move to renewables will be even more critical as the only pathway that avoids potential nuclear terrorism and curbs global warming.

We must recognize the limits of our fossil fuel reserves and begin to push for rapid growth in solar energy. For the first time in history, all of humanity will share the same problem. This common challenge can help unify us, to recognize the futility of war and to make governments more responsive to our needs. We will need large national and international programs, similar in ambition and spirit to the Apollo "Man on the Moon" program, to reduce our oil consumption and to create alternative energy sources. This transition will provide many good local jobs that cannot possibly be outsourced, and we will need a significant grassroots effort.

If we get it right, we will be able to share a future of clean air and fresh water, viable oceans, thriving forests and peaceful coexistence. We must get it right, and be proud that we are members of the generation entrusted with the task. ●

*Francis de Winter, principal of Francis de Winter & Associates, originated the "heat exchanger factor," used worldwide in solar water heating. He served during four years as chair of the American Solar Energy Society. An ASES fellow, he has received the Charles Greeley Abbot Award and many other honors. Contact de Winter at fdw@ecotopia.com. Ronald B. Swenson is cofounder of ElectroRoof, SolarQuest and Solarevolution, and publisher of OilCrisis.com. A former ASES board member representing the Solar Fuels and Transportation Division, he has published numerous peer-reviewed articles in this field. Contact Swenson at rbs@solarquest.com.*



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# THE **SECOND HALF** OF THE AGE OF OIL **DAWNS**

The question is not when the world will run out of oil and natural gas, but how we will prepare today.

By **C.J. Campbell, M.A., D.Phil.**

Soaring oil prices have raised concern about the relative supply and demand of the world's premier fuels, having a central place in the modern economy. It has led people to ask, *"Are we running out of oil?"* A sensible short response would be, *"Yes, we started doing that when we produced the first barrel."* The world is not about to run out of oil, but what it does face is the end of the First Half of the Age of Oil. That opened 150 years ago when wells were drilled for oil on the shores of the Caspian and in Pennsylvania. The cheap, convenient and abundant energy it supplied, led to the growth of industry, transport, trade and agriculture. This growth was accompanied by the creation of huge amounts of financial capital, as banks lent more than they had on deposit, confident that *tomorrow's economic expansion* was adequate collateral for *today's debt*. Many people came to think that it was money that made the world go round, when in reality it was an abundant supply of cheap energy, much derived from oil.

Petroleum geology has made great advances in recent years, such that the conditions under which oil and gas were formed in nature are now well understood. In fact, it transpires that the bulk of the world's current production comes from deposits formed in two brief epochs of extreme global warming 90 million and 150 million years ago. Algae proliferated in the warm sunlit waters, providing the raw material that eventually became oil. It was preserved and trapped in places having the right combination of geological conditions. A glance at the oil map shows that oilfields are clustered in such exceptional places, which are separated by vast barren tracts.

Natural gas was formed in a similar way, save that it was derived from vegetal remains as found in the deltas of tropical rivers. Ordinary oil also broke down into gas if overheated by excessive burial.

Oil and natural gas are clearly finite resources, formed in the geological past, which in turn means that they are subject to depletion. That is not a difficult process to understand, as every beer-drinker knows. The glass starts full and ends empty; the quicker he drinks it, the sooner it is gone; and every bar has a closing time. So, how far along the oil and gas depletion curves are we? The first step in answering this question is to ask how much has been found so far and when it was found, because production has to mirror discovery after a time-lapse.

They sound like simple questions, being just a matter of looking up the data, but as we dig into the details, we find a minefield of confusion, obfuscation and disinformation.

### Assessing the Remaining Reserves

In the past, the word *depletion* was not one the oil companies liked to mention, fearing that it smacked of a dwindling asset that

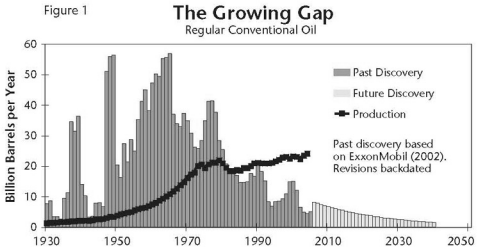
Facing page, A BP Solar array of 5,880 panels in Paulsboro, N.J., provides an adaptive reuse of a former petroleum and specialty chemical storage and distribution facility. The solar field produces 350,000 kilowatt-hours of electricity per year.

NEW JERSEY BOARD OF PUBLIC UTILITIES

did not sit well with the stock market, but now some of them do begin to be more forthright. An example is Chevron, whose CEO deserves great credit for his frank presentation *(see www.willyoujoinus.com)*. The official institutions, for their part, tend to continue to publish bland scenarios and half-truths, recognizing that their governments are not yet ready to face bald reality.

In most contexts, the term *reserves* means something sure, but that is not the case for oil. Estimating the size of an oilfield early in its life poses no particular scientific or technical problem. The difficulty lies in the reporting. Oil in the ground is a financial asset to its owners, against which money can be borrowed. Accordingly, the Securities and Exchange Commission (SEC), very properly moved in the early days of U.S. oil production to introduce strict reporting rules. The SEC recognized two main classes: *proved producing reserves* for the expected future production of current wells; and *proved undeveloped reserves* for the expected production of yet-to-be-drilled infill wells.

Figure 1




The rules were designed to prevent fraudulent exaggeration, but smiled on underreporting as laudable prudence. In practice, the major international oil companies reported just as much as they needed to report in order to deliver satisfactory financial results, building up for themselves a useful stock of unreported reserves to tide them over lean discovery years and cover any temporary setback around the world. As a result, they were able to progressively revise their reported reserves upwards, giving a comforting but very misleading impression of steady growth, which was commonly attributed to technology, when in fact it was mainly an artifact of reporting practice. But the luxury of underreporting is fading fast, forcing the major companies to merge and, in some cases, revise downward their reported reserves. In part, this situation reflects the aging of the giant fields holding most of the world's oil — it being clearly easier to underreport a large field than a small one. In any event, the revisions have to be backdated to the original discovery to obtain a valid discovery trend.

The Organization of Petroleum Exporting Countries, for its part, announced enormous overnight reserve increases in the 1980s. At first, these increases seemed to be a correction of the underreporting inherited from the foreign companies before they were nationalized. But it now transpires that they may have started reporting the total found, not the remaining reserves, explaining why the official numbers have barely changed since, despite massive subsequent production. At all events, the dataset is grossly unreliable, with as much as 300 Gb (billion barrels) being in doubt.

Compounding the problem is confusion over what was measured. There are many different categories of oil, each with its own costs, characteristics and, above all, its own depletion profile. Producing oil from a free-flowing Middle East well is not the same as digging up a tar sand in Canada with a shovel, albeit a big one. Some types are cheap, easy and fast to produce, whereas others are the precise opposite. It is, therefore, useful to identify *regular conventional oil*, defining it to exclude oil from coal and shale, bitumen and heavy oil, deepwater and polar oil, as well as the liquids that are extracted from gasfields in specialized plants. Regular conventional oil has supplied most to-date and will dominate all supply far into the future.

Unraveling all of these confusions, so far as is possible, suggests that the status of depletion for *regular conventional* is as follows (to be generously rounded):

| | | |
|---|---|---|
| Produced to-date (end 2005) | | 968 Gb |
| Future Production | | 882 Gb |
| From known fields | 760 Gb | |
| From new finds | 122 Gb | |
| Total | | 1,850 Gb |

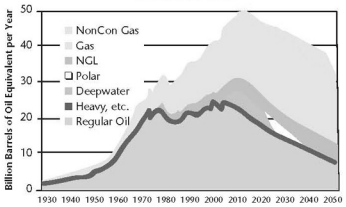
Figure 1 shows the discovery record, using properly backdated industry data published by ExxonMobil *(Longwell, H., "The Future of the Oil and Gas Industry: Past Approaches, New Challenges,"* World Energy, *5:3 2002: 100-104)*. World discovery has evidently been in decline since 1964, despite a worldwide search always aimed at the biggest and best prospects; despite all the many advances in technology and geological knowledge; and despite a favorable economic regime whereby most of the cost of exploration was offset against taxable income. It means that there is no good reason to expect the downward trend to change direction. The world started using more than it found in 1981, and last year found only about one barrel of *regular conventional oil* for every five or six consumed. Oil has to be found before it can be produced, which means that production in any country, region and eventually the world as a whole has to mirror discovery after a time lapse.

Although the skills of a detective are needed to collect the evidence and analyze it properly, we may be confident that the depletion profile in figure 2 represents a realistic general assessment sufficient for planning purposes.

In short, the Second Half of the Age of Oil now dawns. It will be marked by the decline of oil and all that depends upon it. Gas, which has a rather different depletion profile, will also in due course head into steep decline.

There is an irony about depleting a finite resource:
*The better you are at doing the job, the sooner it ends.*

Figure 2
**Oil and Gas Production Profiles**
2005 Base Case




Note: Regular oil excludes oil from coal, shale, bitumen, heavy, deepwater, polar and gasfield natural gas liquids (NGL).

## Preparing for Declining Supply

Much study and debate has been dedicated to determining the date of peak production, but that really misses the point. It is not an isolated or high peak, but merely the maximum value on a gentle curve. What matters, and matters gravely, is the vision of the long, remorseless and relentless decline that comes into sight on the other side of the peak.

That said, the peak does represent an unprecedented turning-point of magnitude marking the shift from growth to decline. It is very difficult for classical economists to accept this, as the notion that the market must always deliver is deeply entrenched in their thinking. They rightly remind us that the Stone Age did not end for want of stones as man found bronze, iron and steel as better materials for tools and weapons. But the decline of oil arises from natural depletion not from the entry of better substitutes. Many people try to reassure themselves in the belief that new technology or new investment will keep the oil and gas flowing, but there is an irony about depleting a finite resource: *The better you are at doing the job, the sooner it ends.*

The transition to decline threatens to be a time of great international tension. The major consuming countries will vie with each other for access to supply, most of which lies in just five countries bordering the Persian Gulf, one of which has already been invaded.

The conditions that will unfold during the Second Half of the Age of Oil appear dire, and for that very reason deserve serious attention *(see Campbell's 2005 book,* Oil Crisis, *Multi-Science Publishing, ISBN 0906522-39-0, for further discussion)*. It looks as if virtually all companies quoted on the stock exchange are overvalued insofar as their accounts tacitly assume a business-as-usual supply of energy, which is no longer justified. Does this point to a second Great Depression, perhaps accompanied by rampant inflation to remove excess financial capital as debt loses its oil-based collateral? Does it mark the end of economics as presently understood? The world's population expanded six-fold exactly in parallel with oil, posing the awful question of how many people the planet can support without oil.

These are serious questions, and there is certainly no solution in terms of finding enough new oil and gas to prolong the past epoch. But there certainly are responses by which to plan and prepare. It is not difficult to formulate some useful steps:

**1) Evaluate the Real Resource Situation.** In this way, we can avoid being misled by erroneous forecasts promulgated by international organizations that are under political pressures.

**2) Educate Users.** Undertake a massive program of public education, so that everyone may become more energy-conscious and find ways to be less wasteful. Eventually, an efficiency factor could be incorporated into utility and fuel charges to penalize the wasteful and encourage the efficient. The transport system, in particular, demands urgent attention.

**3) Ramp Up Renewable Energy.** Encourage the rapid development of renewable energies from tide, wave, solar, wind and other sources, including the growing of energy crops.

**4) Reconsider Nuclear Energy.** Reevaluate the nuclear option, provided that it can be made safe and the waste-disposal issue can be resolved.

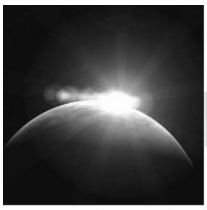
**5) Reduce Imports to Match Depletion Rates.** Arrange for importers to cut their oil imports to match world depletion rates, namely annual production as a percent of what is left, currently standing at 2 to 3 percent.

Of these, perhaps the last item deserves most attention. Such a policy would have the effect of reducing world oil prices by putting demand into balance with supply. The poor countries of the world would be able to afford their minimal needs, and profiteering from shortage would be avoided. The cost of producing oil has not changed materially, so the high prices reflect profiting from shortage, especially by Middle East governments. That in turn gives rise to massive destabilizing financial flows threatening an already fragile system.

Above all, it would force the consumers to face the limits imposed by nature. There are several options for practical implementation, but some form of rationing would seem to be the fairest (e.g., David Fleming's proposed system for tradable energy quotas, described at www.teqs.net). Energy might even develop into a form of currency. Whereas the Kyoto Protocol on climate change requires universal acceptance to work, an Oil Depletion Protocol would not be so dependent, because the countries that adopted its measures would soon find themselves having an enormous competitive advantage over those that continue to live in the past.

Despite the challenges, we may hope at the end of the day that a new benign age will unfold, as people again come to live in communities with a better respect for themselves, their neighbors and the environment in which nature has ordained them to live. Leading happier and simpler lives, mainly in rural circumstances, they may look back and realize that oil, and the excessive free energy it released from fossil sunshine, had been more of a curse than a blessing. ●

*C.J. Campbell is the chairman and founder of the Association for the Study of Peak Oil and Gas (ASPO), which is expanding throughout the world. He started his career in the oil industry as an exploration geologist, ending up as an executive vice-president. His career took him to many countries, giving him a breadth of experience on which his views are based. He is the author of five books on oil depletion as well as many scientific and other publications, being now in demand for radio and TV. Contact him at aspotwo@eircom.net.*



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DAWN OF THE SOLAR ERA

# IMAGINE

Picture a world where peace, health and prosperity reign.
It's no utopian vision, but one built on renewable energy.

By **Thomas J. Starrs**

Imagine the United States a century from now, as a society that produces virtually all of its energy from clean, domestic, renewable energy resources. What does it look like, and how is it different from the one we live in today?

In 2106, there are those who bemoan the loss of cheap oil, who long for the days when a gallon of gasoline cost less than a gallon of milk. But access to cheap oil came at a steep price: the price of dependence on countries that were politically unreliable and economically unstable; the price of climate disruption and its economic and environmental costs; perhaps even the price of our principles, as we spoke of promoting democracy while propping up tyrannical monarchies and other oppressive regimes.

For those of us with no stake in a continued reliance on fossil fuels, however, the 22nd century holds enormous promise for world economies, national security and the personal health and economic well-being of our children and children's children.

The stark contrast between this new century and the last is apparent in many aspects of our lives.

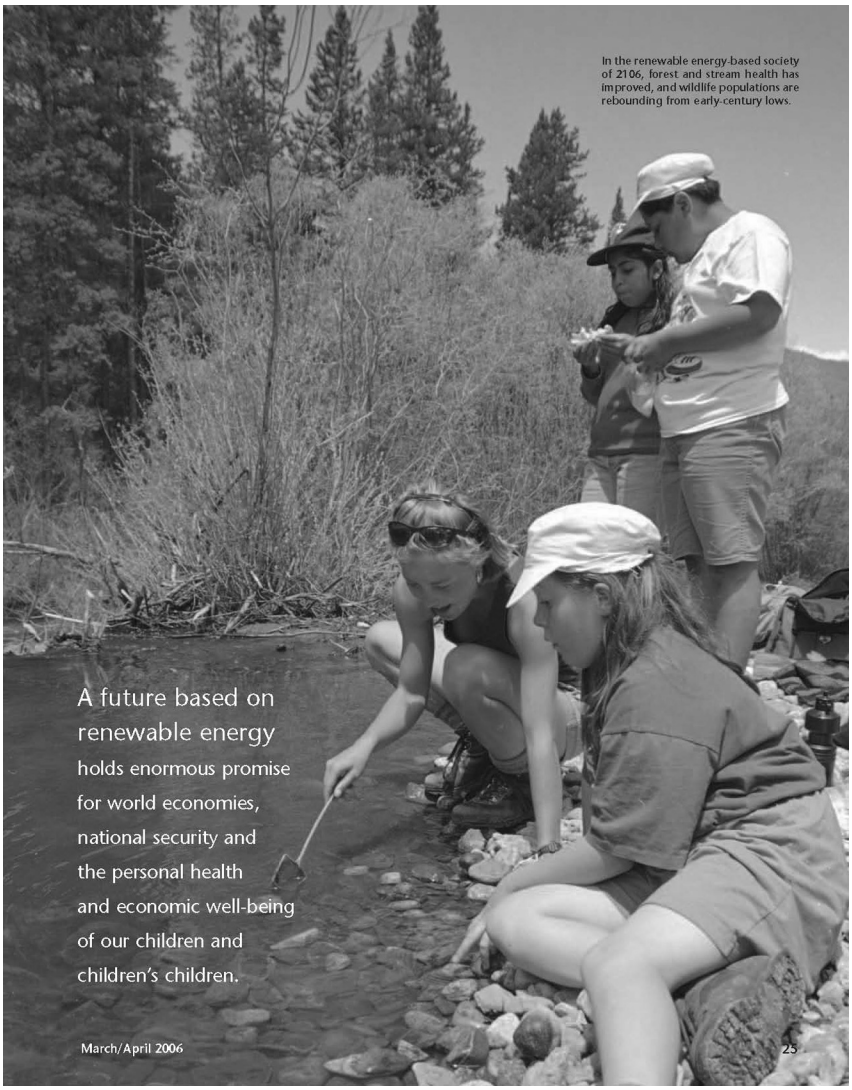
## Exchanging Resource Conflicts for Security, Jobs and Health

*It is more economically stable.* The incredible volatility associated with the Oil Era — particularly with its waning years — is now a thing of the past. Energy prices are predictable and stable, because the energy is derived from the natural flows of the sun, wind and rain. Even transportation — the sector of the economy that found it hardest to wean itself from the petroleum diet — has made the transition. Pedestrian-friendly cities and economies built around locally produced products have drastically reduced reliance on transportation, but what public transportation and shipping fleets remain are powered by liquid fuels derived from dedicated biomass feedstocks and by hydrogen derived from renewable electricity.

*It is more secure.* The stranglehold that the Middle East and former Soviet states had on the industrial economies of the world during the late 20th and early 21st century is broken. The dramatic growth in energy efficiency and renewable energy that started late in the 20th century was sustained for decades. The countries that had been highly dependent on oil and gas imports — including the United States, the European Union and much of Asia — can promote political ideals without the hypocrisy of having to prop up tyrannical, antidemocratic governments simply because they controlled access to strategic energy resources. For the world's military powers, it has meant huge reductions in spending, as the Oil Wars of the early 21st century gave way to the peaceful and profitable transfer of new energy technologies. Progress toward demilitarization was threatened briefly by proposals to increase reliance on nuclear energy, but the inherent risk of nuclear weapons proliferation resulted in the adoption of a global ban on nuclear power by mid-century. In short, conflict has given way to collaboration and competition, and the big winners are the countries that focused on research, innovation and manufacturing to support the new energy paradigm.

*It is more democratic and egalitarian.* The means of production for this new, sustainable energy era are quite evenly distributed across the world, both in terms of available resources and the technologies used to harness those resources. Of course, some of the world's renewable resources are geographically concentrated, such as the geothermal energy reserves around the Pacific Rim's Ring of Fire. But others are virtually ubiquitous — particularly solar energy, which is dispersed with cosmological consistency across the earth's surface. The universal availability and affordability of renewable energy resources has brought greater economic parity within and among societies, drastically reducing world poverty

NREL



In the renewable energy-based society of 2106, forest and stream health has improved, and wildlife populations are rebounding from early-century lows.

A future based on renewable energy holds enormous promise for world economies, national security and the personal health and economic well-being of our children and children's children.

The effect of the transition on communities and commerce will be dramatic.

and hunger. Solar water pumping and solar-powered disinfection alone have added substantially to life expectancies in what had been called the developing world; and universal access to cyberspace — the distributed information and communication networks that superseded the Internet — has eliminated disparities in access to education, research and other knowledge.

The big change in the new century, however, is that the U.S. and other governments have developed trade alliances based on the transfer of energy technologies used to harness local energy resources, rather than the shipment of the resources themselves, as was the nearly universal practice during the Oil Era. Instead of importing oil, countries now import the blueprints for improved photovoltaic manufacturing facilities or design specifications for a wind turbine blade that is optimized for local wind conditions. One implication of this profound shift: The manufacturing of the equipment and the deployment of the products uses much more local labor than the import of energy commodities ever did.

*It is more affluent.* The nations that were largely dependent on oil imports have stopped hemorrhaging money overseas. The United States alone was sending about a quarter of a *trillion* dollars abroad every year to pay for oil imports early in the 21st century. Now those dollars stay at home and get recirculated in the national economy. And because the energy economy is now tied to locally available renewable resources, jobs in those industries are hard to outsource. The agricultural sector has been rejuvenated, with farming communities busily tending to rows of wind turbines as well as rows of corn.

*It is cleaner, healthier and more environmentally benign.* In the prior century, electricity generation was the world's largest source of industrial pollution. Now, most electricity generation is emissions-free. The remainder, based on biofuels, uses advanced catalytic controls to eliminate virtually all pollutants and requires reforestation or replanting to ensure carbon-neutrality. The building sector's heating and cooling loads have been radically reduced through improvements in design, materials and orientation. Homes use virtually no external energy, since on-site solar energy supplies all necessary daylighting, hot water, space heating and electricity. Even the transportation sector has virtually eliminated air pollution, through the shift to biofuels and hydrogen. The retirement of most hydrocarbon technologies stabilized the level of carbon dioxide, one of the principal greenhouse gases, by mid-century. The level has been dropping slowly in the decades since. The health benefits of this transition have astonished the medical community, as the incidence of respiratory diseases such as asthma and emphysema has plummeted. The term "smog" has become archaic, since the air quality in most cities rivals that of the surrounding countryside. And speaking of the countryside, forest and stream health has improved, and wildlife populations are rebounding from early-century lows.

### Transitioning from Ruin to Renaissance

Perhaps this description makes the 22nd century seem idyllic and utopian. But some harsh realities underlie this transition.

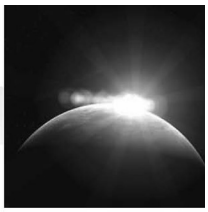
First of all, the intervening years — during which the transition was made — were painful, even devastating. Global warming's early victims included the low-lying Pacific Island nations and the Florida Keys, both of which were inundated by mid-century as rising sea levels took their toll. The Floridians lost their homes; the Pacific Islanders lost their countries. The United States, last among the industrialized countries to abandon the Oil Era, paid the price for having the most energy-intensive economy among countries in the Organization for Economic Cooperation and Development: Its economy shuddered, and nearly collapsed, as rising energy prices made its products uncompetitive and obsolete, since global markets rewarded the countries that had made the transition early, squeezing the most out of each unit of energy they used. And then there were the Oil Wars. …

Second, although the transition to renewable fuels has been completed and energy is abundant, some fuels are much more expensive. The effect on communities and commerce has been dramatic. Cities have reorganized around their urban centers, with dense communities surrounded by greenbelts used for agricultural production. Suburbs, which lost their attraction as the cost of commuting skyrocketed, have become the new slums. Air travel is expensive and exotic, available only to the most affluent. The result is that families tend to be less mobile, and businesses focus on building relationships with materials suppliers and customers closer to home. At the same time, communications networks have expanded, further enabling the flow of information globally, even as the flow of people and materials has slowed.

This communications revolution has reinforced perhaps the most fundamental shift in the global economy, which is that the greater exchange of information and ideas more than offsets the reductions in exchange of resources and other materials. No longer is it common for goods manufactured in China to be sold in the United States, but ideas and technologies developed in China are marketed to the United States — and vice versa. The result has been a renaissance of ideas, with global affluence rooted in entrepreneurship and innovation, rather than in the ownership and control of natural resources. With this renaissance has come world peace and prosperity, based on equitable resource allocation, abundant supplies of food and water, and record improvements in health and mortality.

This new paradigm has also revitalized the U.S. economy, which lagged behind the rest of the industrialized world in weaning itself from fossil fuel resources, but which rose like the Phoenix from the ashes of the Oil Era and emerged as a leading global innovator and developer of new energy technologies and systems. For 22nd-century Americans, life has never been better or more hopeful. ●

*Thomas J. Starrs is the immediate past chair of the American Solar Energy Society board and is vice president for marketing and sales at the Bonneville Environmental Foundation. He can be reached by e-mail at tomstarrs@b-e-f.org.*



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# TRANSITIONING TO A NEW PARADIGM

Now is the time to establish a strategic plan to address the inevitable end of cheap oil.

By **Roscoe G. Bartlett**

Oil runs our economy. Oil runs our military. Oil makes and transports the food that we eat. That's why it makes no sense for our country to wait for global peak oil to impose a radical and permanent end of cheap oil.

Oil production reached a maximum, or peak, in the United States in 1970. It has declined every year since. Oil production has also peaked in 33 of 48 major oil-producing countries. Many experts predict that global peak oil is imminent. Chinese government officials have projected global peak oil in 2012. The Department of Energy's Energy Information Administration estimates global peak oil won't occur until 2037. Only the timing of global peak oil is in dispute among energy experts, but the year won't be known until after it has occurred. Energy advisor Robert L. Hirsch in his recent *World Oil* article cautions that peak oil was not apparent in the 48 continental United States, Great Britain or Norway one year in advance *(see http://worldoil.com/magazine/MAGAZINE_DETAIL.asp?ART_ID=26968&MONTH_YEAR=Oct-2005)*. A 1999 National Petroleum Council report failed to predict the apparent 2005 peak in North American natural gas production.

From 2003 to 2004, the average increase in oil consumption in Belarus, Kuwait, China and Singapore was 15.9 percent. With worldwide demand increasing, what effect would a decline in oil supply from global peak oil have on oil prices? The National Commission on Energy Policy and Securing America's Future Energy issued a report on Sept. 6 titled, "Oil Shockwave" *(access the report at www.energycommission.org)*. The commission estimated a 4 percent sustained shortfall in global oil supply would raise the price of oil above $160 per barrel.

## Our Spiraling Energy Appetite

Our country is much like a young couple whose grandparents died and left them a big inheritance. They have established a lifestyle where 85 percent of all the money they spend comes from their grandparents' inheritance, and only 15 percent comes from their earnings. They realize at the rate they are spending the inheritance it will run out long before they retire. Obviously, they are going to have to spend less money, earn more money or do both.

That is a good analogy for energy use in our country. Eighty-five percent of the energy we use comes from natural gas, oil and coal. Only 15 percent comes from other sources. A bit more than half of that 15 percent, 8 percent, comes from nuclear. Global peak oil will impose a transition from today's 85/15 ratio to generating a major proportion of our energy from renewable sources such as solar, wind and agricultural sources.

These renewable sources contribute trifling amounts of current U.S. energy use. Since the year 2000, solar and wind power have increased approximately 30 percent per year. At that rate, solar doubles in about two-and-a-half years. It is four times bigger in five years. So, how much has solar grown in five years? In 2000, it was 0.07 percent of total U.S. energy use. That is less than one-tenth of 1 percent of the energy Americans consume. In five years, solar has grown to 0.28 percent. It is now a little over one-fourth of 1 percent. If solar and wind continue to grow at the same rate, they would increase four times, to more than 1 percent of our energy use by around 2009.

According to a recent report, a 4 percent sustained shortfall in global oil supply would raise the price of oil above $160 per barrel.

Agricultural sources currently contribute 1 percent of total U.S. energy use. How much more can they contribute? When the oil era began about 100 years ago, world population was 1 billion. Now, it is nearly 7 billion. We're barely able to feed the world. If we use food crops like corn or sugarcane for energy, how will we feed the world? If we take other organic material considered waste such as beet pulp, corn stover, soybean stalks or switch grass to make energy, we will take away the organic material that creates topsoil. How will we maintain the topsoil to grow the crops to feed the world? The U.S. population is increasing by nearly 30 million persons every decade. These are all limitations to expanding energy production from agricultural sources.

### It Takes Energy to Make Energy

How much energy does it take to get 1 barrel of oil? You have got to discover it. You have to pump it out. You have to transport it and refine it. You have to transport the refined products to gas stations or customers. These processes consume an average of 0.23 Btu (British thermal units) of fossil energy inputs to produce one net Btu of refined product.

Almost half of the energy input to make a bushel of corn comes from nitrogen fertilizer. Essentially the only source of nitrogen fertilizer today is natural gas. When natural gas is gone, we are going to have to find another big energy source to produce nitrogen fertilizer. In a real sense, the food we eat is gas and oil.

The energy density in 1 barrel of oil is the equivalent of 12 people working full time for one year. A barrel of oil yields 42 gallons (159 liters) of gasoline. Think about how far 1 gallon (3.8 liters) of gas takes your car. How long would it take you to pull your car that far? That is an example of energy density. It also demonstrates that global peak oil poses the greatest threat to the transportation sector. There are no ready liquid fuels substitutes of comparable quantity and energy density to oil for use in transportation.

### A Call for a New Paradigm

Until now most of the focus has been on how to "fill the gap." That is, how can we find enough other energy sources to continue to meet growing demand? The Department of Energy's February 2005 commissioned report, "Peaking of World Oil Production: Impacts, Mitigation and Risk Management," concluded that a crash program to manufacture current available liquid fuel alternatives at the maximum rate would have to be initiated 20 years before global peak oil to avoid significant supply shortfalls. *(Access www.energybulletin.net/4638.html.)*

It might seem possible to "fill the gap" in the short term. However, in the long term, it will be impossible. For one thing, doing so will hasten the exhaustion of other finite resources. That will make the inevitable transition to renewable sources more difficult and more painful.

For instance, there are 250 years of coal in the United States under current use rates. If that consumption rate is increased by 2 percent per year, coal reserves are reduced to 85 years. If coal is converted to a liquid fuel for transportation, the reserves are reduced to 50 years.

That is why I propose a new paradigm. We need to recognize that "filling the gap" is futile. We will have competing demands for limited resources of time, capital and energy. The challenge we face is a transition to an economy in which we have reduced our energy needs to a level that can easily and affordably be met with sustainable energy resources.

First, and most urgently, we must raise awareness about the impending crisis from global peak oil. Congressman Tom Udall (D-N.M.) and I have formed a Peak Oil Caucus and introduced H. Res. 507, a bill that states that "the United States, in collaboration with other international allies, should establish an energy project with the magnitude, creativity, and sense of urgency that was incorporated in the 'Man on the Moon' project to address the inevitable challenges of 'Peak Oil.'" Congressman Udall and I testified at the first hearing about peak oil held by the Subcommittee on Energy and Air Quality of the House Energy and Commerce Committee on Dec. 7.

With sound information, proactive planning and preparation we can overcome the challenges of peak oil. If we do not prepare, we will still transition to other sources as oil and other fossil fuel reserves are exhausted. However, if we wait for global peak oil to force the transition, we face a really bumpy ride.

*Congressman Roscoe Bartlett is a seven-term representative of the Sixth District of Maryland. He has discussed peak oil extensively in a series of 14 special order speeches and hosted an energy conference on Sept. 26. Transcripts, including charts, are posted on Congressman Bartlett's website at www.bartlett.house.gov.*

## Register Your Support

Your voice matters. Contact your elected representatives and urge them to support efforts for vast improvements in energy productivity to enable transition to domestically available, pollution-free renewable energy. Access Project Vote Smart to search by zip code for your elected representatives in the U.S. House, U.S. Senate, and state house, senate, and executive offices: www.vote-smart.org.

# Making the Transition

A sampling of excerpts from **proposed roadmaps** for getting to a sustainable energy paradigm.

*Compiled By* SOLAR TODAY *Staff*

***Common Sense: Making the Transition to a Sustainable Energy Economy***
American Solar Energy Society
www.ases.org/print_catalog/ases_reports/PS_Common_Sense.pdf

*"What ASES is proposing is possible and could be implemented by [Congress] over the next two years. Many of the recommendations, such as a national Renewable Energy Standard (RES) and a Renewable Fuel Standard (RFS), reflect proposed legislation that has been debated but not acted on for nearly a decade. … ASES' principal recommendation, however, is that the political leadership of the country at federal, state and local levels act now to begin the transition to a clean domestic energy standard."*

***Renewable Energy in America: The Policies for Phase II***
American Council On Renewable Energy
www.acore.org/download/phaseII_forum_summary.pdf

*"Public policy leadership in Phase II [must] come from state and local governments, but also, there must be federal leadership to facilitate the spectrum of strategies, policies, and programs. Indeed, the shift from Phase I — a clean and neat funding of RD&D through traditional government funding mechanisms — to Phase II, where policy must accommodate the breadth of differences across a huge nation, will be a great challenge, and worth our best efforts."*

***Our Solar Power Future: The U.S. Photovoltaics Industry Roadmap Through 2030 and Beyond***
Solar Energy Industries Association
www.seia.org/roadmap.pdf

*"[W]e propose a roadmap that tailors R&D programs to create market solutions, enhances pollution prevention approaches to focus on clean alternatives, ensures customer choice, and provides targeted incentives that seed the market without destroying it. Based on experience in the United States, Japan, and Europe, the actions we propose represent the best and most effective options to achieve these targets."*

***Clean Energy Blueprint: A Smarter National Energy Policy for Today and the Future***
Union of Concerned Scientists with the American Council for an Energy-Efficient Economy and the Tellus Institute
www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=44

*"UCS and its co-authors analyzed a set of policies that includes standards and incentives to increase investment in clean energy by consumers and the electricity sector and to help overcome existing market barriers that currently slow investment. … The analysis reported here examines the following 10 renewable energy and energy efficiency policies [including] renewable portfolio standard; public benefits fund; net metering; production tax credit; increased R&D funding; [and] improved efficiency standards."*

## Partners for Change

***A sample of U.S. organizations whose mission is to address the peak oil challenge.***

The Community Solution
**www.communitysolution.org**

Post Carbon Institute
**www.postcarbon.org**

Association for the Study of Peak Oil & Gas – USA
**www.aspo-usa.org**

Access a more complete listing of organizations focused on creating a sustainable energy future at www.solartoday.org/2006/mar_apr06/roadmaps.htm.

***Transitioning to a Renewable Energy Future***
International Solar Energy Society
www.whitepaper.ises.org

*"Governments need to set, assure and achieve goals to accomplish simultaneously aggressive efficiency and renewable energy objectives. The implementation mechanisms for achieving these goals must be a packaged set of mutually supportive and self-consistent policies. The best policy is a mix of policies, combining long term renewable energy and electricity standards and goals with direct incentive and energy production payments, loan assistance, tax credits, development of tradable market instruments, removal of existing barriers, government leadership by example, and user education."*

***A Responsible Energy Plan for America***
Natural Resources Defense Council
www.nrdc.org/air/energy/rep/rep.pdf

*"The cornerstone of NRDC's plan to secure America's energy future is increased energy efficiency. Not only is energy efficiency free of environmental impacts, but it is also by far the cheapest way of meeting our energy needs. The efficiency improvements we recommend do not rely on pie-in-the-sky, undeveloped technologies, but on readily available and cost-effective processes that allow us to gain more productivity out of less energy."* ●

DISCUSSION

Chairwoman BIGGERT. Thank you very much. Maybe we can organize a science trip to go and see what you are doing down there.

Mr. HONDA. I'm there.

Mr. SWENSON. Love to have you.

Mr. HONDA. Madam Chair, you may want to also notify the audience and our witnesses that we have a very tight schedule.

Chairwoman BIGGERT. Yes.

Mr. HONDA. We need to leave at 2:30 sharp.

Chairwoman BIGGERT. We'll proceed now with the questions, and we will each take five minutes and then rotate. So, if we can have short questions and short answers that would help to get through all that we have.

This past year, we had a—there was a demonstration on the Mall in Washington of solar houses that were built under a competition from DOE and sponsored by numerous corporations. And, the university students participated, and they came and put up 850-foot houses, and put them all together to demonstrate how you could have an all solar powered house.

Now, they happened to pick a week in Washington that it rained the whole week, absolutely the whole week. Now, that reminded me, you know, and I live outside of Chicago, in the wintertime, particularly, I think January and February, we seem to be able to go for weeks and weeks without ever seeing the sun.

So, and being here in this beautiful California all the time, is there—is it practical to use solar energy in the higher latitudes with more diverse climates, like in Chicago, or where you have a lot of rain?

Mr. Pearce?

Mr. PEARCE. Yes. The world's biggest market for solar is Germany, that was 57 percent of all installations last year worldwide, and they have a climate that is as bad, if not worse, than Chicago.

Chairwoman BIGGERT. Yes.

Mr. PEARCE. So, even in the rain solar systems are going to be producing electricity. Obviously, it's going to be not as much like the sun shining brightly, but definitely it may drop there.

Chairwoman BIGGERT. Thank you.

Then, Mr. Larsen, you say that EPRI has different projections for the market for renewable energy than the Energy Information Administration. This Subcommittee sponsored a forum on energy modeling last year, and talked about how important assumptions are to the modeling results.

Why do you think your models and those assumptions differ from EIA?

Mr. LARSEN. I believe part of the answer is that, well, the basis for the model that we created was the NEMS model, so we took the output from that model and then introduced regional differences, the renewable portfolio standards, and other economic inputs into our model to try and shape an output for a 2050 outcome.

So, really, we took in regional differences across the country, across the states, to really start drilling down into what was different with various RPS inputs and assumptions, as well as various assumptions on the cost of electricity.

And again, there was no assumption on a dramatic change in the technology or any disruptive input that would significantly reduce that cost.

Chairwoman BIGGERT. Do you see anything adding to that, with the changed technology that we seem to be moving forward on so many of these things that we haven't in the past?

Mr. LARSEN. Oh, absolutely. It's a—for us, when we create a model, it's difficult for us to take a good snapshot, since often times the technology is moving so quickly, as it is today.

The model that we generated was based on 2005 data, and, I mean, six months ago, that's a long time ago with respect to what's happening in the industry and what we are seeing at the Valley today, with respect to solar technology development.

Chairwoman BIGGERT. Well, if we say an over supply of only one to two percent of the oil demand if sustained can cause prices to drop dramatically, like in the late 1990s, what happens to all of those renewable energy investments if the price of conventional energy drops in two or three years, whether or not this is a deliberate OPEC tactic?

Would anybody like to answer that? Doctor?

Mr. SWENSON. Yes, I can speak to that.

Dr. PENZIAS. I thought——

Mr. SWENSON. Oh, excuse me, go ahead.

Chairwoman BIGGERT. You both can, first Dr. Penzias.

Dr. PENZIAS. The simple answer is price. The price of coal is a price in human lives, in railroads, you can't just drop the price of coal, and coal is what generates our electricity in this country. There isn't, natural gas is not controlled by—if we talk about electricity only, then that isn't the problem. But, the issue is still price, and a dramatic change in the cost of electricity generation will make a huge difference. And so, I think it's beyond on that side.

On the petroleum side, that's a somewhat different story, and we can get into that, but if we talk about just electricity generation, I think it's almost—I think it's, essentially, independent of demand, because there's almost no petroleum used to generate electricity, if I remember from the chart.

Chairwoman BIGGERT. Mr. Swenson.

Mr. SWENSON. Yes. The largest oil field in Mexico, Cantarell, is on the verge of dropping dramatically to maybe a quarter of what it was doing before within the next couple of years. The North Sea is declining, and I believe that there could easily be a reversal where the price of oil could go down for a short period of time, but we are seeing an inextricable change in the availability of oil, and it's not yet hit other than with price, but we are close to that point where the rubber band is stretched very tight, and a little perturbation could mean gas lines again and serious disruption.

So, while there may be some temporary reversals, the trend is distinctly for higher prices in oil.

Chairwoman BIGGERT. Thank you.

Dr. Chu.

Dr. CHU. Yes, going specifically to your question, we have an example in Europe, Danes actually were very successful in encouraging a wind power development, and the way they were able to do that is, they would guarantee some return on investment, so

they would stabilize things. So, just in case the bottom does drop out, they would have a floor that said, okay, you can make a certain amount of money.

A similar thing has to be done, if and when we ever go to let's say a carbon tax trade, if the price of carbon trading goes too far down that could snuff out a lot of investments, and so there should be concern about a minimum floor, otherwise because many of the things that you have heard you are talking about a three, five, even ten year investment. So, you have to be very conscious about guaranteeing some sort of investment over a stable period of time.

Chairwoman BIGGERT. Thank you. I think that's what concerns me, I think we really have to move ahead, and we have in all kinds of renewable technology right. We really have the opportunity to do it, because people are concerned about not having enough of the conventional fuels that we have, and we have to move ahead, you know, the long-term to nuclear, the long-term to hydrogen, and ethanol and all those things in between, and solar can be a long-term—the development that needs to take place, but we have to be moving now to make sure of that. I think, people understand that it is a process that takes a while.

Mr. Honda.

Mr. HONDA. Thank you, Madam Chair, and before I start my question I would just like to recognize four gentlemen up there in the red tee shirts, they are the Santa Clara University solar decathlon team, and we want to welcome you. This is not only solar energy we tap into, it's youth energy, too. So, welcome, thank you for being here.

Mr. Larsen, could you discuss further the issue of grid integration of renewables and how they arrive at the projection that costs will go up, could you integrate us as to the percentage or the numbers of renewables in Brazil? I think I heard you say that, and I was curious about what they are thinking.

Mr. LARSEN. Yes, Mr. Honda. The issue with renewables in the state of the technology today is one related to dispatching and controlling that resource. So, for instance, we have wind or solar, which the wind blows certain times of day, the sun is out certain times of day, and we still have not fundamentally solved the bulk of large energy or electricity storage count from a technology standpoint.

So, for instance, if you look at the peak coincidence, so the peak load versus peak demand, if you compare demand versus what we are dispatching with wind, the peak coincidence is probably in the single digit percentage points. So, when we have peak demand during our hot days or hot times, such as we did in the state a week or two ago, the wind may not be blowing at all times for us to be able to dispatch that wind power to support that demand.

So, that presents a significant integration challenge to the grid. So if we don't have—if we are relying solely on a non-controllable resource, then we are going to have to get that energy somewhere else, and with today's state that would come from, in the State of California, most likely natural gas, or combusted turbines, or other dispatchable assets.

The other issue with respect to wind would be just the ramp rates that we are seeing when the wind does blow, and when we

are able to dispatch that energy. The ramp rate or the increase from zero to 100 percent on a lot of these wind farms is significant, that's a significant integration count to the grid.

So, where we are today with two percent across the country, or less than two percent of renewable as a part of our generating portfolio, we have the capacity to make up for a situation where we can't dispatch wind, or we don't have that resource available. If that percentage increases significantly, then we will have to either achieve that gap, close that gap that we are going to have by end-use efficiency or other storage means in order to make up that lost demand or demand that we can't meet.

Mr. HONDA. So, it's really a juggling of the different sources, and I guess in terms of what you can control immediately with your grid.

Mr. LARSEN. Absolutely.

Mr. HONDA. That sounds like the back-up, so your peaks would reverse probably from a management perspective.

Dr. CHU. Well, most of the grid decisions are made, we don't transfer electricity very far distances. If you look at how it is generated and where it's used, there is very little research being done in the United States on very high voltage DC transmission. The cost of DC transmission is very—is high. It's scaled $1 million a mile, but once you can think about transmitting electricity over 2,000 miles, a lot of the issues that you just heard about are greatly diminished.

And so, one of the things is that renewables, wind, you know, it blows somewhere in the United States quite often, and so once you have very efficient long distance transmission this opens up so that renewables can be a larger part of the portfolio of our energy. This is something that's rarely discussed.

Mr. HONDA. Okay.

Dr. PENZIAS. The northeast blackout, the way the present grid transits energy from one place to another is that everything has to stay 60 cycles, and that—when something gets a little out of whack, and one cycle is going up the other one down, all of a sudden the northeast United States becomes the darkest spot on the planet.

So, a national security issue could be to separate pieces of the grid, even if you don't get the DC across the country, if you just put DC in the next area, instead of having all DC—all AC connect others, there is technology there and, perhaps, EPRI can talk about that, but we don't stabilize the present grid because of the private enterprise, and they can't afford it.

But, it may be, if you folks want to look into the possibility of making our grid more secure, and then also when it is more secure that also allows it, it can respond to the loss of energy in some way, and also respond to the loss of renewables. So, you get both at the same time, national security and the robustness display as well. That's another possibility.

Mr. HONDA. Thank you.

Mr. Pearce, you said that the government labs did good fundamental research, but that the problem has been scaling it up to manufacturing scale. Do you think that DOE could work differently to address these areas, and then because DOE does not focus on

this how does industry really look at the Department of Energy as compared to relying on internal labs or universities?

Mr. PEARCE. Well, I think DOE is starting to make some changes. In the last few weeks, there was a new major laboratory opened at the National Renewable Energy Lab, specifically designed for manufacturers to bring in their equipment, place it in the facility, and operate it there with NREL personnel. And, Miasolé intends to put a system in that facility, just for the purposes of accelerating our process development for high-volume manufacturing technology.

You know, so I think the DOE and, particularly, the NREL team is absolutely on the right track to make that happen.

Mr. HONDA. Mr. Pearce, on a personal basis, I'm thinking of doing my roof all over again, I heard you say that, you better do it when you are doing it then, so how do thin-film photovoltaics perform compared to silicon, and in terms of durability, long-term efficiency, average daily energy outputs and so on?

Mr. PEARCE. Well, right now most of the thin films are less efficient than the crystalline silicon, but, you know, you are comparing 50 years of technology maturity versus relatively new.

The thin films are reported to do better in low light conditions, early in the morning.

Mr. HONDA. I see.

Mr. PEARCE. Late in the evening. So, some of that washes out. In most applications, you are not constrained by the amount of roof space. In fact, an area of about 400 square feet, about the size of a two-car garage roof, would be adequate to power the needs of most residential applications, even at 10 percent efficiency.

I myself am holding out for Miasolé solar panels on my roof. I hope you can hold out also.

Mr. HONDA. Well, I need my roof before the rainy season, and this is not the Gulf State.

Dr. Chu, the Helios Project is a dramatic example of potential revolutionary technology advances in energy, and it may help to have a better understanding of the time frame of true market penetration of such revolutionary disruptive technology. So, do you have any idea what that is, five, ten, 15 years?

Dr. CHU. Well, we are hoping for something on the scale of ten years. If you think of, look at the Brazil experience of how it had to scale up its ethanol production using the existing technology, it still took more than a decade.

Mr. HONDA. Yes.

Dr. CHU. So, I think one would think that right now most of our ethanol production in the United States is via corn, although in the long run that is not sensible. It can be viewed as a means of transition, so you get ethanol in the pipeline, you get it in the service stations, you get all that infrastructure going, in the meantime you develop very aggressively better plants and better means of converting that feedstock, bio feedstock, into fuel, which ethanol again is only a temporary stop measure.

Dupont and DP are partnering saying butanol is much more desirable than ethanol. But you get it going. When it becomes a 20, 30, 50 percent replacement for gasoline, this is of scale which will

literally take a decade, maybe a decade and a half, even if it's aggressively pushed. If it's not aggressively pushed, it takes longer.

Mr. HONDA. One of the things that I'm concerned about is: I hear all the time the concern about other countries graduating 300,000 engineers and scientists. My sense is that they are not all in the area of technology that we are discussing right now, it's probably more in the infrastructure science for the developing countries.

But, the way I think that we can stay ahead is the way we teach, and looking at those who are creative and innovative in the industries; and you look at each company, you look at their employees, a handful have, if you did a bar thing you'd see maybe a handful of engineers and scientists having a lot of patents and the rest are less.

Looking at these folks, and trying to understand how they think and how they perceive things, my question to you is, do you think that it's possible to look at these individuals and extract from them the skill-sets and be able to do that and teach those skill-sets from pre-kindergarten to post-graduate?

I'll just start with Mr. Swenson.

Mr. SWENSON. Are you saying here in the United States, or are you thinking in terms of the international, or both?

Mr. HONDA. Whomever that we would identify as, you know, folks that we'd like to study in terms of looking at those skill-sets.

Mr. SWENSON. Well, in the developing world, the people have maybe the ability to do basic reading, and they have hand-me-down tech and so forth. So, there's a huge gap to raise up the level where you have the background in math and so forth, to be able to start getting into science and technology.

There are others here who could speak more effectively to the domestic circumstance, but I think that, as I said earlier, if there were some opportunity for the U.S. to encourage education in other countries, and to bring people here, send people there, that what would happen for the students here in this country is, they would be stimulated because you learn by teaching and you learn by doing, and I think that could make a big difference.

Mr. HONDA. I'll come back to that question again, if the Chair would like to go through another round.

Chairwoman BIGGERT. Okay, thank you.

Mr. Swenson, do you think it's possible that some developing nations will just leap frog the U.S. and other developed countries in using fossil fuels and go straight to economies based on renewable energy? If they could do that, why do we see, you know, China and India turning to fossil fuels and really having such a need for those?

Mr. SWENSON. Well, I hope that we can turn that situation around very quickly. I think that the debate is pretty well over about whether the use of coal is creating a hazard that is untenable.

And so, to the extent that we can set an example here in this country, by doing an about face and ramping up in a big way our renewable technology, that will become possible in other countries. And, our experience is that these technologies are embraced, and when you consider that there's about two billion people who have no electricity at all, and the rural environments in which they live

are very hard to provide infrastructure. I think that a small amount of solar could be a huge benefit. And as I mentioned it's ubiquitous; it can be put anywhere on the face of the Earth and you are ready to go.

So, I think that it may be true that China is heading in that direction and India to some extent, but my hope is that their political leadership will join with ours in recognizing that we have to start protecting our atmosphere and ramp this up.

And, I guess the other question is, can renewables be ramped up? And, my answer is very distinctly yes. It can be ramped up, and it has to be ramped up, I feel, at something in excess of 50 percent a year. We did that in the .com era, we pushed very hard and growth rates were enormous. I think we can do the same thing, particularly, with thin film PV as Mr. Pearce has suggested.

Chairwoman BIGGERT. Well, we certainly, I think we are a very competitive country, and with the super computers, when Japan moved ahead with the largest computer or simulator I think then, that Microsoft came in and brought it back to the country as having the biggest computers. So, I'm sure we don't want to let anybody get ahead of us in the renewable energy either.

I'd like to go back to wind just for a minute. Illinois has put on hold the windmills that they were planning on doing, talking about, it was going to affect the radar and the air flight over that area. Has California had any trouble with that, have they had to change patterns or anything?

Mr. LARSEN. I'll try first with the answer. I'm not aware of any issues like that in the State of California. I do think that there were issues or concerns about avian migration paths, but I'm not aware about that issue in the State of California.

Dr. CHU. I had a discussion with John Roe, who is the CEO of Exxon, which does that, he actually—I heard a different story from him, and he said that the regulatory would not allow him to raise the rates by a quarter or less than a cent per kilowatt hour. They see themselves as consumer advocates.

Chairwoman BIGGERT. I see.

Dr. CHU. So, it was really people who set the rates and said "no, let's increase the cost."

Chairwoman BIGGERT. Maybe that was an excuse then. I must say that I have an article that was written in May about putting rooftop turbines on city hall in Chicago, to generate wind power, and they say that already installed was one atop a hill in a museum courtyard in San Francisco, one in the Chicago suburb of Round Lake and one in Taos, New Mexico, and in East Troy, Wisconsin, I haven't heard much about them, but they said that safety was the big issue. The Aerotech Customer Relations Director said, "The most important thing is to ensure that the turbines don't come loose and fly off," especially when you are in a downtown city, but I wondered if you'd heard anything about those turbines. I've not seen them in the cities, so I don't think that's there yet.

While we are introducing people, I would like to note that Dr. Percy Drell, the Director of Research at the Stanford Linear Accelerator Center, is here, and her group from SLAC. We'd like to welcome all of you.

Mr. Pearce mentioned some very specific policy options, including incremental funding for building integrated solar third-party financing, loan guarantees, federal purchase requirements, et cetera. If we had $10 billion to spend on these kind of policies, and I don't mean to imply that we do, I'm only an authorizer, not an appropriator, how do you think we should divide the spending up among the options? Which is likely to get us the most for our investment and why? Maybe we could do that, I'll start with you, Dr. Chu.

Dr. CHU. That's actually a tough one, because I mean you, for example, heard today discussions about solar, and there were three approaches to solar, and so I would go back on the basic philosophy I and many others advocate, it's don't really pick one winner, but adjust the boundary conditions to spur the investment of industry. I'll go back to the, you know, have a guaranteed stabilization of what long-term investments will be.

And again, it comes back to starting to put in the real costs of emitting carbon, and once you do something like that, then all sorts of things will build, and then industry, coupled with science, with national labs, with all the rest, will develop winners, and they'll find their way.

Chairwoman BIGGERT. Good answer, thank you.

Doctor?

Dr. PENZIAS. Thank you. Again, I would echo what he said, and again, with the idea of creating a climate rather than picking any one thing. And so, the climate in which it is possible to put wind power, but wind power, to answer your earlier question, is most effective the larger the windmill becomes. And so, right now, the biggest windmill, the rotor size is now getting to be the size of a football field for a single machine. But, this is probably the best solar energy that your state can get, because after all wind is a way of converting solar energy into mechanical energy for you there.

So, it's that general climate of not subsidies, but encouragement, so that we level this playing field in things like these other alternatives. It isn't just solar, there are a number of others, but again, and please continue your fine efforts on this.

Chairwoman BIGGERT. Mr. Larsen.

Mr. LARSEN. We at EPRI firmly believe in investing in R&D, and we also firmly believe that we need to work to keep our options open. There are uncertainty in both the cost of the various fuels, there is uncertainty for the electricity industry today in carbon legislation, so keeping technology options open to generate economic power is important. So, picking a winner might constrain us or limit our ability to address an alternate future.

That having been said, I think there is obviously investments that need to be made into the various renewable technologies, but we also can't lose sight of the grid issues and the integration into the grid of those technologies, because a lot of these do change the make-up and the operations of the system.

Chairwoman BIGGERT. Thank you.

Mr. Pearce.

Mr. PEARCE. Well, I would say ultimately, you know, the funding will come out of private enterprise, that the focus of government programs should be to stimulate the market conditions, to stimulate the early research, but there's nothing that is going to compare

to the success of a very healthy alternative energy market as far as generating research dollars from private industry.

Chairwoman BIGGERT. Thank you.

Mr. Swenson.

Mr. SWENSON. Well, as I travel through the developing countries, I bump into Germans all the time, and then I was doing a project here in Salinas, a solar project, and one of the American companies told me, well, we have to consult our engineers in Germany to figure out how to do this, because I presented them with a tough issue.

So, I think that what that shows you is that the subsidizing, I know Dr. Penzias is objecting to the subsidies, but the fact of the matter is round the world we have huge subsidies. In Egypt electricity is practically given away, in Venezuela, you know, gasoline is practically given away, and so when you compare these existing conditions, and then see what one country, Germany, has done with a lousy solar resource to augment the market, it wasn't about the cost of putting electricity together for Germany that in the final analysis mattered. What matters is that they have the high ground now in the market. Because they pushed it so aggressively domestically, now they have the expertise to go around, and they've got solar companies here in the United States. They are treating the United States as a Third World country, because we do not have the expertise that they do anymore. It's incredible how quickly it's happening.

And, Mr. Pearce and his colleagues in this field of thin film have the potential for a huge leap, and if we gave them a boost it would give us a chance to get back, recapture that lead we once had in solar.

But, the Germans are offering him and his people in the same business huge opportunities: discounts, and free space, and here, "Come to our place and we'll put up a factory for you, and, you know, give you five years free rent, no taxes," and we are just not doing that.

So, I think that the opportunity here exists. If we cover our domestic need, we will begin to have the ability to export again.

Chairwoman BIGGERT. Thank you very much, point well taken.

Mr. Honda.

Mr. HONDA. Thank you, Madam Chair.

Starting out with Dr. Penzias, and then others, the idea that no area of this country felt the impact of the .com boom and the bust more than Silicon Valley, and there's a similar market frenzy developing around renewables, especially ethanol.

How do lessons learned in the .com era apply to energy tech, and are we heading down that path already, and if we are, how do we avoid this phenomena we have experienced at that time?

Dr. PENZIAS. I think there are two ways, two things to avoiding it. One is, again, this idea of not picking winners. I think in the .com bubble there was a focus on certain things, like consumer behavior which didn't happen, in a number of other cases the, what was it called, the deregulation of telephone companies is going to change the world, all kinds of stuff like that.

So, here we have a huge market, which is not going to go away. There is a huge market in energy. It almost, the sun never shines

in Denmark, and they are getting almost, they are getting 20 percent of their electricity today from solar in the form of wind. And, the solar that they are putting in today is the machines which are being put in today, talking about these football fields, they are getting bigger than that.

The technology of something as old fashioned as a windmill has gone at an unbelievable pace in the last ten years. Look at all the dead stuff in Altamont Pass, it doesn't work, but today, this huge change in technology has made these things happen.

So, I see this power of technology, plus the huge need for energy. I don't think the people in China are waiting for a cue from the United States, they desperately understand, they can't breath in Beijing. Sometimes their factories are turned off, they don't have enough electricity. They would use solar if it worked, and it will work, but not yet, and that's where we are going. So, stay tuned on solar, a number of other areas, there are enormous opportunities also in conservation, which we didn't mention. I can speak to some of those later, fuel cells, there are a great number of others. We have kept our eye on solar today, but the story is a march of technology coming to America, the diversity, and, oh, yes, in one of my solar companies we do partner with the Germans, for instance, but the innovation edge is still in the United States, and I think we are moving there.

The only—and I think we are doing a lot of the right things, and we will learn from mistakes.

Mr. HONDA. Thank you.

Dr. Chu.

Dr. CHU. I think if you over subsidize you can do a real danger, just as if you don't do any subsidies in order to get it started.

The idea of a subsidy, in whatever form, is to give long-term stability and encouragement, but where a plan is in sight. So, take wind in California, in the '70s and '80s it was, quite frankly, it might have been over subsidized, and so a lot of inappropriate technology was just stuck up there, because you are going to get money even if you stick up something that doesn't work.

So, Denmark did it right in the long term, and then that sustained the technological improvement that's leading to these huge windmills that are extraordinarily efficient.

So, I think that's a very good question, you can't just do a huge subsidy, because that will possibly lead to a boom bust.

Mr. SWENSON. Well, I could speak to this a little further. I think that because of the subsidies that are now in place, that we have already picked ethanol as the winner, and the truth be known, because of the way it's produced it has high carbon content, that is to say that the power plants that run the mill use coal, that a lot of natural gas is used in the heating process, and so pretty much 80 to 90 percent of ethanol is fossil fuel, the way it's currently being fabricated.

So, I think that therein lies the danger, and if we look at the example of ethanol in Brazil, if truth be known there, only if this were happening in the United States, it would be equal to about four percent of the energy that we use here, because they use vehicles about 10 percent as much as we do. Their transportation per capita is about 10 percent of ours.

So, these lessons don't necessarily translate just by multiplying their success with ours, because our circumstances are very different.

And, I'm quite concerned about the over emphasis on ethanol. If you put solar over every square foot of paved land in the United States, you could produce five times as much as you could from all of the cultivated lands of the United States, because, after all, it has something to do with our being able to eat. So, you have to balance food with fuel.

Mr. HONDA. Thank you.

Let me get back to that question of innovation, teach innovation, unless, Mr. Larsen, you have another comment to the last question.

Mr. LARSEN. Just a quick comment on the pitfalls of the boom bust, and avoiding making past mistakes. I think we need to keep the options open, but we also need to focus on the cost of generating electricity on a cents per kilowatt hour, in comparison to where we are today, and also in the future and to keep that in mind in evaluating all renewable technologies as we move forward, with the goal in mind to develop technology that is cost effective, economic and competitive with other technologies.

Mr. PEARCE. With respect to your question on education, I think Miasolé's experience is pretty typical here of Silicon Valley. We have 58 people, a significant portion of those are engineers and scientists, and I would guess 40 to 50 percent of them were born in some other country and trained here in the U.S.

I think the whole education issue really goes back to middle school. We have to get more boys and girls interested in science and math, because if we lose them there we lose them in high school, and they don't go on to engineering programs.

Mr. HONDA. What I was driving at was taking the phenomena of being innovative and creative that's embodied in a person who is creative and innovative, and being able to extract that—what is it about that person that makes that person innovative and creative—and be able to extract that and teach those skills to children, from preschool to post-graduate. The idea of being able to teach that skill, so that it doesn't matter whether they go into science, or math, that they have different insights and different ways of looking at things that are equal to music, or to performing arts, or to social studies, that it's a different way of thinking and looking. And, I was just curious whether you thought that those are teachable, that's possible, number one, and, number two, teachable.

Mr. PEARCE. Well, I think that is possible, and I think, in fact, the U.S. does a pretty good job in that area. I mean, particularly, our institutions on higher learning, we generate a lot of people that are, you know, creative, and you don't get that to the same extent in other countries.

Mr. HONDA. But, is it a conscious process of teaching innovation and creativity?

Mr. SWENSON. In our case in the Galapagos Islands, we gave students meters to measure the performance of the refrigerators in their homes, and students showed their electricity bill next to the graph that showed the performance of their refrigerator. They were quickly galvanized and motivated because one kid's family had

twice the electricity bill as the other, and that was like 10 percent of their income, you know, living a different lifestyle than we have. It was a lot of money for them.

So, there was a motivation, and I think that service learning, which is productive, so I go back to that term productivity-centered service learning, that galvanizes young people into being aware that they can make an impact in their community.

The Ministry of Energy came from the Mainland and interviewed our students, because they had a conservation program that wasn't working, and they wanted to see how our kids did it. And, it all had to do with the fact that we gave them something productive, something meaningful in their community, to work with.

Mr. HONDA. Yes, Dr. Penzias.

Dr. PENZIAS. I have two ways for innovation. One of them would work here in the United States very well, I think, which is diversity. I wasn't born in the United States, a lot of other people weren't, but I think the fact that having a mix of ages, I mean, one of the nice things about Silicon Valley is, it's not youth oriented, age agnostic. I mean, many of the CEOs I work with could date my granddaughter and nobody would know it, but they don't care because it's age agnostic. So, if we can go age agnostic, race agnostic, ethnicity agnostic, that's one good thing.

The thing about school, I would say, which is quite the opposite, I'm sorry to be a grouchy old guy in this, I think we have to get the school out of the way of undermining creativity. Kids, we have, I'm blessed with 12 grandchildren, they drive you nuts with their questions until they get to school and learn to stop asking questions.

We are, and there's a very simple thing, and I think we really ought to encourage teachers. We are, I think, the only country in the world that spends more money on bureaucrats in the education budget than the people actually going to the classroom.

And then, we decide, okay, let's put in, and let's fix that by putting in a testing program which gets yet another level of conformity. So, you know, if we could somehow get all these folks out of the way of teachers, I think by itself that would be—it would make a difference, and the better teachers, and, in fact, one of the things we've learned is, of course, and I've seen studies on this, the classes, any school, whether it's inner city, large, rural, urban, better teachers make for better kids. I don't think we have to impose anything on them, I think we can get rid of this upper structure.

Now, as far as taxes, maybe you could put a tax on bureaucrats, any educational—stop encouraging, stop subsidizing the administrators and put the money into the classroom and out of that. Change that balance to where it is in other countries.

Mr. HONDA. Right.

I know Dr. Chu's family is full of innovative, creative thinkers. What goes on in there?

Dr. CHU. Well, I was born into a family, and me and my siblings always questioned authority, but in sort of taking where Arno Penzias left off, I think the United States in higher education does it better than any other country, but I would agree with him that when you look at kids preschool, they are full of curiosity, and even in science class that's stamped out of them. Other countries do it

much worse, or much better, they are much more effective at stamping out of this natural curiosity.

The greatest thing in the United States school system, because I get asked this question when I go to Asia all the time, why doesn't China have home grown Nobel Prize winners? Or, Japan has some, but, you know, Taiwan, you know, and think about it, I think it's because teachers in those countries aren't questioned by their students. It's considered disrespectful, they are punished for it, but you can question your teacher in a very respectful way, and that's the way it should be.

So, the United States is actually quite good at it, what is it that we have done better? In science it actually goes back to when we were in first, second, third grade, when we were asked to give book reports, and it was a different thing. What do you think about what you just read—very different than in many European countries, and certainly Asian countries. You are not asked what you think. So, we have to encourage more of that.

Chairwoman BIGGERT. Would you like to say a few words in closing, Mr. Honda?

Mr. HONDA. I have a list here that I want to comment on, let me find my notes.

Chairwoman BIGGERT. Let me just say we could spend a whole hearing talking about education in the science field, and I agree with you, I go out to the schools, and, particularly, middle school, and I find particularly the young girls say, boys do math and science, girls don't, and that's a real shame, and I try to encourage them that this is a field wide open to them.

Mr. HONDA. Thank you, Madam Chair.

Before we close, in this area we put together a group called the Blue Ribbon Task Force on Nanotechnology, and there are some of the folks that helped us move that whole effort forward, Delilah Brambot is here, Carry Yang, Bell Wade, she left already, Bern Beecham, he's left, was introduced earlier, and our selection committee, I just wanted them to be recognized and thanked for their efforts in making the Silicon Valley the kind of place that it is.

And, I guess I would close with this thought, that the Federal Government has been a major player in innovation and technology, and moving technology forward. I guess my question in terms of, and the thought that I want to leave with people is that, we still have to impact more people and individuals, citizens and consumers if you will, and I guess we might want to also look at, what is the role of city government, county government, in changing some of our attitudes and creating some demand on alternative energy? Because cities and counties, and states if you will, also bear the brunt of that burden in many different ways.

So, I would beseech all of us to start thinking about another way of moving this agenda forward in terms of promoting alternative energy and having us think outside the box in a new paradigm.

And, to the witnesses, thank you, I thank the Chair for her willingness to bring the Committee out here, having this great discipline.

Thank you.

Chairwoman BIGGERT. Well, thank you, Mr. Honda, and I want to thank you for your participation, and he's a great Member of the

Science Committee and really knows his stuff, and we are happy to have you on that committee.

I would like to thank all of you. I hope that we will have a successful transformation of our energy system in time to avoid the harmful effects of global climate change, and we will be having a hearing on global climate change in the near future when we go back in September. So, I would like to thank both of our staffs, the Majority staff and the Minority staff, for all their hard work in putting this hearing together, it takes a lot of work, and you did a great job.

And, I want to thank our panelists for testifying before the Subcommittee today. If there's no objection the record will remain open for Members to add any follow-up questions that the Subcommittee may ask of the panelists. Without objection, so ordered.

This hearing is now adjourned.

Mr. HONDA. Thank you, Madam Chair, and to the audience, you have an evaluation form, please turn them in. If you parked in the garage here, we will validate your parking.

Chairwoman BIGGERT. All right, thank you.

[Whereupon, the Subcommittee was adjourned at 2:26 p.m.]

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