TECHNOLOGY RESEARCH AND DEVELOPMENT EFFORTS RELATED TO THE ENERGY AND WATER LINKAGE

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

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TECHNOLOGY RESEARCH AND DEVELOPMENT EFFORTS RELATED TO THE ENERGY AND WATER LINKAGE

THURSDAY, JULY 9, 2009

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND ENVIRONMENT,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Brian Baird [Chairman of the Subcommittee] presiding.

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Hearing on

Technology Research and Development Efforts Related to the Energy and Water Linkage

Thursday, July 9, 2009
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Kristina Johnson
Under Secretary of Energy
U.S. Department of Energy (DOE)

Ms. Anu Mittal
Director
Natural Resources and Environment
U.S. Government Accountability Office (GAO)

Dr. Bryan Hannegan
Vice President
Environment & Generation
Electric Power Research Institute (EPRI)

Mr. Terry Murphy
President
SOLARRESERVE

Mr. Richard L. Stanley
Vice President
Engineering Division
GE Energy

HEARING CHARTER

SUBCOMMITTEE ON ENERGY AND ENVIRONMENT
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

Technology Research and Development Efforts Related to the Energy and Water Linkage

THURSDAY, JULY 9, 2009
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, July 9, 2009 the Subcommittee on Energy and Environment will hold a hearing entitled: *"Technology Research and Development Efforts Related to the Energy and Water Linkage."*

The hearing will explore the role of the Federal Government and industry in developing technologies designed to address the link between our energy and water resources and how deployment of such technologies could help to avoid resource supply disruptions. Energy and water are directly linked. Water is essential for energy generation and fuel production—it is used in energy resource extraction, refining, processing, transportation, hydroelectric generation and thermoelectric power plant cooling and emissions scrubbing. Equally important is the energy needed for water pumping, treatment, distribution and end-use requirements. Climate variability and demand growth affect both our water and energy resources, so it is important to acknowledge their interdependency and develop technologies and adopt practices that allow us to manage these resources effectively. The Subcommittee will hear from expert witnesses who will discuss the issues relevant to deployment of advanced technologies related to energy-water issues.

Witnesses

- **Dr. Kristina M. Johnson is the Under Secretary of Energy.** Dr. Johnson will testify on the current research, development and demonstration activities at the Department of Energy to advance technologies related to the link between our energy and water resources. She will include a discussion of the Department's program offices' coordination in this area.
- **Ms. Anu Mittal is the Director, Natural Resources and Environment at the U.S. Government Accountability Office (GAO).** Ms. Mittal will provide a preview of two GAO reports due later this year. One report covers water use in power generation and the second report addresses water use in biofuel production. In addition, she will identify some of the technology research and development gaps related to the energy and water linkage.
- **Dr. Bryan Hannegan is the Vice President, Environment & Generation for the Electric Power Research Institute.** Dr. Hannegan will testify on the water use at thermoelectric power generation plants, including future water use anticipated should carbon capture and storage technologies be deployed broadly. He will describe existing and advanced cooling technologies and operation practices available today and the challenges and benefits with deployment of these technologies and strategies. He will also comment on the Department of Energy's energy/water RD&D programs.
- **Mr. Terry Murphy is the President of SolarReserve.** SolarReserve builds utility-scale solar power plants to deliver energy using integrated storage. The company is headquartered in Santa Monica, CA. Mr. Murphy will provide an overview of concentrating solar thermal technologies and how water is used in the generation process. He will discuss the different cooling technologies used today and under development. He will also comment on the Department of Energy's energy/water RD&D programs.

- **Mr. Richard L. Stanley is Vice President, Engineering Division with GE Energy.** GE Energy is one of the world's leading suppliers of power generation and energy delivery technologies. Mr. Stanley will provide an overview of the range of technologies GE is developing to address energy-water related issues, including water filtration, desalinization, organic rankine cycle, Jenbacher gas engines and advanced gas turbine technologies. He will also discuss research and development needs in this area and comment on the Department of Energy's energy/water RD&D programs.

Thermoelectric Power

Water is a critical resource in the thermoelectric power industry. The primary purpose for water withdrawal is cooling. Thermoelectric power generation uses a variety of fuel sources including coal, nuclear, oil, natural gas, and the steam portion of gas-fired combined cycle plants. The United States Geological Survey (USGS) estimates that thermoelectric generation accounts for approximately 136,000 million gallons per day of freshwater withdrawals, ranking only slightly behind agricultural irrigation as the largest source of freshwater withdrawals in the United States.[1] According to the National Energy Technology Laboratory Director's testimony before the Senate Energy and Natural Resources Committee earlier this year, nuclear power plants consume approximately 40 percent more water than an equivalent contemporary sub-critical pulverized coal (PC) plant and natural gas combined cycle plants consume approximately 60 percent less than the PC plant.

Water availability represents a growing concern for meeting our future power demands. As our population grows, our demand for water continues to rise while supplies are dwindling. In water-stressed areas of the United States, power plants will increasingly compete with other sectors of the economy and end users for water resources. In addition, water and energy-related regulatory policy may add to the challenge of operating our existing power plants and permitting new thermoelectric power plants. As water use decisions become more difficult, it is apparent that there is a role for the federal government to manage a comprehensive research, development and demonstration strategy to help ensure we are well-equipped to prevent energy and water supply disruptions.

In discussing water use at thermoelectric power plants, it is necessary to make a distinction between water withdrawal and water consumption. Water withdrawal represents the total water taken from a water source or reservoir, such as a lake or river. Water consumption measures the amount of water withdrawal that is not returned to the source. Freshwater consumption for thermoelectric uses appears low at only three percent when compared with other use categories such as irrigation which is responsible for 81 percent of water consumed.[2] Still, at that consumption rate, thermoelectric power plants consumed more than 32 billion gallons per day.

Thermoelectric power plants require large quantities of cooling water to produce electricity. There are two types of cooling water system designs: Once-through or open loop and re-circulating or closed loop. In once-through cooling systems, a local water body supplies the water, which is circulated through the heat exchangers, and then the warm water is discharged back into the same water body from which it came. This type of system has a high water withdrawal, but low water consumption. Closed-loop cooling refers to cooling systems in which water is withdrawn from a source, circulated through heat exchangers, cooled and then recycled. Subsequent water withdrawals for a closed-loop system are used to replace water lost to evaporation or leakage, for example. There are three common types of closed loop cooling water systems: wet cooling towers, cooling ponds and air cooled (dry re-circulating). Wet cooling tower systems withdraw 30–50 times less water than once-through systems, but 75 percent of the water is lost during plant operations.[3] Dry re-circulating cooling systems use either direct or indirect air-cooled steam condensers. The dry re-circulating systems, in general, have minimal water withdrawal and consumption. In the United States, existing thermoelectric power plants use all of these cooling systems with approximately 42 percent of generating capacity using once-through, 42 percent using wet cooling towers, 14 percent using cooling ponds, and just under one percent using dry re-circulating systems.[4]

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[1] Feeley, Thomas J., et al., 2006 "Department of Energy/National Energy Technology Laboratory's Power Plant-Water R&D Program," Pittsburgh, PA.

[2] Feeley, Thomas J., et al., 2007, "Water: A Critical Resource In the Thermoelectric Power Industry," U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA.

[3] Feeley, Thomas J., et al., 2007, "Water: A Critical Resource In the Thermoelectric Power Industry," U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA.

[4] *Ibid.*

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Given that the energy-water relationship is already under strain, the Department of Energy's National Energy Technology Laboratory (NETL) is developing advanced technologies targeted at reducing freshwater withdrawal and consumption associated with thermoelectric power generation. NETL's Innovations for Existing Plants (IEP) program has two major objectives: 1) develop cost-effective technologies for commercial demonstration by 2015 that can help reduce freshwater withdrawal and consumption by 50 percent at plants equipped with wet re-circulating cooling technology and 2) develop cost-effective technologies for commercial demonstration by 2020 that can reduce freshwater withdrawal and consumption by 70 percent.

The following research and development categories include the major initiatives supported by NETL: alternate sources of cooling water make-up, including produced water, mine water or reuse of treated wastewaters; advanced cooling technology; reclamation of water from combustion flue gas for use as cooling; and reduction of cooling tower evaporative losses. In Fiscal Year 2009, $12 million is available for NETL's energy/water R&D under the IEP program. The President's Fiscal Year 2010 budget request does not continue funding this R&D.

Oil, Gas and Oil Shale

Initial extraction of oil and gas does not require a lot of water, but as oil deposits are depleted enhanced oil recovery (EOR) techniques are applied to extract additional oil from existing wells. These techniques oftentimes involve injection of water or steam into the well to extract the additional resource. In 1995, the American Petroleum Institute estimated that oil and gas operations generated 18 billion barrels of produced water and estimates that over 70 percent of the produced water is recycled and used for EOR. The Department of Energy estimates that conventional petroleum refineries consume one gallon of water for each gallon of oil refined. Additional water is needed for cooling during the refining process. DOE also estimates that the U.S. has 500 billion to 1.1 trillion barrels of oil in the form of oil shale deposits. Recovery of these deposits could consume two to five gallons of water per gallon of refinery-ready oil, according to DOE.

Renewables

The use of water in the extraction and processing of petroleum-based transportation fuels is relatively small compared to the electric-generating industry. However, similar to fossil and nuclear technologies many renewable energy technologies use water in their generation process. The Department's Office of Energy Efficiency and Renewable Energy has started to address these issues through their Industrial Technologies Program (ITP) as well as through studies and research activities in individual renewable energy technology programs. Concentrating solar thermal, geothermal and biomass combustion are all renewable technologies which generate power through conventional heat-engine operating cycles which are generally water intensive. One area of research funded by ITP is the organic rankine cycle (ORC), which can improve recovery of waste heat in industrial processes and be used in solar thermal and geothermal operations. An ORC uses an organic fluid instead of steam to power a high-efficiency turbine, hence reducing water use and increasing energy efficiency. Additional efficiency gains can be achieved for solar thermal and geothermal technologies if a power plant forgoes a wet cooling technology for the more expensive dry cooling technology, similar to fossil power plant technologies.

Biofuel production has come under significant scrutiny for its use of water. From feedstock production to final conversion to a liquid transportation fuel, biofuels have an impact on water resources. Dedicated energy crops grown specifically for energy production can be very water intensive if irrigation is necessary for sufficient yields. On the other hand low-value woody biomass, algae, agriculture residues or other organic waste streams used as feedstocks for energy production biomass have a much smaller demand for water. Additionally, water is used in several other processes during conversion, but the biorefining process is modest in absolute terms compared to the water applied and consumed in growing the plants used to produce the biofuels. According to a 2007 Sandia National Laboratories report a traditional dry mill corn-ethanol facility uses four gallons of water per gallon of ethanol produced (gal/gal).[5] A new study by the Argonne National Laboratory has shown that this

[5] Pate, R., M. Hightower, C. Cameron, W. Einfeld. 2007. Overview of Energy-Water Interdependencies and the Emerging Energy Demands on Water Resources, Sandia National Laboratories, Los Alamos, NM, USA.

number has significantly decreased over time.[6] Technologies being researched such as gasification and pyrolysis may also help to decrease the need for water in biofuels production.

At the same time, there are positive synergies between some renewable energy technologies and water. For example, biogas produced by anaerobic digestion of organic waste is a co-product of wastewater treatment facilities. Biogas is more than 60 percent methane, a valuable energy resource. About 3,500 of the large wastewater facilities already utilize wastewater to produce biogas which can be used as a substitute for natural gas. The biogas can also be utilized for internal process heat needed to complete the digestion process. Anaerobic digestion reduces the need for fossil based natural gas while also treating the wastewater. The Point Loma Plant in San Diego, California is a successful illustration of anaerobic digestion of wastewater. The plant has the capacity to treat 240 million gallons of wastewater per day, is energy-self-sufficient and sells excess energy in the form of electricity back to the grid. In 2000, the city of San Diego saved more than $1.4 million in operational energy costs and sold $1.4 million in excess power to the electrical grid while also treating its wastewater.

As future demands for energy and water continue to grow, the reliability of our energy and water supplies is likely to be an increasing challenge. In 2005, Congress directed the Department of Energy to develop a report to Congress identifying current and emerging national issues associated with the link between our energy and water resources and develop an Energy-Water Research and Development Roadmap. That roadmap is now under review by the new Administration.

[6] Wu, May. 2008. Analysis of the Efficiency of the U.S. Ethanol Industry 2007, Center for Transportation Research, Argonne National Laboratory, delivered to Renewable Fuels Association.

Chairman BAIRD. Welcome to today's hearing. We have just received information that we expect a whole series of votes in about 15 minutes, and there are, what did we hear, 30?

STAFF. Thirteen.

Chairman BAIRD. Thirteen? That is good, 13 votes, which will take a long time. Accordingly, what I am going to do is dispense with any opening comments except to thank our witnesses for their presence today, for their expertise, and for their input on an important topic.

I will introduce you briefly. We will have five minutes for opening comments from each of the witnesses. With luck and alacrity, we can possibly get through at least the opening comments and then depending on how it looks over on the Floor, we will proceed.

I will recognize my colleague and friend, Mr. Inglis, for brief opening comments as well.

[The prepared statement of Chairman Baird follows:]

PREPARED STATEMENT OF CHAIRMAN BRIAN BAIRD

Good morning and welcome to today's hearing on *Technology Research and Development Efforts Related to the Energy and Water Linkage.*

I would like to welcome our expert panelists who will discuss the ongoing RD&D activities to develop technologies that will help us to avoid disruptions in supplies of these two vital resources.

Climate variability and demand growth affect both our water and energy resources, and it is critical that we acknowledge that interdependency and develop technologies and adopt practices that allow us to manage these resources most effectively.

If new power plants continue to be built with today's technologies, consumption of water for electrical energy production could more than double by 2030 from 3.3 billion gallons per day in 1995 to 7.3 billion gallons per day.

During the last Congress and continuing into this year, the Committee brought attention to water supply challenges through a series of hearings and passage of several pieces of legislation.

Additionally, during the last Congress Chairman Gordon requested that the Government Accountability Office undertake several analyses to explore the relationship between energy and water resources. We are pleased to have GAO here today to talk about some preliminary findings of their work.

We have tended to think about these two essential resources independently. However, the strong linkage between water and energy requires that we make a more concerted effort to ensure that water and energy technologies are being developed synergistically.

Again, I would like to thank the witnesses for their participation today and I look forward to your testimony.

Mr. INGLIS. I agree with you, Mr. Chairman. We should go with alacrity.

[The prepared statement of Mr. Inglis follows:]

PREPARED STATEMENT OF REPRESENTATIVE BOB INGLIS

Good morning and thank you for holding this hearing, Mr. Chairman.

This summer, my home State of South Carolina got the good news that we finally emerged from a long and difficult two year drought. The drought forced us to consider how we use water at home, in irrigation, and for industrial use. Especially in the upstate, we'll be dealing with the long-term impacts of this drought for quite some time.

I bring this up to highlight the importance of water scarcity in the decisions we make in our economy and communities. Climate change will further stress our water resources and make water management more difficult. While we need to make wise decisions to minimize our impact on the natural environment, we also need to consider how changes in our environment may impact the way we do business.

Electricity generation is the second largest source of freshwater withdrawals in the United States. The technologies we use today are very water inefficient, despite the availability of cooling systems that substantially reduce our water needs. As we change our choice of fuels in order to minimize our greenhouse gas emissions, we should also work to minimize the strain we put on our limited water resources. I'm encouraged by the work of DOE's National Energy Technology Laboratory to develop the technologies that will reduce our water withdrawal and consumption.

Fossil fuel and renewable energy resources also demand a considerable amount of energy in the generation process. I am looking forward to learning about the technologies and techniques that will help us recover and use this energy with a limited impact on other natural resources.

There's one aspect of energy and water linkage that this hearing fails to address. Our oceans are a tremendous source of kinetic energy that we can harness without consuming water. Despite millions of dollars in federal investment, not a single project to harness that energy has been added to our electricity grid. I hope that our committee will explore these alternatives at the cutting edge of renewable energy development.

Thank you again for holding this hearing, Mr. Chairman, and I look forward to hearing from our witnesses.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good Morning. Thank you, Mr. Chairman, for holding today's hearing to examine the link between energy and water and explore how the government and the private sector can best coordinate efforts to develop and deploy technology to utilize the energy-water nexus.

Water is a vital component of nearly every form of energy production. It creates energy through hydroelectric power, provides the cooling element necessary for all thermoelectric power generation, aids in the extraction of oil from nearly depleted wells, and is necessary for the growth of biomass and the creation of renewable energy sources. In addition, energy is necessary to move, treat, and use water. The connection between these two important resources makes the increased demand for energy and the limited supply of water more troublesome.

Research, development, and demonstration of technology and practices that will stabilize and conserve our water supply while continuing to meet our energy demands will require a coordinated effort by the Department of Energy, the 20 other federal agencies that engage in water research, and the private energy sector. I am pleased to see representatives from each of those stakeholders here today, and I look forward to hearing their testimony.

In particular, I am interested in hearing about the use of water for renewable energy production, in particular ethanol, biodiesel, and other biofuels. I would like to hear from our witnesses what their current research efforts on this issue are and how this committee can assist you in moving those efforts to the development and demonstration phases.

Again, I welcome our panel of witnesses and I thank the Chairman.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Good morning, Mr. Chairman.

As Chair of the Water Resources and Environment Subcommittee of the House Committee on Transportation, water is a subject of great interest for me.

The efforts of the Science Committee can greatly enhance that of the Water Resources Subcommittee, as research is needed to better understand and manage this critical resource.

In Dallas, the Trinity River is a wonderful resource.

It feeds six thousands of acres of the Great Trinity Forest. It is an important source of natural beauty and inspires nature enthusiasts to this day.

However, improper management of the lands around the Trinity River put the city of Dallas and surrounding areas of flooding.

The Trinity River Project is one of the most monumental public works and economic development projects every attempted.

As flood protection, recreation, environmental restoration, economic development, and major transportation projects converge along the Trinity River, residents and visitors from around the world will have a new and exciting image of the City of Dallas.

I have been heavily engaged in seeing that the Trinity River Project will not only improve traffic flow, but it will also give citizens access to wildlife, trails, parks, lakes, and the Great Trinity Forest.

The project also seeks to include a world-class equestrian center, as well as the award-winning Audubon Environmental Interpretive Center.

All of these special features will stimulate new urban development such as waterfront condominiums, beautiful townhouses, office towers, and sidewalk cafes and shops.

Today, this subcommittee will hear more about the connection between energy and water.

It is our hope to hear about the future of thermoelectric power. We hope to hear about new technologies to reduce freshwater withdrawal and consumption.

We hope to learn more about how to mitigate actions such as irrigation that account for 81 percent of all freshwater consumed.

In Texas, oil extraction and production is a major economic driver. I will be interested to hear, in more detail, how we can use less water for the enhanced oil recovery techniques that are water-intensive.

In areas of Texas that have been severely impacted by drought, I am curious to know if those techniques had to be reduced because of the water shortage.

As energy demands increase, it will become more important for our nation to innovate, when it comes to our energy supply.

Welcome to today's witnesses. Your knowledge and interest in this issue will be valuable to Members of the Subcommittee.

Thank you, Mr. Chairman. I yield back the balance of my time.

Chairman BAIRD. Alacrity being the order of the day, it is my privilege to introduce our witnesses quickly. Dr. Kristina Johnson is the Under Secretary of Energy of the U.S. Department of Energy. Ms. Anu Mittal—is that properly pronounced—is the Director of Natural Resources and Environment at the U.S. Government Accountability Office. Dr. Bryan Hannegan is the Vice President of the Environment and Generation for the Electric Power Research Institute. Mr. Terry Murphy is the President of SolarServe. Is that all proper?

Mr. MURPHY. SolarReserve.

Chairman BAIRD. SolarReserve? I knew I was missing something. Mr. Richard L. Stanley is the Vice President of the Engineering Division of GE Energy.

As witnesses know, we will have five minutes for each person's spoken testimony followed, apparently in this case, by a break and then a series of questions from the Committee. Thank you all, and with that, Dr. Johnson, please begin.

STATEMENT OF DR. KRISTINA M. JOHNSON, UNDER SECRETARY OF ENERGY, U.S. DEPARTMENT OF ENERGY

Dr. JOHNSON. Thank you, Mr. Chairman, and Members of the Committee. I definitely appreciate the opportunity to be here to provide testimony on DOE's programs for developing water-efficient and environmentally sustainable energy technologies.

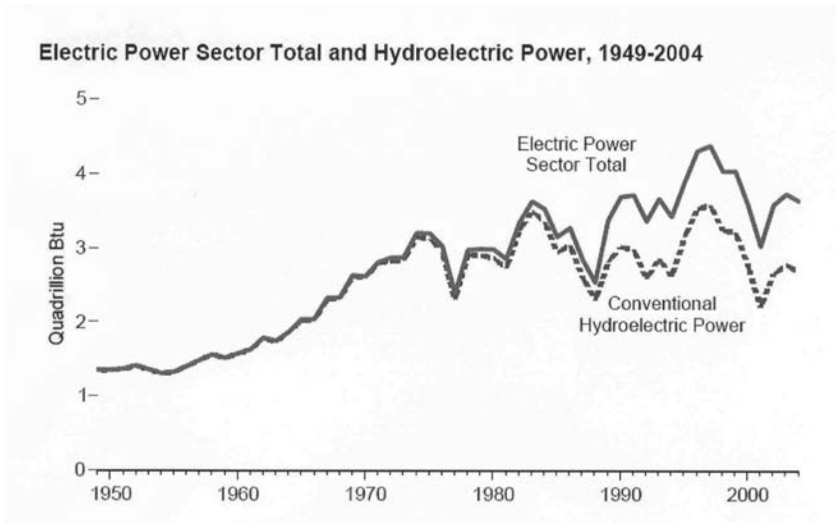
Let me just say a couple words about my background. To demonstrate my particular and passionate interest in this area, I am a third-generation engineer. My grandfather worked with George Westinghouse at the first turn of the last century in helping to electrify the country. My father then worked for 37 years with Westinghouse, started his career in hydroelectricity and ended it in nuclear. I was inspired by their examples of using energy and technology to better their communities, and therefore, it is a privilege to be here to serve the country in this position.

I also understand the purpose of this hearing is to talk about the relationship between energy and water resources and to explore the ways that we work across not only the programs within the Department but also the different agencies. So to that point, I just want to say a word about my academic background. After getting a Ph.D. and teaching for many years, I became a dean and then a provost. Interestingly enough, the Under Secretary of Science has also been a provost, and what do provosts do? Most people don't know. Our goal is to make the whole greater than the sum of the parts. And so in thinking about these issues I was particularly pleased to be here because I personally had not explored in depth the relationship between energy and water, and after preparing for this hearing, it is quite an interesting story. So without further ado, let me continue.

In thinking about the energy-water nexus, it is important to step back in my view and think about climate. Climate affects water, water affects energy. The way we use energy affects climate. And it is a critical time right now for our country and our planet. Global climate change is real and it is happening. And that was the important message from the U.S. Global Climate Change Research Program that released a report three weeks ago. The report showed that there had been significant impact already occurring, including changes in precipitation across the U.S., more rainfall in the Northwest, and less in the Southeast. The oceans are becoming more acidic, and studies have shown, and in fact a statement released by the Academies of Sciences of 70 countries including the United States, said that at the current emission rates of greenhouse gases, the coral reefs and the polar ecosystems will be severely affected by 2050, if not earlier. Marine and food supplies are likely to be reduced with significant implications for food production and security in regions that depend on fish protein for human health and well-being. And finally, ocean acidification is irreversible on time scales of tens of thousands of years.

So in thinking about energy and water, we also have to think about climate, and we must address the global climate change now or we are in danger of losing the coral reefs, the Amazon, and the Arctic caps.

So how does climate specifically affect water and energy resources? Professor Roni Avissar from Duke University, his models have shown that the deforestation of the Amazon resulted in, or contributed greatly to, the drought that we experienced in the mid part of this decade in the West, and if we think of just a graphic for a moment, so less water, about 90 percent of our electricity is derived from thermoelectric generation.



Energy Information Administration (EIA), *Annual Energy Review 2004*, Report # EIA/DOE-0384. EIA/DOE, Washington, DC, Aug/2005

So in the first graphic here, I just want to show that where the droughts have occurred, we also see that conventional electric power sees a tremendous decrease of about 35 percent.

So 90 percent of our electricity requires water to cool the thermal generation of electricity, and so when we have droughts, we don't have the water to generate the electricity. And the drought in the Southeast in 2007 in August, our nuclear plants in that area had a reduction of 50 percent of electrical generation. So there is an intimate relationship between climate, water, and energy.

So I want to talk a little bit about what we are doing in the Department of Energy to address this issue with our R&D. I will say recent advances in coal-fired plants and gas plants, i.e., integrated gasification combined cycle plants and natural gas combined cycle plants, are about 20 percent more efficient than the older pulverized coal plants, and they consume 40 percent to 60 percent less water. That is the good news.

The other news is that 80 percent of those plants are older than 30 years. So a big consideration moving forward is this aging infrastructure that we have. We have to be ready that when they, the fleet that is older and aging, can be turned over, we have to have that more efficient technology ready to deploy. The more efficient the power plants, the less water. So this is one of the areas where we are working.

So first let me just summarize then that our approach has been three-pronged. First is energy efficiency. We use less energy, we need less water. Second is the energy that we generate, let us make it more efficient. Third, renewables use less water—for example, solar PV, wind—we have goals for 2030 where we believe that by 2030, 20 percent of our electrical generation will come from wind, six percent can come from solar, and a significant percentage from geothermal and also biomass, and hydroelectric we anticipate could be as high as 10 percent.

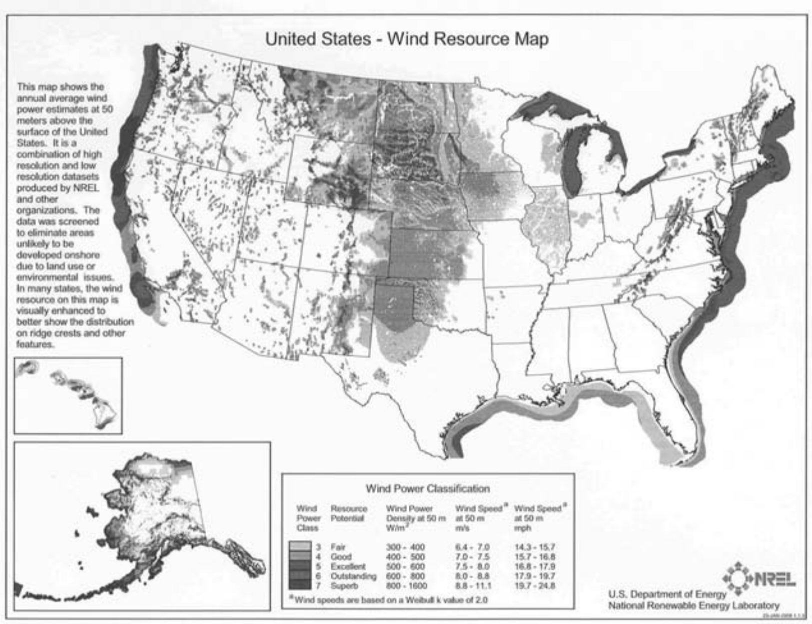
By reducing the electric generation from thermoelectric to these other renewables, we can actually reduce the amount of water we need by possibly a third or more.

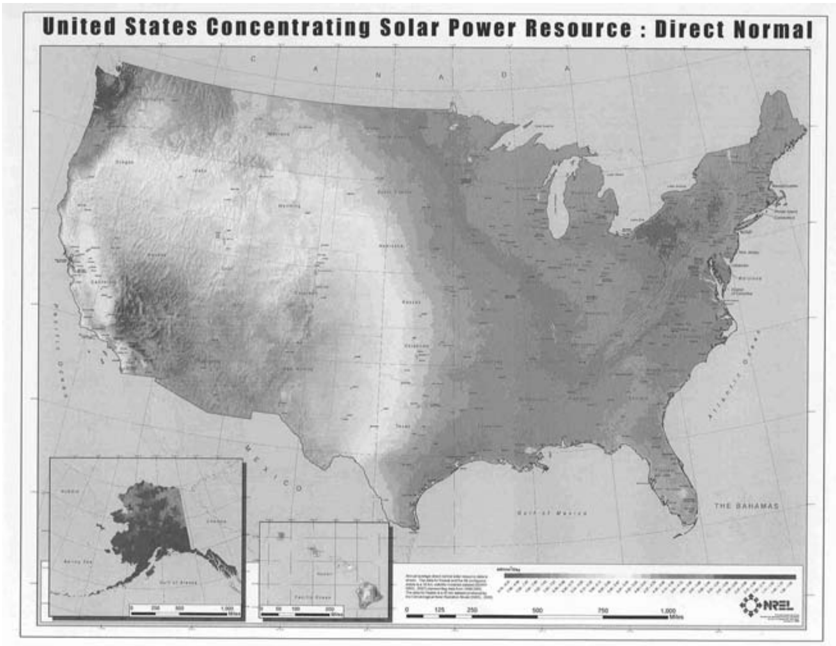
So first, it is important to look at energy conservation and efficiency. I would like to just mention that energy efficiency in our buildings, industry and transportation presents a tremendous opportunity to reduce our energy use, and over the last 40 years our energy use per dollar of gross domestic product has been cut in half. The lighting standards that Secretary Chu announced last week will not only save consumers $4 billion a year, they will eliminate the need for 14 500-megawatt power plants which would consume 50 million to 100 million gallons of fresh water a day. DOE has several efficiency programs that directly cut water use including the Energy Star labels and appliance standards that cover washers, dishwashers and lighting.

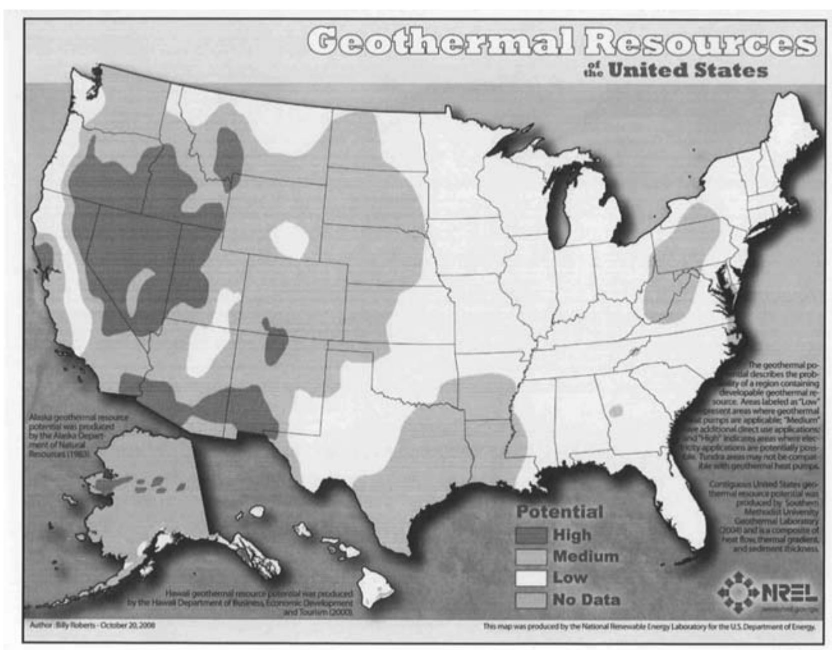
Second, our research to improve the efficiency of power plants also reduces water consumption as I mentioned.

Third, the renewables including concentrated solarthermal power and geothermal power require water for cooling. However, we are looking at ways of doing dry cooling in that area. Fourth, our renewable power plants such as wind and solar PV do not require water for cooling and can sharply reduce our power consumption.

And the only thing I want to point out here in these graphics is that the Midwest and the West are in some sense the breadbasket of renewables. If you look, here is a map of the United States, of course. Here is the wind, here is where our solar is, our hydroelectric in this area, and finally geothermal.







So we have a tremendous possibility to exploit these new technologies, and we are working vigorously to do that.

Lastly, I want to state a little bit about the growth and conversion of biomass energy. It can consume a great deal of water if we use irrigated crops and fertilizers. But if we go to switchgrass and miscanthus, we don't need to use any additional water in terms of irrigation, and I think that is really a focus for some of our R&D activities.

Let me just end by finally applauding the House for passing the *American Clean Energy and Security Act of 2009.* We believe it will help position the United States to be a leader in the green economy, and we are committed to reducing greenhouse gas emissions and our dependence on foreign oil while investing in the R&D so that we can be leaders in the new energy technologies of the future.

Chairman Baird and Members of the Subcommittee, I would like to thank you for the opportunity to provide this testimony on this important topic and to discuss with you the activities of the Department and plans for developing even further water efficient technologies and sustainable energy. Thank you.

[The prepared statement of Dr. Johnson follows:]

PREPARED STATEMENT OF KRISTINA M. JOHNSON

Thank you, Mr. Chairman and Members of the Committee. I appreciate this opportunity to provide testimony on the U.S. Department of Energy's (DOE's) programs for developing water-efficient environmentally-sustainable energy-related technologies and DOE strategies for coordinating these activities. Energy production of all types affects and is affected by the natural water cycle, and increasingly, water-efficient technologies are being developed to reduce these impacts.

Interactions with Others/R&D Selection

It is, of course, important to point out that a number of other federal agencies also have significant water programs, in particular the U.S. Army Corps of Engineers, the Environmental Protection Agency, and a number of Department of the Interior Agencies and Bureaus, although they are much less focused on energy-related aspects. In addition, the private sector must be congratulated for the progress they have made in introducing cost-effective water efficiency approaches into their operations over the last several decades as competition for water among all sectors of society has increased. Finally, State and local governments have major roles in energy and water issues through their Public Utility Commissions, State lands and waters management authority, and their various regulatory departments. The Federal Government and its agencies can contribute innovative research and development activities to support these other sectors. Overall, we work closely with all of these partners in identifying important energy-water related issues, and in developing appropriate federal level strategies to address the issues. DOE supports precompetitive basic and applied research for water-efficient technology development, which enables the identification of cross-cutting challenges that will have broad potential applicability.

Research Coordination and Synthesis

The Federal Government, in general, and DOE in particular, supports a broad range of research and development activities at universities, at National Laboratories, and in cooperative research agreements with the private sector. DOE, as the landlord of the Nation's largest civilian National Laboratory system, supports research and development activities ranging from the most basic to the most applied at various sites across the United States. We regularly support national workshops and conferences that draw our researchers together with those from other institutions to build understanding and research collaborations. Researchers within our Laboratories are not partitioned based on their funding sources, and we expect our scientists and managers to provide mutual support across the range of basic to applied challenges.

DOE program planning, and research and development coordination and integration, occurs within individual DOE offices and across offices frequently. Under Secretary Koonin and I are committed to continuing progress in enabling cross-office dialogues. More broadly, water-related R&D activities of federal agencies are discussed with the White House Office of Science and Technology Policy (OSTP)—National Science and Technology Council (NSTC), Committee on Environment and Natural Resources (CENR), Subcommittee on Water Availability and Quality (SWAQ). DOE is an active participant.

I would now like to discuss some of DOE's current energy-water related activities, and how we are working on the challenges we have identified related to water use in energy production and end-use. In general, water is only one of many factors such as materials inputs, energy production and consumption, emissions, and others that must be considered in the life cycle construction, operation, and decommissioning of energy technologies. Consequently, water-related technology R&D is best done as part of the broader R&D effort to improve performance, lower costs, and reduce environmental impacts, including water, of energy supply and end-use technologies.

THERMOELECTRIC POWER

Water, once considered a nearly inexhaustible resource, is becoming constrained in many areas, and water requirements for electricity production may compete with other demands, such as agriculture and sanitation. The August 2007 drought in the southeastern U.S. underscored this issue with several nuclear power plants in the region reducing their output by up to 50 percent due to low river levels. This situation could be exacerbated as more areas become drought-prone due to changing climate.

Thermoelectric power plants (including coal, oil, natural gas, and nuclear, with small contributions from biopower, geothermal, and concentrating solar thermal power), generate about 90 percent of the electricity in the United States, and require large quantities of cooling water, a resource that is limited in parts of the Nation. A recent DOE analysis estimated that in 2005 the U.S. thermoelectric power generation sector withdrew 147 billion gallons per day (Bgal/d) from surface water bodies such as rivers or lakes of which about 3.7 Bgal/d of freshwater were consumed, for cooling systems.

An important distinction should be made between water withdrawal and consumption. *Withdrawal* is defined as the removal of water from any natural source or reservoir such as a lake, river, stream, or aquifer for human use. The withdrawn water that is not consumed typically is returned to the original water body, making it usable again farther downstream, but the withdrawal can still place stress on the water bodies and ecosystems affected. *Consumption* is that portion of the water withdrawn which is no longer available for use because it has evaporated, transpired, been incorporated into products and crops, consumed by people or livestock, or otherwise removed from freshwater resources.

In thermoelectric power plants, heat is used to create steam, which then turns a steam turbine. A cooling system is then used to condense the steam as part of the thermodynamic cycle. There are three general types of cooling systems used for thermoelectric power plants: once-through, wet re-circulating, and dry. Older power plants equipped with once-through cooling water systems have relatively high water withdrawals, typically 20,000–60,000 gal/MWh, but low water consumption, typically 200–400 gal/MWh, since most of the water is returned to the original water body at a roughly 20°F higher temperature. *Clean Water Act* regulations effectively prohibit the use of once-through cooling systems for new power plants due to environmental concerns. New thermoelectric power plants therefore must be equipped with either wet re-circulating cooling systems or dry cooling systems. Wet re-circulating systems have relatively low water withdrawal, typically 300–700 Gal/MWh, but the water withdrawn is entirely consumed, giving them higher water consumption than once-through systems. Dry cooling systems rely on heat exchange with ambient air, rather than water, and therefore both water withdrawal and consumption are minimal. However, dry cooling is not as effective as wet cooling and can result in significant efficiency and capacity penalties during hot weather conditions. In the United States, approximately 43 percent of generating capacity uses once-through cooling systems, 56 percent of the plants use wet re-circulating cooling systems, and one percent use dry cooling systems. DOE reported to Congress in October 2008 the potential impact of converting the once-through cooling systems to re-circulating systems, "Electricity Reliability Impacts of a Mandatory Cooling Tower Rule for Existing Steam Generation Units."

Although commercially available cooling technology options can reduce water consumption, they result in some added cost and complexity, and reduce the power available from the plant. DOE is developing new technologies that will reduce the cost and complexity of these systems.

On a generating unit basis (gal/MWh produced), nuclear plants consume approximately 40 percent more water and natural gas combined cycle plants consume approximately 60 percent less than contemporary subcritical pulverized coal (PC) technology. Advanced technology coal plants can significantly reduce the water consumptive footprint, with integrated gasification combined cycle technologies (IGCC) reducing water consumption by about 40 percent compared to PC technology.

DOE, within Office of Fossil Energy programs implemented at the National Energy Technology Laboratory (NETL), is developing advanced water management technologies applicable to fossil and other power plants in three specific areas: *non-traditional sources of process and cooling water* to demonstrate the effectiveness of utilizing lower-quality water for power plant cooling and processing needs; *innovative water reuse and recovery* research explores advanced technologies for the recovery and reuse of water from power plants; and *advanced cooling technology* research examines advanced wet, dry, and hybrid cooling technologies.

Concentrating Solar Thermal Power (CSP)

Because of the huge solar resource across the Southwest U.S., and because of the ability of Concentrating Solar Thermal Power (CSP) to use thermal storage so that they can provide dispatchable power at any time, utilities are showing increasing interest in CSP systems. In the U.S. Southwest, however, water availability is an issue. During the public meetings held in 2008 as part of the Solar Energy Development Programmatic Environmental Impact Statement conducted with BLM, much of the discussion by environmental groups centered on water usage.

DOE analyzed water use by CSP plants in a report to Congress last fall: "Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation" under P.L. 106–554, Section 515.[1]

The study found that a dry-cooled parabolic trough plant in the Mojave Desert—about the worst possible thermal conditions—would "provide five percent less electric energy on an annual basis and increase the cost of the produced electricity by seven to nine percent" compared to wet cooling. However, air cooling at a site in New Mexico—with cooler daytime temperatures than the Mojave—would raise electricity costs just two percent. The impact of air cooling on a power tower is even less, with annual generation dropping by only 1.3 percent while that of a trough plant would drop 4.6 percent. Analysis of a hybrid wet/dry cooling system for a parabolic trough plant found that water consumption could be reduced 50 percent with only a one percent drop in annual electricity output, or 85 percent reduction in water consumption with only three percent reduction in output. Further R&D on hybrid wet/dry cooling systems could have significant benefits across a wide range of thermal power plants.

CRS also recently analyzed water requirements for CSP.[2] CRS found that "resource data gaps on current and projected non-CSP water consumption and on availability of impaired water supplies add uncertainty to analyses of the potential significance of CSP freshwater use and alternatives to its use. For these reasons, any estimate of how much water may be consumed by CSP at the regional, State, or county level is highly uncertain."

Geothermal power plants

Geothermal power plants also use water, air, or hybrid cooling systems in their power conversion cycle and similar considerations apply to them as for fossil and CSP plants above. In addition, geothermal power plants—hydrothermal and Enhanced (or Engineered) Geothermal Systems (EGS)—circulate water through the hot underground reservoir to extract heat for the power conversion cycle. Successful operation requires that most of the injected water is returned to the surface. In the next five years, emerging technology is expected to reduce total water loss in an EGS reservoir to no more than two percent of the total water injected, and as the technology matures the goal is to reduce that water loss to less than one percent over the life of the reservoir, or about 30 years. Current research activities to achieve this and other program goals include the development of high temperature sensors and tools for use in the reservoir; the ability to isolate and control the flow of fluids through the reservoir; the development of detailed computational models of the reservoir and the thermal, chemical, and fluid interactions within it; and the ability to image fluid flow through the reservoir.

[1] *http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf*

[2] CRS Report, Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest; R40631.

Wind and Solar PhotoVoltaic (PV) Power

Wind and solar PV electricity generation are not based on thermoelectric power cycles and only require minimal water for occasional cleaning. The DOE Report, "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply" estimated that in a 20 percent wind by 2030 scenario, water consumption for power generation could be reduced by 17 percent in 2030 as compared to the business-as-usual scenario, saving roughly 1.2 Bgal/d.

Hydroelectric Power

Water Power R&D within the Office of Energy Efficiency and Renewable Energy investigates technologies that use the motion of water to generate electricity, including both conventional hydropower and emerging marine and hydrokinetic technologies such as wave, current, and tidal power. While hydropower reservoirs do have evaporative losses that are shared across the many uses of the reservoir (flood control, recreation, power generation, etc.), water power technologies do not themselves directly consume water. The deployment of these technologies thus contributes to the overall reduction of water consumption in the Nation's energy generation portfolio. Consequently, the program does not conduct research specifically to reduce water consumption in the production of energy.

For both marine hydrokinetic and conventional hydropower, the program focuses its efforts in two key areas: technology development and market acceleration. The goal of technology development is to characterize different technology types, reduce costs and obstacles associated with design, development, deployment, and testing, and to improve device reliability and performance. Market acceleration research aims to more accurately quantify the potential magnitude, costs and benefits of water power generation, and reduce the time, expense and negative impacts associated with project siting.

Under the *American Reinvestment and Recovery Act of 2009,* funds have been made available under a cost sharing program for efficiency and/or capacity upgrades at existing hydropower infrastructures, including both large (>50 MW) and small (<50 MW) conventional hydroelectric facilities. The goal is to generate more electricity with less water, while concurrently increasing both the environmental benefits and grid services of hydropower systems.

Several studies are currently underway to more precisely quantify the energy generation potential of all U.S. water resources. These include conventional hydroelectric supplies as well as new resources derived from ocean, current, tidal or ocean thermal power. Accurately identifying realistically extractable amounts of energy will allow both public policy and industry decision-makers to better prioritize future efforts.

Finally, the Water Power Program is facilitating the initial development and testing of new marine hydrokinetic technologies through a number of competitive public-private partnerships. Products from this process will include new engineering designs for wave energy converters, development and testing of improved tidal power turbines, and the validation of the latest low-cost, high reliability ocean thermal energy components.

Carbon Capture and Sequestration

Using today's technologies, capturing carbon dioxide (CO_2) from existing coal and natural gas plants, or from new fossil-fuel fired plants, would increase water consumption because capturing CO_2 requires the addition of several processes that are both energy and water intensive. Processes that use solvents to capture CO_2 require energy to regenerate the solvent so it can be used again. Once the CO_2 is captured, it must be compressed for sequestration or beneficial use, with compressors usually having significant operating power and cooling requirements. These processes are common for both conventional fossil-based combustion processes and advanced technologies such as IGCC. The added internal energy requirements for these processes can effectively subtract 10 to 30 percent of the energy from the net plant power output and also correspondingly increase water consumption.

Efforts to capture 90 percent of carbon emissions by using current near-commercial carbon capture and storage (CCS) technologies on pulverized coal (PC) plants could more than double the amount of water consumed per unit of electricity generated. Studies of this consumptive footprint have indicated that IGCC plants with CCS have a comparative advantage, with water consumption significantly lower than that of PC plants with CCS.

A key objective of DOE R&D activities is to mitigate the potential impact of CO_2 capture on water resources. This is being addressed in a key component of its Office of Fossil Energy R&D Program—the development of advanced CO_2 capture technologies that require less cooling.

In addition to CO_2 capture, CO_2 sequestration can also impact water resources. The focus of regulatory activities governing geologic storage of CO_2 has been on developing rules that will protect underground sources of drinking water. EPA published a proposed rule for geologic storage on July 29, 2008, which uses *Safe Drinking Water Act* (SDWA) authorities and revises the Underground Injection Control (UIC) Program. The rule is designed to provide consistency across the United States and transparency that will build public confidence. As part of the rule-making process, EPA drew heavily on experience gained from DOE's Carbon Sequestration Program, particularly the Regional Partnership Program, which is helping to develop a CCS infrastructure throughout the United States and parts of Canada.

Sequestration Program research and field testing are developing best practices for characterizing geologic formations and predicting and tracking the movement of stored CO_2. This will help to minimize the possibility of CO_2 contacting underground sources of drinking water. For example, significant effort has been made on ways to assess the potential for leakage through existing wellbores, which is important if CO_2 is injected into older oil fields. Another focus area is the management of existing water in large, deep saline formations, which are vast and represent the most abundant CO_2 storage opportunities in the U.S. DOE is currently leading a National Risk Assessment Program that will develop the strong science and technology base necessary to ensure the potential risks at each site are comprehensively identified and understood, thereby providing large scale projects with the tools and knowledge necessary for safe and secure storage.

FUELS

Natural Gas and Oil

There are a variety of water-related issues associated with natural gas and oil production, including produced water and its effects on the environment, treatment of process waters, and the availability of water in arid lands. During the extraction of crude oil, water is often injected into the reservoir to increase the pressure and stimulate the production of oil. This water, along with mobile water that naturally occurs in hydrocarbon-bearing rock layers is pumped to the surface along with the oil and/or natural gas, and is collectively called produced water. Pumping and managing additional liquid from the formation requires considerable energy, and constitutes a significant cost for operators of oil and natural gas wells. Produced water is the largest by-product or waste stream generated by the oil and natural gas industry. An estimated 20 billion barrels (840 billion gallons) of produced water are generated in the U.S. each year. The characteristics of produced water vary considerably ranging from near potable waters to those containing residual hydrocarbons, salts, metals, and dissolved solids, depending on geographic location, geology and whether natural gas or oil is being produced. As the availability of usable water supplies is becoming a more significant issue in communities across the country, the protection of existing water supplies is even more critical and produced water from oil and natural gas production is being viewed as a potential water resource for agriculture and other beneficial uses, rather than a waste.

Since the early 1990's, DOE's Office of Fossil Energy has conducted over 100 science and technology research projects involving industry, universities, National Laboratories, states, and other federal agencies on various aspects of water management related to oil and natural gas development. Twenty-three states currently utilize similar risk-based data management systems (RBDMS) protocols for regulating oil and natural gas production and underground injection well activities which were developed with DOE funding under the auspices of the Ground Water Protection Council.

U.S. natural gas supply is expected to come increasingly from domestic gas-filled shales. New shale gas developments in existing plays, such as the Barnett and emerging plays such as the Marcellus, Haynesville, Fayetteville, and Woodford, are expected to expand significantly in the coming years. These new resources and the required technologies to exploit them are introducing new challenges as well as new opportunities for water re-use and recycling. As oil and natural gas development expands to new areas of the country, water issues are also expanding to include concerns about community water supplies and infrastructure needed to support the influx of workers.

Mature oil wells, which accounted for 16 percent of the Nation's oil production in 2007, yield large quantities of produced water. DOE-funded research in collaboration with the National Stripper Well Consortium, regional universities and others has included efforts to develop and demonstrate cost-effective, environmentally sound water management technologies and methods that can maintain well productivity and protect water quality.

Alaska is unique with respect to the environmental and water issues. The cold winter climate, environmental sensitivity of the tundra and permafrost covered areas, the reliance on ice roads and ice pads for oil and natural gas exploration activity in remote regions, the unique characteristics of Alaska's fisheries and ecosystems, and the importance of subsistence hunting and fishing to many of Alaska's citizens make it imperative that development of fossil energy resources, including oil and natural gas, whether for delivery to the Lower-48 States, or for local use, be environmentally responsible. Office of Fossil Energy oil and natural gas and Arctic research projects are managed by NETL.

Hydrogen

Water is a key feedstock for the production of hydrogen. Water is used as both a chemical feedstock and as a cooling medium for most of the proposed hydrogen production pathways (i.e., central and distributed, steam methane reforming and electrolysis). Since water is an essential input for the production of hydrogen, a preliminary analysis was conducted using the well-to-wheels methodology to determine the water use for each renewable hydrogen production pathway compared to conventional fuel pathways. The preliminary analysis of water consumption found the water consumption to be equal to or less than other conventional fuels, up to 70 percent less than conventional fuels on a gasoline equivalent basis. At current water prices, it is unlikely that water will have a major economic impact on the adoption of hydrogen as a fuel nor would the adoption of hydrogen significantly increase stress on the U.S. water supply overall, recognizing that there may be the need for permitting agencies in some areas to manage the phase-in of hydrogen with the phase-out of production of other fuels to avoid overlaps.

A more detailed analysis is required to examine impacts of hydrogen on regional water resources, the water cost on hydrogen product cost, regional permitting constraints and options to reduce water consumption in the hydrogen production pathways. The DOE Fuel Cell Technologies Program commissioned Lawrence Livermore National Laboratory to conduct this in-depth analysis and recommend technology improvements to reduce the water use. The analysis will be completed by the end of FY 2009. The results will be incorporated in the cost analysis of each of the hydrogen production pathways.

Moreover, stationary fuel cells for combined heat and power applications show promise of having no net water consumption at the application site and can actually produce clean water which can potentially be used there. These attributes of fuel cells and the technology requirements for water production will be characterized in FY 2010.

Biomass Energy

The Office of Energy Efficiency and Renewable Energy's Biomass Program has funded several National Laboratories to assess water consumption and water quality impacts of biofuels production. Argonne National Laboratory is working on an assessment of the net water consumption of two major steps of the biofuels life cycle: feedstock production and fuel production. The work addresses irrigation and process water, and has evaluated five fuel pathways, including ethanol from corn, ethanol from cellulosic feedstocks, gasoline from conventional crude oil, gasoline from Saudi Arabian crude oil, and gasoline from Canadian oil sands. The analysis to date revealed that the amount of irrigation water used to grow biofuel feedstocks varies significantly from one region to another and that water consumption for biofuel production varies with processing technology.

Argonne has also been funded to examine water quality issues related to the production and conversion of biomass feedstocks. This task addresses the impact of biomass feedstock and fuel production on water quality at a regional or watershed level. Water quality impacts addressed include nutrient from agricultural run-offs, water pollutant outputs from point sources that are generated by major industries, and discharge from fuel production plants.

Finally, Argonne is examining the opportunities and benefits of alternative production strategies to leverage the use of impaired water and marginal land at the State to regional level to supply biomass feedstock for biofuel production. To date, assessments have shown that there are sizable opportunities to grow biomass on marginal and underutilized land in the study area of Nebraska, and that this production could be doubled with no further land commitment if impaired water and the nutrients that it entrains could be efficiently recovered. Future work will expand the study area, as well as the scope to include economic data and the optimization tools to determine tradeoffs between productivity with marginal resources and farmer profits.

Oak Ridge National Laboratory (ORNL) has begun an analysis of current and future water quality issues in several major hydrologic regions of the U.S., identifying those sites with water bodies listed by the U.S. Environmental Protection Agency as having water quality problems related to agricultural practices. They are examining if such water quality problems can be improved by replacing crops requiring intensive management with more sustainable crops that could be used for bioenergy production. A series of economic and environmental models will be linked to forecast water quality implications of landscape changes associated with the production of new more environmentally sustainable bioenergy crops such as switchgrass at a national scale. These studies will analyze both economic and environmental impacts including nutrient and sediment loading and changes in biotic habitat.

In addition, ORNL is pursuing opportunities to gather field data to quantify effects of large-scale bioenergy plantings in several locations. Field studies are being designed to consider how bioenergy feedstock production can affect water quality as well as how bioenergy crop production can affect habitat for a variety of organisms.

ENERGY EFFICIENCY IMPROVEMENTS

Energy efficiency improvements in buildings, industry, and transportation avoid the consumption of water in producing power and fuels. Thus, all of these programs have an impact on water and offer a very significant opportunity for reducing water consumption in the production of electricity and fuels. Most of the R&D activities in these programs, however, are not directly targeted towards water usage. The Buildings Technology Program (BTP), however, will be conducting a thorough review of the R&D opportunities for increased energy efficiency in appliances, including appliances that use water.

For Buildings, in particular, the *Energy Policy and Conservation Act* (EPCA) states that procedures for testing and measuring water use of faucets and showerheads, and water closets and urinals, shall be American Society of Mechanical Engineers (ASME)/American National Standards Institute (ANSI) Standards, but that if ASME/ANSI revises these requirements, the Secretary shall adopt such revisions unless the Secretary determines that the revised test procedures are not satisfactory for determining water use or they are unduly burdensome to conduct. It further provides that if the requirements of the ASME/ANSI Standard are amended to improve the efficiency of water use, the Secretary shall publish a final rule establishing an amended uniform national standard unless adoption of such a standard is not (i) technologically feasible and economically justified, (ii) consistent with the maintenance of public health and safety; or (iii) consistent with the purposes of this Act.

BTP currently conducts activities in both the deployment and rule-making (appliance standards) areas that directly impact water usage. These are listed below.

Energy Star

ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy, helping us all save money and protect the environment through energy efficient products and practices. The ENERGY STAR label appears on products that have met strict requirements for energy, and in some cases direct water savings. DOE is responsible for the labeling programs for commercial and residential ENERGY STAR clothes washers and residential dishwashers.

Residential Clothes Washers

The average American family washes almost 400 loads of laundry each year. Families can cut their related energy costs by more than a third and water costs by more than half by purchasing an ENERGY STAR clothes washer. Effective July 1, 2009, DOE raised the minimum Modified Energy Factor (MEF) to 1.8 and lowered the maximum water factor to 7.5. In comparison, before January 1, 2007, the minimum MEF was 1.42 and there was no Water Factor requirement. MEF is an equation that takes into account the amount of dryer energy used to remove the remaining moisture content in washed items. Water Factor is the water use of the washer measured in gallons per cycle per cubic foot of clothes washer tub volume. This change in criteria level applies to both residential and residential-style commercial clothes washers. The change in criteria level is the fourth since 2001. The effective date gives manufacturers 17 months to prepare for the criteria change. The annual program savings for ENERGY STAR qualified clothes washers are projected at 538 million kWh/year and 7.9 billion gallons of water. DOE will further raise the min-

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imum MEF to 2.0 and lower the maximum water factor to 6.0 effective January 1, 2011. To qualify for ENERGY STAR, a clothes washer must have a minimum of 1.72 and also a maximum Water Factor of 8.0.

Residential Dishwashers

ENERGY STAR qualified dishwashers use at least 41 percent less energy than the federal minimum standard for energy consumption and much less water than conventional models. Because they use less hot water compared to new conventional models, an ENERGY STAR qualified dishwasher saves about $90 over its lifetime. Effective August 11, 2009, the requirements will be a maximum energy use of 324 kWh/year and 5.8 gallons per cycle for standard models and a maximum energy use of 234 kWh/year and 4.0 gallons per cycle for compact models. The inclusion of water consumption is a new addition to the ENERGY STAR dishwasher criteria. The criteria will be changed again on July 1, 2011 with standard ENERGY STAR dishwashers using 307 kWh/year and 5.0 gallons of water per cycle and compact models using 222 kWh/year and 3.5 gallons per cycle. Currently, standard ENERGY STAR models must have an energy factor of 0.65 or more (equivalent to roughly 339 kWh/year) and compacts must have an energy factor of 0.88 or greater (equivalent to roughly 252 kWh/year). These performance measures are not strictly comparable to the new levels as the efficiency metrics have changed and now also include, for example, stand-by losses.

Appliance Standards

The Appliance Standards program develops test procedures and minimum efficiency standards for residential appliances and commercial equipment. Each standard must "be designed to achieve the maximum improvement in energy efficiency, or, in the case of showerheads, faucets, water closets, or urinals, water efficiency, which the Secretary determines is technologically feasible and economically justified." The direct link between energy and water means that all energy conservation standards result in water conservation, and vice versa. In addition, certain covered products are specifically regulated for their water consumption. These products are discussed below.

Residential Clothes Washers

The *Energy Independence and Security Act of 2007* (EISA 2007) also prescribed water conservation standards for residential clothes washers. Previously, federal standards regulated only the energy use of residential clothes washers. Effective January 1, 2011, top-loading and front-loading standard-size residential clothes washers must have a water factor of not more than 9.5. DOE is currently undertaking a rule-making to amend the standards for residential clothes washers manufactured after January 1, 2015. The final rule is scheduled for completion no later than December 31, 2011.

Commercial Clothes Washers

New federal water and energy conservation standards for commercial clothes washers went into effect on January 1, 2007. DOE is currently conducting a rule-making to consider revising these standards. The final rule is scheduled for completion by January 1, 2010 and will apply to products manufactured three years after the date of publication of the final rule.

Residential Dishwashers

Section 311(a) of EISA 2007 amended section 325(g) of EPCA to adopt energy conservation standards and water conservation standards for residential dishwashers manufactured on or after January 1, 2010. Standard size dishwashers may not exceed 6.5 gallons per cycle and compact size dishwashers may not exceed 4.5 gallons per cycle. Again, the water efficiency requirements are a new addition. DOE is scheduled to complete a rule-making amending the standards for dishwashers that would take effect in 2015.

DOE Facility Efficiency Options

Executive Order 13423 (2007) called for a reduction in water consumption of each agency's water consumption through life cycle cost effective measures by two percent annually through the end of FY 2015. The DOE Federal Energy Management Program provides information on water conservation in federal facilities at *http://www1.eere.energy.gov/femp/water/*. All National Laboratories are supporting DOE's

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efforts in this area by tracking water consumption and actively implementing water conservation measures as well as energy conservation measures.

Conclusion

Again, Chairman Baird and Members of the Subcommittee, I want to thank you for this opportunity to provide testimony on this important topic of energy and water linkage, and to discuss with you the Department's activities and plans for developing water-efficient, environmentally-sustainable energy technologies. I would be pleased to take your questions now.

BIOGRAPHY FOR KRISTINA M. JOHNSON

Kristina M. Johnson is currently the Under Secretary of Energy in the U.S. Department of Energy. She received her B.S., M.S. (with distinction) and Ph.D. in electrical engineering from Stanford University. After a NATO post-doctoral fellowship at Trinity College, Dublin, Ireland, she joined the University of Colorado–Boulder's faculty in 1985 as an Assistant Professor and was promoted to full Professor in 1994. From 1994 to 1999, Dr. Johnson directed the NSF/ERC for Optoelectronics Computing Systems Center at the University of Colorado and Colorado State University, and then served as Dean of the Pratt School of Engineering at Duke University from 1999 to 2007. From September of 2007 to April 2009, Dr. Johnson served as Provost and Senior Vice President for Academic Affairs at The Johns Hopkins University.

Dr. Johnson was named an NSF Presidential Young Investigator in 1985 and awarded a Fulbright fellowship in 1991. Her awards include the Dennis Gabor Prize for creativity and innovation in modern optics (1993); State of Colorado and North Carolina Technology Transfer Awards (1997, 2001); induction into the Women in Technology International Hall of Fame (2003); the Society of Women Engineers Lifetime Achievement Award (2004); and, most recently, the John Fritz Medal, widely considered the highest award in the engineering profession (May 2008). Previous recipients of the Fritz Medal include Alexander Graham Bell, Thomas Edison and Orville Wright.

A fellow of the Optical Society of America, IEEE, SPIE and a Fulbright Scholar, Dr. Johnson has 142 refereed papers and proceedings and holds 45 U.S. patents (129 U.S. and international patents) and patents pending. These inventions include pioneering work on liquid crystal on silicon (LCOS) micro-displays and their integration into demonstration and commercial systems such as heads-up automotive displays (HUD); pattern recognition systems for cancer pre-screening, object tracking and document processing; HDTV and 3D projection displays; displays brought to the eye and 3D holographic memories. Other inventions include tunable optical filters, spectrometers and color filters, microscope auto-focus systems, rechargeable pacemakers and new methods for efficiently licensing intellectual property.

Chairman BAIRD. Thank you, Dr. Johnson. Your grandfather would be proud——

Dr. JOHNSON. Thank you.

Chairman BAIRD.—as are we grateful for your presence.

Ms. Mittal.

STATEMENT OF MS. ANU K. MITTAL, DIRECTOR, NATURAL RESOURCES AND ENVIRONMENT, U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Ms. MITTAL. Mr. Chairman and Members of the Subcommittee, I am pleased to be here today to participate in your hearing on R&D needs for the energy-water nexus.

At the request of this committee, GAO currently has work under way related to three aspects of the energy-water nexus. These include reviews of the water used to produce biofuels, water used to produce electricity, and water used to extract oil from shale. We expect to release reports on each of these studies later this year or early next year.

For each study, you asked us to pay particular attention to the technologies that could help reduce the amount of water needed to produce energy from these sources. My testimony today will discuss key themes that we have identified to date from our biofuels and electricity work because these reviews are the furthest along. Our work on oil shale is in its very preliminary stages, and we will have more information to share with the Committee later this year.

Our ongoing work on biofuels and electricity provide two excellent case studies that highlight the types of R&D and data collection activities that the Federal Government can focus on to help address energy-water nexus issues. Our biofuels work specifically has identified a variety of data and technology areas where more research is needed, and our electricity work has identified key areas of data collection that DOE can improve.

I will briefly describe our preliminary observations in each of these areas.

With regards to biofuels, our work has identified a number of research needs at all stages of the biofuels life cycle, from cultivation to conversion to distribution and storage. In the area of cultivation, some examples of the research needs that we have identified include the following: The need for information on impacts of feedstock production on aquifer water supplies, the need to develop additional drought-tolerant crop varieties, the need for research on how the production of cellulosics and algae can be scaled up in a sustainable way and the need for research to determine the maximum amount of agricultural residues that can be removed while maintaining soil and water quality.

In the area of conversion of feedstocks into biofuels, we have found that while much is known about the water needed to convert corn into ethanol, more research is needed on how to reduce the water needs of biorefineries that use cellulosics, and there is need for research on technologies that can effectively extract oil from algae.

In the area of storage and distribution of biofuels, we have identified still other research needs. Because ethanol is highly corrosive and poses a risk of damage to pipelines and storage tanks, it could therefore lead to groundwater contamination. To overcome potential compatibility issues, experts have told us that further research is needed on conversion technologies that can produce renewable fuels that are compatible with the existing infrastructure.

Shifting to our work on electricity, we have found that the use of advanced cooling technologies such as air cooling or hybrid cooling can reduce the amount of fresh water needed by thermoelectric power plants, but DOE's current data collection efforts may not fully capture the extent to which the industry is moving in this direction. Moreover, higher costs associated with using these technologies may cause power plant developers to reject these options, and research that can help reduce the cost of these technologies can help make their use more widespread. Similarly, the use of alternative water sources, such as effluent from sewage treatment plants, brackish water or sea water can also reduce fresh water use by power plants. But DOE's data collection efforts also are not systematically capturing this trend in the industry.

Water experts and federal agencies we spoke to told us that not having data on the extent to which advanced cooling technologies or alternative water sources are being used by the industry limits the ability of industry analysts to assess the extent to which these technologies have reduced fresh water use. Lack of such information also impacts the ability of federal decision-makers to target research efforts most appropriately. According to DOE officials, the agency is currently redesigning the process it uses to collect data on advanced cooling technologies and will implement this new process in 2011.

In conclusion, Mr. Chairman, both of our ongoing reviews have identified a number of R&D efforts that are being supported by DOE and other federal agencies. However, our work has also identified a number of R&D areas that still need to receive attention in the future. Investments in these areas will help resolve many of the uncertainties that currently exist relating to the energy-water nexus.

That concludes my prepared statement. I would be happy to respond to questions.

[The prepared statement of Ms. Mittal follows:]

PREPARED STATEMENT OF ANU K. MITTAL

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to participate in your hearing on technology research and development for the energy-water linkage often referred to as the energy-water nexus. As you know, water and energy are inexorably linked, mutually dependent, and each affects the other's availability. Energy is needed to pump, treat, and transport water, and large quantities of water are needed to support the development of energy. Production of biofuels that may help reduce our dependency on oil, and the cooling of power plants that today provide the electricity we use, represent two examples where water supply is tied directly to our ability to provide energy.

However, both water and energy are facing serious supply constraints. Freshwater is increasingly in demand to meet the needs of municipalities, farmers, industries, and the environment. Likewise, rising demand for energy—fueled by both population growth and expanding uses of energy—may soon outstrip our ability to supply it with existing resources. Looking just at electricity, according to the Energy Information Administration's (EIA) most recent Annual Energy Outlook, 259 gigawatts of new generating capacity—the equivalent of 259 large coal-fired power plants—will be needed between 2007 and 2030. As the country's energy needs grow along with its population, additional pressure will likely be put on our water resources.

Given the importance of water and energy, both the Federal Government and State governments play key roles in monitoring, regulating, collecting information, and supporting research on energy and water issues. In general, State governments play a central role in overseeing water availability and use by evaluating water supplies and permitting water uses. However, while much of the authority governing water supply and distribution lies with State and local governments, the Federal Government also has a role in helping the country meet its energy needs without damaging or depleting our supplies of freshwater. For example, federal agencies, including the Department of Energy (DOE), have provided data and analysis about water use for energy production, as well as funded related research and development. These activities are important to further our understanding of how to more efficiently use such critical resources.

At the request of this committee, GAO currently has work under way related to three aspects of the energy-water nexus—water use in the production of biofuels, water use at thermoelectric power plants, and water use in the extraction of oil from shale. We expect to release reports on biofuels and thermoelectric power plants later this year. For each study, the Committee asked us to identify technologies that could help reduce the amount of water needed to produce energy from these sources. My testimony today discusses key themes we have identified during our work to date on the two ongoing energy-water nexus jobs that are furthest along, specifically (1) biofuels and water use and (2) thermoelectric power plants and water use. Our work on oil shale is in its very preliminary stages and we will have further information to share with the Committee on this aspect of the energy-water nexus later this year.

To identify the effects of biofuel cultivation, conversion, and storage on water supply and water quality, we are conducting a review of relevant scientific articles and key Federal and State government reports. In addition, in consultation with the National Academy of Sciences, we identified and spoke with a number of experts who have published research analyzing the water supply requirements of one or more biofuel feedstocks and the implications of increased biofuel cultivation and conversion on water quality. Furthermore, we are interviewing officials from DOE, the Environmental Protection Agency (EPA), and the Department of Agriculture (USDA) about impacts on water supply and water quality during the cultivation of biofuel feedstocks and the conversion and storage of the finished biofuels. To identity the relationship of thermoelectric plants and water, we are reviewing selected reports, interviewing federal officials and experts, and examining relevant energy and water data. In particular, we are examining reports on alternative cooling technologies and water supplies and the impact they can have on water use at power plants. We are also interviewing officials from DOE, EPA, and the Department of Interior's U.S. Geological Survey, as well as State water regulators and water and energy experts at national energy laboratories and universities. In addition, we are interviewing representatives from electric power producers, sellers of electric power plant equipment, cooling technology companies, and engineering firms that design new power plants. Finally, we are examining power plant data on water source, use, consumption, and cooling technology types collected by EIA and data collected and reported by the U.S. Geological Survey. Our work is being conducted in accordance with generally accepted government accounting standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Biofuels are an alternative to petroleum-based transportation fuels and derived from renewable resources. Currently, most biofuels are derived from corn and soybeans. Ethanol is the most commonly produced biofuel in the United States, and about 98 percent of it is made from corn that is grown primarily in the Midwest. Corn is converted to ethanol at biorefineries through a fermentation process and requires water inputs and outputs at various stages of the production process—from growth of the feedstock to conversion into ethanol. While ethanol is primarily produced from corn grains, next generation biofuels, such as cellulosic ethanol and algae-based fuels, are being promoted for various reasons including their potential to boost the Nation's energy independence and lessen environmental impacts, including on water. Cellulosic feedstocks include annual or perennial energy crops such as switchgrass, forage sorghum, and miscanthus; agricultural residues such as corn stover (the cobs, stalks, leaves, and husks of corn plants); and forest residues such as forest thinnings or chips from lumber mills. Some small biorefineries have begun to process cellulosic feedstocks on a pilot-scale basis; however, no commercial-scale facilities are currently operating in the United States.[1] In light of the federal renewable fuel standard's requirements for cellulosic ethanol starting in 2010,[2] DOE is providing $272 million to support the cost of constructing four small biorefineries that will process cellulosic feedstocks. In addition, in recent years, researchers have begun to explore the use of algae as a biofuel feedstock. Algae produce oil that can be extracted and refined into biodiesel and has a potential yield per acre that is estimated to be 10 to 20 times higher than the next closest quality feedstock. Algae can be cultivated in open ponds or in closed systems using large raceways of plastic bags containing water and algae.

Thermoelectric power plants use a fuel source—for example, coal, natural gas, nuclear material such as uranium, or the sun—to boil water to produce steam. The steam turns a turbine connected to a generator that produces electricity. Traditionally, water has been withdrawn from a river or other water source to cool the steam back into liquid so it may be reused to produce additional electricity. Most of the water used by a traditional thermoelectric power plant is for this cooling process, but water may also be needed for other purposes in the plant such as for pollution

[1] For example, Range Fuels has operated a pilot biorefinery in Denver, Colo., since 2008 that has successfully converted pine and hardwoods into cellulosic ethanol. The company plans to optimize the technologies from this pilot plant at its cellulosic biorefinery, expected to begin commercial-scale production in 2010. This biorefinery, located in Soperton, Ga., is targeted to produce approximately 100 million gallons of ethanol and mixed alcohols from wood byproducts when it is at full scale.

[2] The *Energy Independence and Security Act of 2007,* Pub. L. No. 110–140 (2007).

control equipment. In 2000, thermoelectric power plants accounted for 39 percent of total U.S. freshwater withdrawals.[3] EIA annually reports data on the water withdrawals, consumption and discharges of power plants of a certain size, as well as some information on water source and cooling technology type. These data are used by federal agencies and other researchers in estimating the overall power plant water use and determining how this use has and will continue to change.

Information Is Limited on the Water Supply and Water Quality Impacts of the Next Generation of Biofuels

Our work to date indicates that while the water supply and water quality effects of producing corn-based ethanol are fairly well understood, less is known about the effects of the next generation of feedstocks and fuels. The cultivation of corn for ethanol production can require substantial quantities of water—from seven to 321 gallons per gallon of ethanol produced—depending on where it is grown and how much irrigation water is used.[4] Furthermore, corn is a relatively resource-intensive crop, requiring higher rates of fertilizer and pesticide applications than many other crops; some experts believe that additional corn production for biofuels conversion will lead to an increase in fertilizer and sediment runoff and in the number of impaired streams and other water bodies. Some researchers and conservation officials have told us that the impact of corn-based ethanol on water supply and water quality could be mitigated through research into developing additional drought-tolerant and more nutrient-efficient crop varieties thereby decreasing the amount of water needed for irrigation and the amount of fertilizer that needs to be applied. Furthermore, experts also mentioned the need for additional data on current aquifer water supplies and research on the potential of biofuel cultivation to strain these water sources.

In contrast to corn-based ethanol, our work to date indicates that much less is known about the effects that large-scale cultivation of cellulosic feedstocks will have on water supplies and water quality. Since potential cellulosic feedstocks have not been grown commercially to date, there is little information on the cumulative water, nutrient, and pesticide needs of these crops, and it is not yet known what agricultural practices will actually be used to cultivate these feedstocks on a commercial scale. For example, while some experts assume that perennial feedstocks will be rainfed, other experts have pointed out that to achieve maximum yields for cellulosic crops, farmers may need to irrigate these crops. Furthermore, because water supplies vary regionally, additional research is needed to better understand geographical influences on feedstock production. For example, the additional withdrawals in states relying heavily on irrigation for agriculture, such as Nebraska, may place new demands on the Ogallala Aquifer, an already strained resource from which eight states draw water. In addition, if agricultural residues—such as corn stover—are to be used, this could negatively affect soil quality, increase the need for fertilizer, and lead to increased sediment runoff to waterways. Considerable uncertainty exists regarding the maximum amount of residue that can be removed for biofuels production while maintaining soil and water quality. USDA, DOE, and some academic researchers are attempting to develop new projections on how much residue can be removed without compromising soil quality, but sufficient data are not yet available to inform their efforts, and it may take several years to accumulate such data and disseminate it to farmers for implementation. Experts we spoke with generally agree that more research on how to produce cellulosic feedstocks in a sustainable way is needed.

Our work also indicates that even less is known about newer biofuels feedstocks such as algae. Algae have the added advantage of being able to use lower-quality water for cultivation, according to experts. However, the impact on water supply and water quality will ultimately depend on which cultivation methods are determined to be the most viable. Therefore, research is needed on how best to cultivate this feedstock in order to maximize its potential as a biofuel feedstock and limit its potential impacts on water resources. Other areas we have identified that relate to water and algae cultivation in need of additional research include:

- *Oil extraction.* Additional research is needed on how to extract the oil from the algal cell in such a way as to preserve the water contained in the cell along with the oil, thereby allowing some of that water to be recycled back into the cultivation process.

[3] Water consumed by thermoelectric power plants accounts for a smaller percentage.
[4] Wu, M., M. Mintz, M. Wang, and S. Arora. *Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline.* Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, January 2009.

- *Contaminants.* Information is needed on how to manage the contaminants that are found in the algal cultivation water and how any resulting wastewater should be handled.

Uncertainty also exists regarding the water supply impacts of converting feedstocks into biofuels. Biorefineries require water for processing the fuel and need to draw from existing water resources. Water consumed in the corn-ethanol conversion process has declined over time with improved equipment and energy efficient design, according to a 2009 Argonne National Laboratory study, and is currently estimated at three gallons of water required for each gallon of ethanol produced. However, the primary source of freshwater for most existing corn ethanol plants is from local groundwater aquifers and some of these aquifers are not readily replenished. For the conversion of cellulosic feedstocks, the amount of water consumed is less defined and will depend on the process and on technological advancements that improve the efficiency with which water is used. Current estimates range from 1.9 to 5.9 gallons of water, depending on the technology used. Some experts we spoke with said that greater research is needed on how to manage the full water needs of biorefineries and reduce these needs further. Similar to current and next generation feedstock cultivation, additional research is also needed to better understand the impact of biorefinery withdrawals on aquifers and to consider potential resource strains when siting these facilities.

Our work to date also indicates that additional research is needed on the storage and distribution of biofuels. Ethanol is highly corrosive and poses a risk of damage to pipelines, and underground and above-ground storage tanks, which could in turn lead to releases to the environment that may contaminate groundwater, among other issues. These leaks can be the result of biofuel blends being stored in incompatible tank systems—those that have not been certified to handle fuel blends containing more than 10 percent ethanol. While EPA currently has some research under way, additional study is needed into the compatibility of higher fuel blends, such as those containing 15 percent ethanol, with the existing fueling infrastructure. To overcome potential compatibility issues, future research is needed on other conversion technologies that can be used to produce renewable and advanced fuels that are capable of being used in the existing infrastructure.

Key Efforts to Reduce Use of Freshwater at Power Plants May Not Be Fully Captured in Existing Federal Data

In our work to date, we have found (1) the use of advanced cooling technologies can reduce freshwater use at thermoelectric power plants, but federal data may not fully capture this industry change; (2) the use of alternative water sources can also reduce freshwater use, but federal data may not systematically capture this change; and (3) federal research under way is focused on examining efforts to reduce the use of freshwater in thermoelectric power plants.

Advanced cooling technologies offer the promise to reduce freshwater use by thermoelectric power plants. Unlike traditional cooling technologies that use water to cool the steam in power plants, advanced cooling technologies carry out all or part of the cooling process using air. According to power plant developers, they consider using these water-conserving technologies in new plants, particularly in areas with limited available water supplies. While these technologies can significantly reduce the amount of water used in a plant—and in some cases eliminate the use of water for cooling—their use entails a number of challenges. For example, plants using advanced cooling technologies may cost more to build and operate; require more land; and, because these technologies can consume a significant amount of energy themselves, witness lower net electricity output—especially in hot, dry conditions. However, eliminating or minimizing freshwater use by incorporating an advanced cooling technology provides a number of potential benefits to plant developers, including minimizing the costs associated with acquiring, transporting, and treating water, as well as eliminating impacts on the environment associated with water withdrawals, consumption, and discharge. In addition, the use of these advanced cooling technologies may provide the flexibility to build power plants in locations not near a source of water.

For these reasons, a number of power plant developers in the United States and across the world have adopted advanced cooling technologies, but according to EIA officials, the agency's forms have not been designed to collect information on the use of advanced cooling technologies. Moreover, the instruments the agency uses to collect these data were developed many years ago and have not been recently updated. EIA officials have told us that while some plants may choose to report this information, they may not do so consistently or in such a way that allows comprehensive identification of the universe of plants using advanced cooling technologies. Water experts and federal agencies we spoke to during the course of our work identified value in the annual EIA data on cooling technologies, but some explained that not having data on advanced cooling technologies limits public understanding of their prevalence and analysis of the extent to which their adoption results in a significant reduction in freshwater use. According to EIA officials, the agency is currently redesigning the instrument it uses to collect these data and expects to begin using the revised instrument in 2011. In addition, during the course of our work we noted that in 2002, EIA discontinued reporting water-related data for nuclear power plants, including water use and cooling technology. As we develop our final report, we will be looking at various suggestions that we can make to DOE to improve its data collection efforts.

Our work to date also indicates that the use of alternative water sources can substantially reduce or eliminate the need to use freshwater for power plant cooling at an individual plant. Alternative water sources that may be usable for power plant cooling include treated effluent from sewage treatment plants; groundwater that is unsuitable for drinking or irrigation because it is high in salts or other impurities; industrial water, such as water generated when extracting minerals like oil, gas, and coal; and others. Use of these alternative water sources can ease the development process where freshwater sources are in short supply and lower the costs associated with obtaining and using freshwater when freshwater is expensive. Because of these advantages, alternative water sources play an increasingly important role in reducing power plant reliance on freshwater, but can pose challenges, including requiring special treatment to avoid adverse effects on cooling equipment, requiring additional efforts to comply with relevant regulations, and limiting the potential locations of power plants to those nearby an alternative water source. These challenges are similar to those faced by power plants that use freshwater, but they may be exacerbated by the lower quality of alternative water sources.

Power plant developers we spoke with told us they routinely consider use of alternative water sources when developing their power plant proposals. Moreover, a 2007 report by Argonne National Laboratory indicates that the use of treated municipal wastewater at power plants has become more common, with 38 percent of power plants after 2000 using reclaimed water. EIA collects annual data from power plants on their water use and water source. However, according to EIA officials, while some plants report using an alternative water source, many may not be reporting such information since EIA's data collection form was not designed to collect data on these freshwater alternatives. One expert we spoke with told us that not having data on the use of alternative water sources at power plants limits public understanding of these trends and the extent to which these approaches are effective in reducing freshwater use. As we develop our final report, we plan to also develop suggestions for DOE that can improve this data gathering process.

Power plant developers may choose to reduce their use of freshwater for a number of reasons, such as when freshwater is unavailable or costly to obtain, to comply with regulatory requirements, or to address public concern. However, a developer's decision to deploy an advanced cooling technology or an alternative water source depends on an evaluation of the tradeoffs between the water savings and other benefits these alternatives offer and the cost involved. For example, where water is unavailable or prohibitively expensive, power plant developers may determine that despite the challenges, advanced cooling technologies or alternative water sources offer the best option for getting a potentially profitable plant built in a specific area.

While private developers make key decisions on what types of power plants to build and where to build them, and how to cool them based on their views of the costs and benefits of various alternatives, government research and development can be a tool to further the use of alternative cooling technologies and alternative water supplies. In this regard, the Department of Energy's National Energy Technology Laboratory (NETL) plays a central role in DOE's research and development effort. In recent years, NETL has funded research and development projects through its Innovations for Existing Plants program aimed at minimizing the challenges of deploying advanced cooling technologies and using alternative water sources at existing plants, among other things. In 2009, the lab spent about $9 million to support research and development of projects that, among other things, could improve the performance of advanced cooling technologies, recover water used to reduce emissions of air pollutants at coal plants for reuse, and facilitate the use of alternative water sources such as polluted water for cooling. Such research endeavors, if successful, could alter the trade-off analysis power plant developers conduct in favor of nontraditional alternatives to cooling.

Concluding Observations

Ensuring sufficient supplies of energy and water will be essential to meeting the demands of the 21st century. This task will be particularly difficult, given the interdependency between energy production and water supply and water quality and the strains that both these resources currently face. DOE, together with other federal agencies, has a key role to play in providing key information, helping to identify ways to improve the productivity of both energy and water, partnering with industry to develop technologies that can lower costs, and analyzing what progress has been made along the way. While we recognize that DOE currently has a number of ongoing research efforts to develop information and technologies that will address various aspects of the energy-water nexus, our work indicates that there are a number of areas to focus future research and development efforts. Investments in these areas will provide information to help ensure that we are balancing energy independence and security with effective management of our freshwater resources.

Mr. Chairman that concludes my prepared statement, I would be happy to respond to any questions that you or other Members of the Subcommittee might have.

GAO Staff Acknowledgments

Key staff contributors to this testimony were Jon Ludwigson, Assistant Director; Elizabeth Erdmann, Assistant Director; Scott Clayton; Paige Gilbreath; Miriam Hill; Randy Jones; Micah McMillan; Nicole Rishel; Swati Thomas; Lisa Vojta; and Rebecca Wilson.

BIOGRAPHY FOR ANU K. MITTAL

Ms. Anu K. Mittal, is a Director with the Natural Resources and Environment team of the U.S. Government Accountability Office (GAO), in Washington, D.C. She is responsible for leading GAO's work in the areas of Water Resources and Defense Environmental Cleanup.

Ms. Mittal has been with GAO since 1989, during which time she has led a variety of reviews of federal programs relating to water resources, oceans and fisheries, environmental restoration programs, energy, housing, food safety, science and technology, and agriculture issues. She has also served in other organizational capacities and worked on special projects for the Comptroller General.

Ms. Mittal received a Masters in Business Administration from the University of Massachusetts, and has completed the senior executive fellow program at the John F. Kennedy School of Government at Harvard University. She has received numerous GAO honors for sustained leadership and exceptional contributions to the agency's mission.

Chairman BAIRD. Thank you, Ms. Mittal. Dr. Hannegan.

STATEMENT OF DR. BRYAN J. HANNEGAN, VICE PRESIDENT, ENVIRONMENT AND GENERATION, THE ELECTRIC POWER RESEARCH INSTITUTE

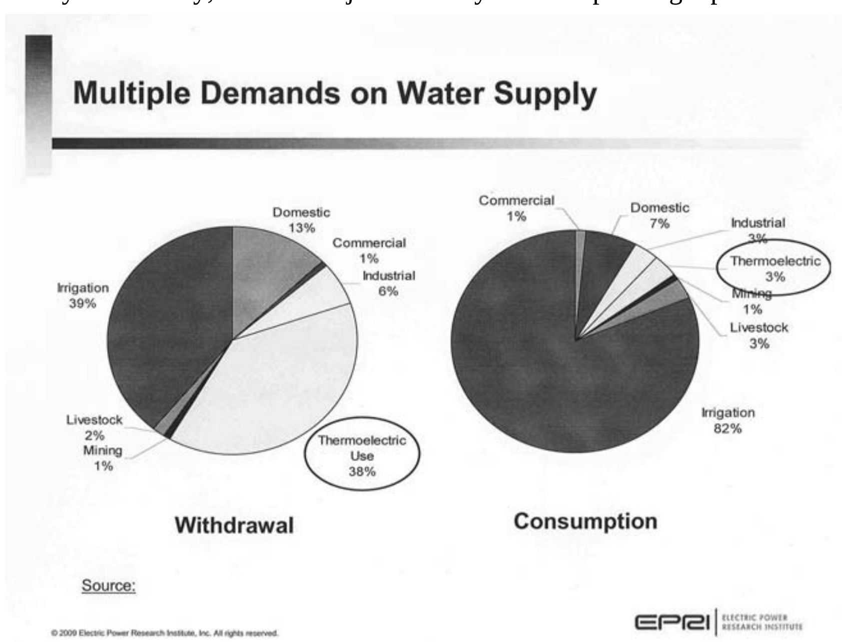
Dr. HANNEGAN. Thank you, Mr. Chairman, Ranking Member Inglis, and Members of the Subcommittee. It is a great pleasure to be with you here today to join this distinguished panel in discussing the research needs for the energy-water nexus.

I want to focus first on a couple points about EPRI, the Electric Power Research Institute founded in 1973 as an independent, non-profit center for collaborative research regarding energy and environment issues in the public interest. A key element of EPRI's mission is informing the public policy process, and we are very thrilled to be here today to have this opportunity.

One of the key points I would like to make in my testimony this morning is that water is a finite resource with multiple uses, and when you look at the totality of both water demand and water supply going forward, it is increasingly obvious in the electric sector not only are we looking at a carbon-constrained world, we are also looking at a water-constrained world. When you think about the competing uses from population growth, from agriculture, from climate variability and change affecting both the timing and the magnitude of water availability, think about the demand for water increasing over time as a result of economic growth and increasing electrification, the shift to low-carbon technologies, some of which are more water intensive as the Under Secretary alluded to in her comments, particularly around CO_2 capture and storage, work that we have been doing identifies the CCS technologies at present will roughly double the water demand in a conventional coal or natural gas-fired unit. So there are tremendous opportunities there to improve water availability for CCS.

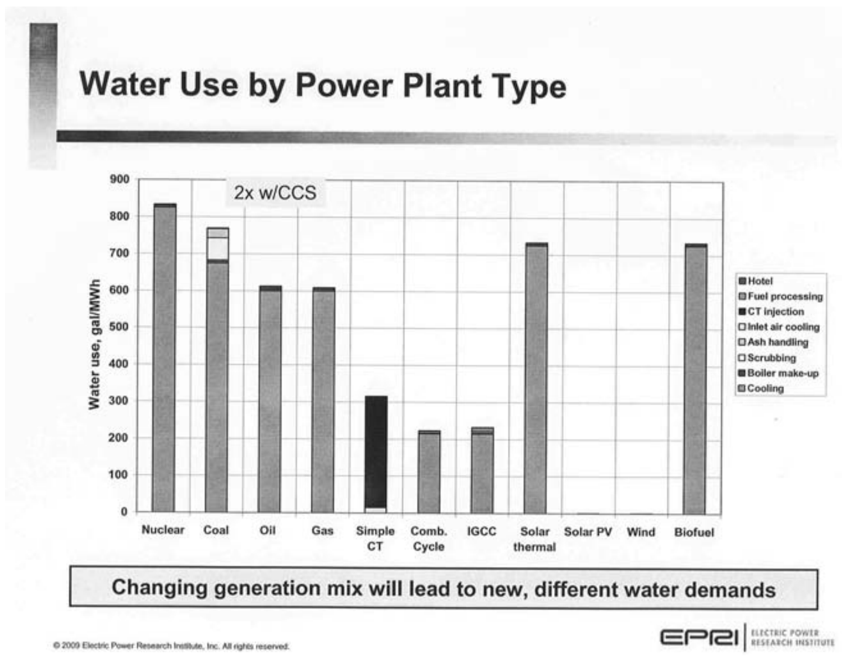
As my colleague, Ms. Mittal from GAO, just mentioned a moment ago, advanced cooling technologies do exist. They offer a lot of promise, but at present their costs, their performance are not where we would want them to be for widespread commercial application. And so as you look to future research needs in this area, not only the whole notion of water resource management and understanding the supply of water but also moderating and mitigating the demand of water from the electric power sector through advanced cooling technologies is going to be a key effort going forward.

To expound upon these key points which are described in detail in my testimony, I want to just show you a couple of graphics.



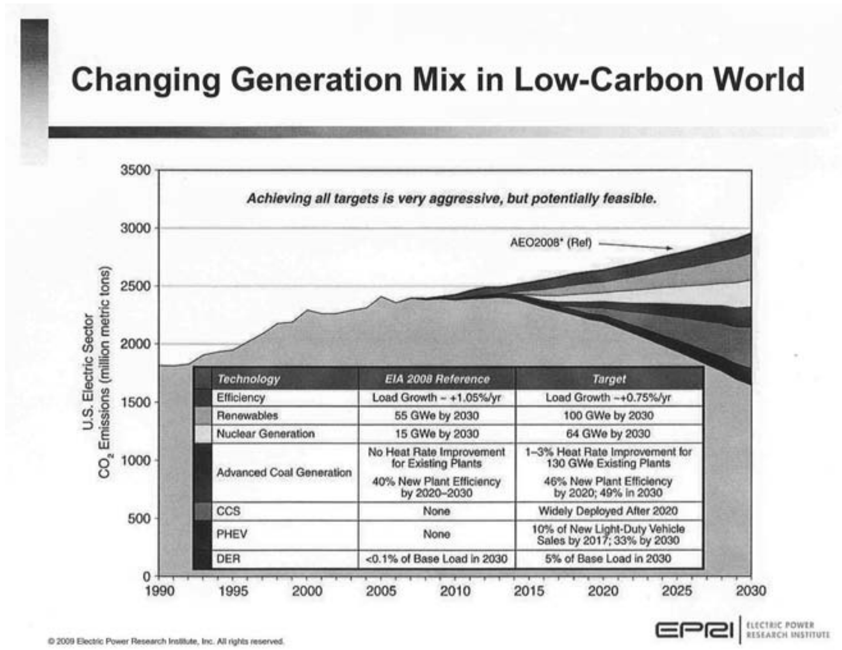
This is from an outdated USGS assessment of water use. On the left-hand side, you see water withdrawals, thermoelectric power and particularly, cooling is a significant withdrawer of water. But one of the key elements I want to stress is that the electric power industry needs access to water but doesn't necessarily consume it. If you look at the right-hand side, as a fraction of consumption, electric power utilities only consume three percent. It is really a question for us of access. It is also a question of returning that water back to the environment in a state that it can be used. And so it is mitigating the impact of taking that water in, where fish protection and other aquatic organisms are concerned, and also bringing that water back with minimal or no effluence that cause environmental degradation as well, and I think that is a key point to make.

When you look at the water used by power plant type, nuclear, fossil, but even solar-thermal and biofuel are big consumers of water from a cooling standpoint. And even simple gas combustion turbines use a lot of water for fuel injection. And as we change this generation mix, we are going to be changing the water demands.



To drive that home, one of the ways in which we are looking at the transition to a low-carbon economy in the electric sector is to bring on, as shown here in this chart, increasing amounts of renewables, increasing amounts of nuclear energy, increasing amounts of CO_2 capture and storage for both existing and new units. This shift is going to change the way we use water in this important segment of society.

So we have existing technologies that are on the board right now, once through cooling and wet cooling towers, roughly about half and half with existing plants in the application there, a lot of advanced technologies such as dry or hybrid cooling approaches, recycling the water within the plant, using gray waters and increasing the thermal efficiency of plant are all going to be important. The challenge with dry cooling as the Under Secretary mentioned is that these things are emerging technologies.



There is a lot of work to be done here, and at present, if you look at the left-hand side of this chart, it is at a significant increased cost, both from capital as well as operations and reducing the power output, even things like noise and the size of the units that you need for a typical 500-megawatt plant are things that are of concern.

We talked about the impact here in the United States. It is also worth reflecting on the heat wave in France in 2003. It was an impact not just on the availability of water for cooling, but in fact the generation capacity and the resulting changes in the market that led to more spot market purchases of electricity, higher prices ultimately to consumers, and large-scale load shedding and other mechanisms to maintain the reliability of the system. So it is really at the heart of maintaining a reliable and low-cost electrical system.

So to sum up, we have worked with the Department of Energy, the NETL, and Sandia National Labs through the energy-water nexus program to outline about a $40 million, 10-year research program that would be focused around these five areas, both understanding the financial and operating impacts of cooling technologies. As Ms. Mittal suggested, there is a big gap there that can be addressed there in the near-term, working on the technologies, particularly dry and hybrid cooling approaches, using degraded waters. One of the issues with carbon capture and storage is the potential production of saline waters from the saline aquifers that we are injecting CO_2 into. If there was a way to treat that saline water to use that for thermoelectric plant cooling, you are solving multiple problems with one approach. And finally, getting our arms around how climate interacts with water and how water interacts with climate, both in the production of renewable energy, but just in the availability of the resource, that is improving decision support, developing better climate modeling tools that allow us to get a handle around the hydroelectric cycle. There is a lot of work that can be done here, and we are well under way working very collaboratively with the Department on pursuing next steps.

Thank you, and that concludes my testimony.

[The prepared statement of Dr. Hannegan follows:]

PREPARED STATEMENT OF BRYAN J. HANNEGAN

Thank you, Chairman Baird, Ranking Member Inglis, and Members of the Subcommittee. I am Bryan Hannegan, Vice President—Environment and Generation, at the Electric Power Research Institute (EPRI). EPRI conducts research and development on technology, operations and the environment for the global electric power industry. As an independent, non-profit Institute, EPRI brings together its members, scientists and engineers, along with experts from academia, industry and other centers of research to:

- collaborate in solving challenges in electricity generation, delivery and use;
- provide technological, policy and economic analyses to drive long-range research and development planning; and
- support multi-discipline research in emerging technologies and issues.

EPRI's members represent more than 90 percent of the electricity generated in the United States, and international participation extends to 40 countries. EPRI has major offices and laboratories in Palo Alto, California; Charlotte, North Carolina; Knoxville, Tennessee, and Lenox, Massachusetts.

EPRI appreciates the opportunity to provide testimony to the Subcommittee on the subject of *"Technology Research and Development Efforts Related to the Energy and Water Linkage."* In my testimony today, I would like to highlight the following key points:

- While thermoelectric power plant cooling accounts for approximately 40 percent of freshwater withdrawals in the U.S., it accounts for only three percent of total consumption.
- Water use for power generation has declined steadily per unit of power produced; however more significant growth in power demand has led to a total increase in water use by the electric power sector over the past five decades.
- The largest users of water are nuclear and coal-based power plants; however renewable energy resources such as concentrated solar and biomass can also use significant water resources on a life cycle basis.
- Advanced cooling technologies, such as dry cooling and use of degraded waters, can reduce water use in power plants but come at a significant increased cost using existing technologies available today.
- EPRI, working with DOE and others, has identified a $40 million, 10-year research program focused on reducing the cost of existing cooling options, and developing new technology options and decision support tools to reduce the demand for fresh water resources in the coming decades.
- These research efforts are urgently needed to mitigate the expected shortfall in water needs for thermoelectric cooling as a result of future electricity demand growth, competing demand for water resources by other economic sectors, and new water demands from low-carbon generation sources such as nuclear, biomass, and CO_2 capture and storage.

I. Fresh Water Use at Thermoelectric Power Plants

The major use of water for thermoelectric plants is condensing of steam. These plants convert heat energy (as steam) to electric energy. The source of the heat energy may be nuclear, coal, gas, oil, biofuel, solar or geothermal. The heat source boils water and the resulting steam is driven through a turbine which turns a generator. The steam exits the turbine into the condenser where it must be condensed and cooled in order to be pumped backed to the boiler and converted to steam to complete the overall cycle.

According to the most recent available survey of water withdrawals by the USGS (Figure 1), thermoelectric power plant cooling accounts for approximately 40 percent of freshwater withdrawals in the U.S. Agricultural irrigation accounts for approximately the same amount. Most of the water withdrawn by thermoelectric generation is discharged back into the receiving water body. On the other hand, thermoelectric power plants account for approximately three percent of total freshwater consumption in the U.S. (Figure 2). The USGS stopped reporting water consumption values after the 1995 survey; water use numbers were reported for 2000 but have not changed substantially. In arid regions of the U.S., power companies employ significant use of cooling towers, non-traditional water sources, water recycling within the power plant and use of evaporation ponds. In these instances the total amount of freshwater withdrawn by power plants is likely to be significantly less that in other regions.

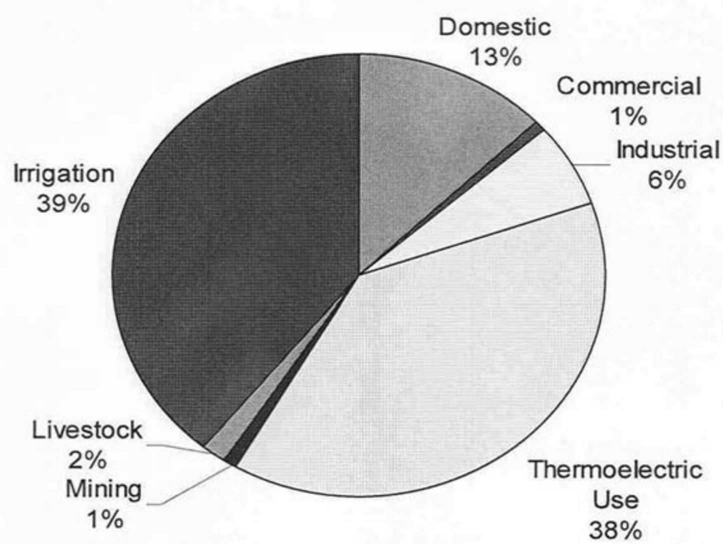


Figure 1 – 1995 Fresh Water Withdrawal by Type (USGS)

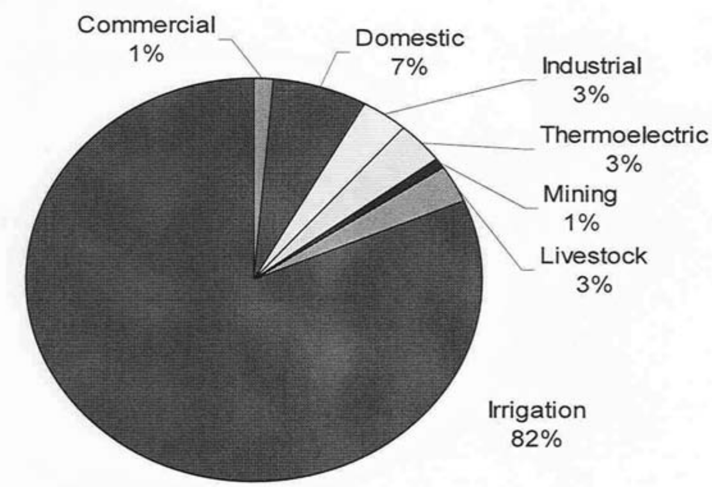


Figure 2 – 1995 Fresh Water Consumption (USGS)

The use of recirculating systems (e.g., cooling towers) and freshwater conservation measures, such as substitution of sewage treatment effluent for freshwater in the arid parts of the country, has been driven by limited water availability. In other parts of the country, the main driving factor for recirculating systems has been water intake and discharge regulations (e.g., fish protection and thermal discharge requirements).

These measures have enabled the electric power industry to reduce its water withdrawals per unit of electric power generated by a factor of three (Table 1). However, the electric industry increased its output of electric power by a factor of 15 over the same period. The net result was a five-fold increase in water withdrawals by the electric power industry since 1950, most of which occurred before 1980. Total water withdrawal by the industry has actually declined since 1980.

	1950	1960	1970	1980	1990	2000
Withdrawals (billion gal)	14,500	36,500	62,100	77,000	71,000	71,000
Power Generated (billion MWh)	0.23	0.61	1.28	2.00	2.68	3.45
Water Withdrawal Efficiency (gal/MWh)	63,000	60,000	49,000	39,000	27,000	21,000

Table 1—Water Withdrawals, Power Generated and Improvement in Water Withdrawal Efficiency, 1950-2000

Power plant water use is often measured as the amount of water withdrawal per unit of electric energy generated. The lower this number, the more efficient is the plant's use of water. Power plant water use varies with type of generation (Figure 3). The efficiencies shown in the figure are representative of the type of generation. In reality, there is considerable variability depending not only on the type of generation but also on numerous other factors. For example, with respect to coal plants with wet cooling towers, a survey conducted by EPRI showed that cooling water withdrawal ranged from 500 to 700 gallons/megawatt-hour.

Note that a coal plant uses water not only for cooling but also for flue gas scrubbing and ash handling. A combined cycle gas plant, which uses the exhaust of a gas turbine to drive a single steam cycle, is significantly more water efficient than a single steam cycle plant. A renewable energy plant may or may not have significant cooling requirements. While a wind energy or solar photovoltaic plant uses little water, a solar thermal or biofuel plant is conceptually no different than a fossil or nuclear steam plant and needs significant amounts of water for cooling. With respect to biofuel, there can also be significant water demand associated with fuel production. Although Figure 3 does not show water demands by geothermal electricity production, its water needs are conceptually no different than those of nuclear and coal plants. In fact, geothermal electricity production requires more cooling water since its thermal efficiency (ratio of electricity output to thermal energy input) is relatively low compared to other electric generation technologies.

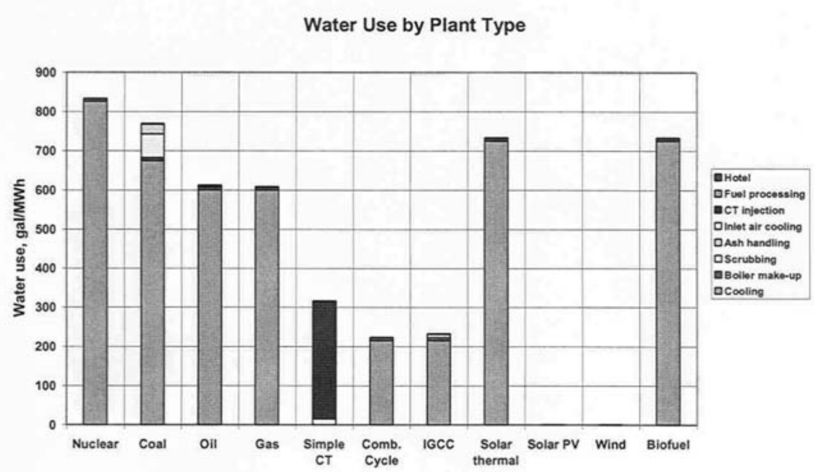


Figure 3 – Water Use by Power Plant Type

Under severe drought conditions or heat waves, the generating capacity of operating power plants is more likely to be limited by an inability to meet thermal discharge permits than by the quantity of available water. When thermal discharge limitations occur it is possible for the appropriate regulatory agency to grant the plant a waiver to continue operating. However, when there is inadequate water to operate the plant at full capacity, the only options are either to reduce power plant generation or completely shut down the plant. Over the last several years, there have been isolated incidents in the U.S. of plants having to reduce power or shut down because of limited available water. In France, in 2003, there was a major multi-week heat wave that resulted in a regional impact consisting of a 7–15 percent loss of nuclear generation capacity for five weeks, a loss of 20 percent of hydro generation capacity, large scale load shedding, purchase of large amounts of electricity on the wholesale power market, and sharp increases in electricity prices on the spot market.

II. Existing Cooling Technologies in Use Today

Historically, condensing and cooling of the steam has been provided by once-through cooling systems (Figure 5) in which cool water from a river, lake, ocean or a pond is pumped to the condenser where it condenses the steam from the turbine. After exiting the condenser, the heated cooling water is discharged back into the receiving water body.

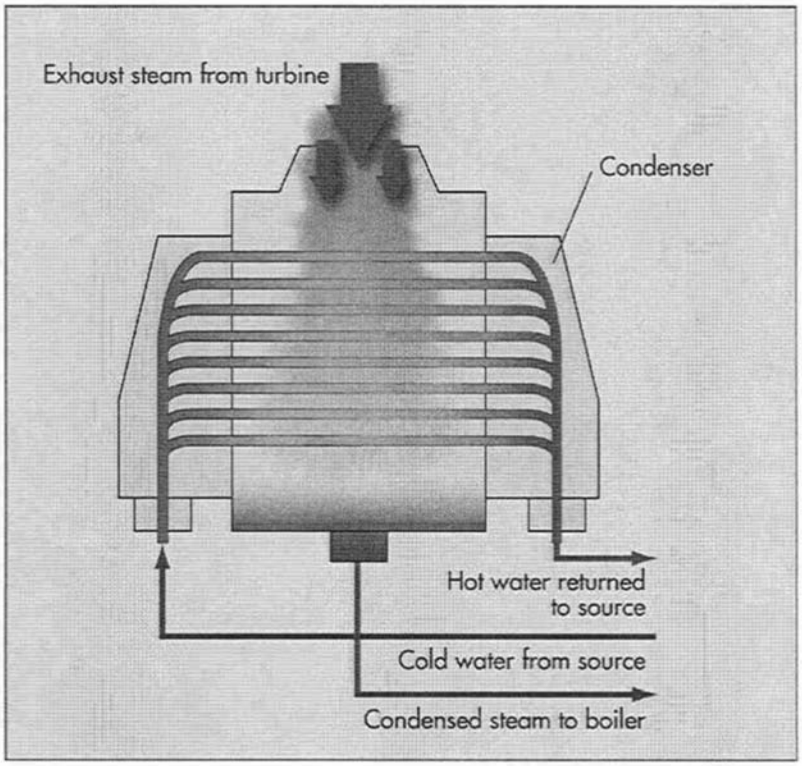


Figure 5 – Schematic of Once-Through Cooling

To minimize the impacts on fish and address thermal discharges, new electric power generation plants typically use recirculating cooling water systems (Figure 6). In a recirculating cooling water system, the cooling water is cooled either in a cooling tower or cooling pond and then recycled back to the condenser.

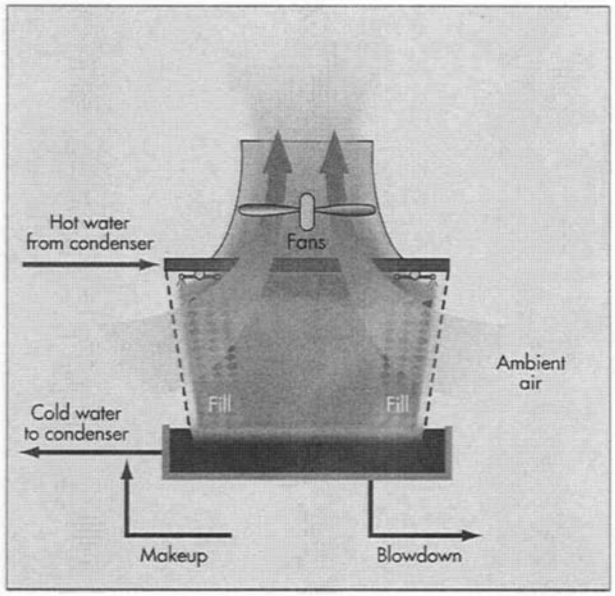


Figure 6 – Schematic of Wet Cooling Tower for Recirculating Cooling

If a recirculating cooling water system was completely closed, the salt concentration in the water would build up to a point where the condenser tubes would collect saline scale (affecting performance) and corrosion would be excessive. For this reason, it is necessary for a percentage of the recycling water be released during each cycle. This water is called blowdown. To makeup for the blowdown and cooling water that is lost to evaporation and drift of the cooling tower exhaust, the recycling system must continuously withdraw water. This water is called makeup.

Figure 7 shows a schematic of typical water use in a 500MW thermal plant with a recirculating cooling system (wet cooling tower). The cooling tower is the largest water consumer in the plant, and in this example, requires 9537 gal/min (gpm) of fresh water when running at full load. This makeup is required to replace the water lost to evaporation and drift (about two-thirds of the total) and blowdown (about one-third).

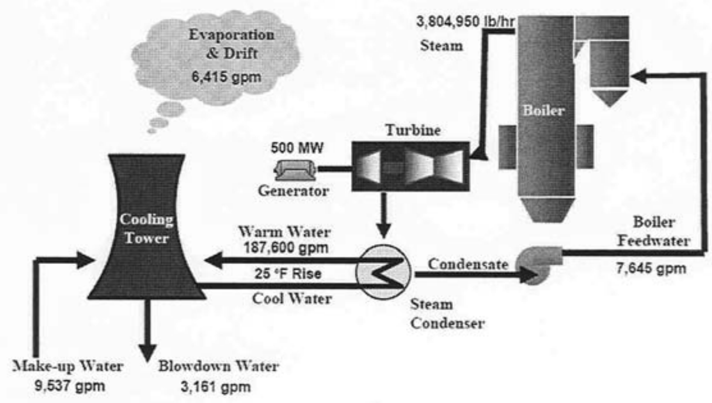


Figure 7 – Typical Water Requirements for 500 MW Thermal Plant with Cooling Towers

There are four major strategies for reducing fresh water use in thermoelectric generation, all of which are being applied to some extent today:

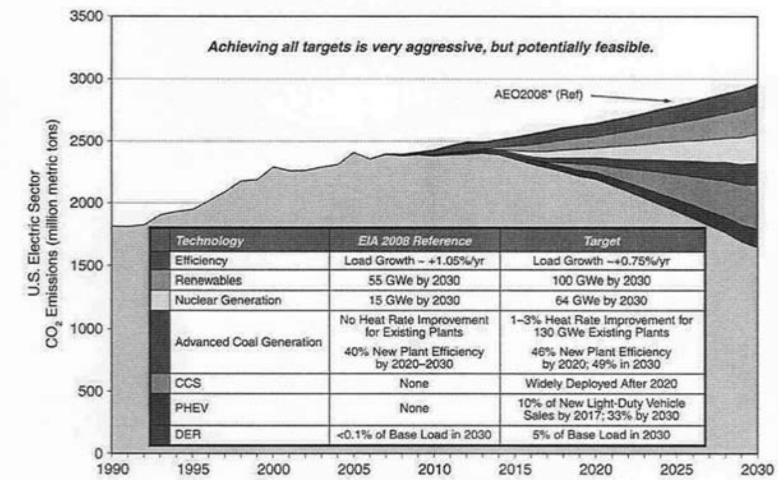
1. **Dry/hybrid cooling** substitutes air for water as the cooling medium.
2. **Non-traditional water sources** substitute degraded waters such as sewage treatment effluent, agricultural runoff, produced water associated with the extraction of oil and gas, mine water, saline groundwater, and stormwater for freshwater.
3. **Water recycle strategies** will treat waste streams within the plant and reuse the water; e.g., remove salts from cooling tower blowdown and recycle as makeup.
4. **Increased thermal conversion efficiency** through use of the waste heat of one plant process to drive another. For example, combined heat and power applications use the waste heat from the electric generation process to satisfy space heating needs, reducing the overall fuel and water use required while providing the same level of energy services.

The advantages and limitations of each of these technologies depend on local conditions and fuel costs; hence there is no universal optimal approach. The objective of EPRI's advanced cooling research program is to optimize the various technologies in terms of technological and economic performance with the goal of minimizing both overall costs and environmental impact.

III. Future Impacts on Water Use in the Electric Power Industry

Water availability is expected to become a major issue for the electric utility industry over the next decade and beyond. Siting of new plants is already constrained by access to cooling water, especially fresh water. Electric power is frequently assigned the lowest priority for water allocation after residential, commercial industrial and agricultural uses. Given limited supplies of fresh water and increasing demands, it is critical to examine options for reducing this anticipated demand as electricity is needed to drive the U.S. economy. This demand must be viewed in light of anticipated changes in climate and new technologies expected to enter the marketplace.

CO_2 Policy and New Generation—With the expectation that the United States will soon have some form of regulation for carbon dioxide and other greenhouse gases, utilities are already anticipating and planning for the changes that will need to occur. Many of these changes will impact water requirements, and new generation will need to be responsive to public and regulatory pressures.



Technology	EIA 2008 Reference	Target
Efficiency	Load Growth ~ +1.05%/yr	Load Growth ~+0.75%/yr
Renewables	55 GWe by 2030	100 GWe by 2030
Nuclear Generation	15 GWe by 2030	64 GWe by 2030
Advanced Coal Generation	No Heat Rate Improvement for Existing Plants 40% New Plant Efficiency by 2020–2030	1–3% Heat Rate Improvement for 130 GWe Existing Plants 46% New Plant Efficiency by 2020; 49% in 2030
CCS	None	Widely Deployed After 2020
PHEV	None	10% of New Light-Duty Vehicle Sales by 2017; 33% by 2030
DER	<0.1% of Base Load in 2030	5% of Base Load in 2030

Figure 8 – The EPRI PRISM--Potential U.S. Electric Sector CO_2 Reductions

EPRI's PRISM analysis (Figure 8) examines the potential for CO_2 reductions under varying assumptions of conservation, energy efficiency and new technologies entering the marketplace over the next 20 years. These technologies, if implemented, would have water resource impacts which are briefly described below.

More Nuclear, More Biomass, and More Solar—Figure 8 shows EPRI's assumed increases in power generation from nuclear, biomass and solar generating stations from the PRISM analysis. Each of these technologies has potential water impacts. Current nuclear power plant designs use slightly more cooling water than their fossil-fueled equivalents. This is due to the lower peak steam temperature and pressure that nuclear units can achieve and the subsequent impact on efficiency. It is also much more difficult and expensive to use some of the water conserving technologies (such as dry cooling) because of the containment and safety issues inherent to nuclear plants.

Dedicated biomass generation is growing as an electric power source and has no net carbon emissions. These plants have similar water requirements to other fossil-fueled plants while in operation. However, from a life cycle perspective, water is likely required to cultivate the fuel and should be taken into consideration when examining future water use and consumption. Solar power can be generated by photovoltaic systems, which have little water requirement aside from cleaning the panels, or solar thermal. Solar thermal plants operate much the same as traditional thermal power plants, where solar radiation is used in place of fuel to boil a working fluid, which is then used to turn a turbine and condensed and cooled with a cooling system. Water requirements for solar thermal plants are similar to other thermal plants.

Carbon Capture and Storage—The application of carbon capture and storage (CCS) for fossil power plants will entail additional water requirements and could ultimately lead to doubling of the water requirement for such plants. Figure 9 shows data from a DOE–NETL study that compares water use among different technologies, including coal with CCS. EPRI studies show very similar results: an ultra-supercritical pulverized coal (USC) plant with carbon capture would incur a 38 percent increase in water consumption compared to one without CCS. When the decrease in net power is factored into the calculation (due to the parasitic load of the carbon capture equipment), a facility with a CCS system will use more than twice as much water compared to a facility without CCS.

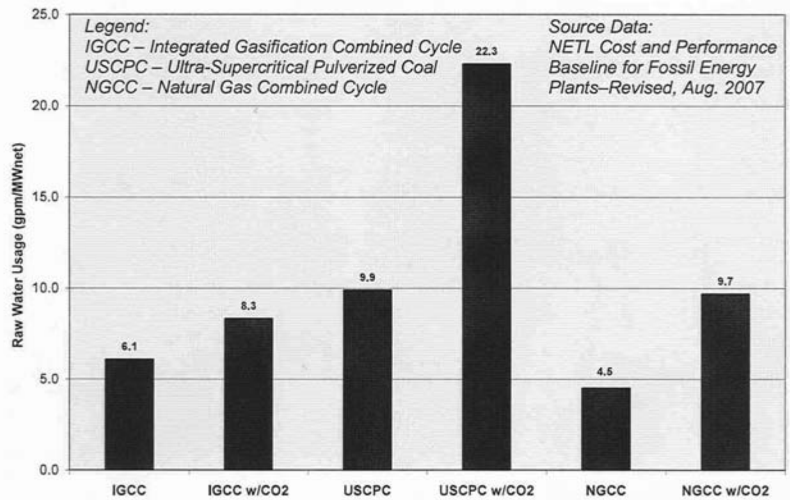


Figure 9 – Advanced Coal Power Plant Water Use (DOE - NETL Study)

Shift of Other Carbon Emitters to Electricity—EPRI's PRISM study and other analyses of greenhouse gas reductions predict that other sectors of the economy will switch to electric technologies in response to CO_2 emission constraints as the reductions in the electric sector would be more cost-effective in many cases. Examples include:

- Industrial—change to electric motors, eliminate package boilers, etc.
- Agricultural—electric motors for water pumps and other stationary equipment
- Residential—switching to electric water heating, cooking, etc.
- Transportation—increased use of electric and plug-in hybrid vehicles

Some of this new electric load will be met with renewable energy sources that may not require water, but some portion of this increased demand for electricity will require access to water including those with advanced water conserving technologies.

Change of Existing Once-Through Cooling to Cooling Towers—As current once through cooled plants are retired, new electric generating facilities will likely employ cooling towers (primarily for fish protection). While the use of cooling towers reduces water withdrawal by 95 percent or more, it also doubles water consumption (through evaporative losses). Unless power companies have cost-effective options to reduce water use, there will be an increasing demand for fresh water for cooling. Many new plants are already being challenged on water use grounds.

Potential Increase in Climate Change Impacts and Drought—A recent study performed by the University of California–Santa Barbara Bren School of Environmental Science for the California Energy Commission predicts that climate change would potentially reduce the snow pack in the Sierra Nevada Mountains and the runoff from snow melt would be shorter and stronger. While it is often difficult to use climate model precipitation data and predict localized impacts, changes in the global climate will have impacts on water resource distribution and availability, and precipitation patterns. These changes could require additional storage capacity, additional treatment to address water quality degradation, and lower water volumes with higher variability. All of these potential changes would have dramatic effects on operation of thermal power plants.

New Regulations—There are several pending regulations that will govern how water is used in current and future thermal generation power plants. Each of these regulations will provide additional limits that must be met, and could have a significant impact on water withdrawals and water consumption.

- Pursuant to Section 316(b) of the *Clean Water Act*, EPA is developing new regulations to address fish entrainment and impingement losses at Cooling Water Intake Structures (CWIS) for once-through cooled plants. New plants must already meet fish protection equivalent to wet cooling towers. EPA is still drafting regulations for retrofitting CWIS for existing once through cooled plants. These requirements, while still under development, could potentially require retrofit of cooling towers on many once through cooled power plants.
- EPA is considering development of new Effluent Guidelines for the utility industry. These new regulations could potentially require significant change in how water is managed and treated within power plants including the potential to reduce overall water discharges.
- The California State Water Resources Board is going one step further and considering regulations that would require all ocean-cooled power plants in the state to retrofit cooling towers.

IV. Opportunities to Reduce Water Needs in the Electric Sector

EPRI conducts and plans research to allow the power industry to address risks associated with growing limitations on water availability. The objectives are two fold: (1) to reduce energy and costs associated with increasing water use efficiency while reducing overall water use and (2) to develop integrated risk analysis tools that can be used for planning water use among various stakeholders. The former consists of studies to improve existing water conserving technologies, demonstration of emerging technologies, and development of new technologies. Research plans also call for fundamental strategic studies of heat transfer, fluid flow and desalination to make major technological breakthroughs with respect to air cooling and water treatment. The second objective is to create and test integrated risk analysis tools for community and regional water resource planning and management.

Another important facet of the EPRI program is collaboration with government agencies and other research organizations. EPRI has been working closely with the Energy-Water Nexus (EWN), a group of national energy laboratories, to further the understanding of the many facets of the overall energy-water sustainability issue. EPRI belongs to the EWN Executive Advisory Committee and has contributed to the Report to Congress and Research Roadmap that EWN has produced for USDOE. EPRI has also provided assistance to GAO as they review the issue of energy-water sustainability. EPRI is an active member of the Federal Advisory Committee on Water Information (ACWI), a FACA committee chaired by USDOI. EPRI co-chairs, with U.S. Forest Service, the Energy-Water Sustainability Subcommittee of ACWI. Other organizations that EPRI has collaborated with on the issue include: American Society of Mechanical Engineering, Water Environment Research Foundation, WateReuse Research Foundation, California Energy Commission, and Water Research Foundation. A listing of government funding that EPRI has received is included in Appendix A.

There are many opportunities for reducing fresh water use in the electric sector and the following sections pinpoints some of the additional research needs. Many of these needs have been outlined in a recent DOE Roadmap report which was completed with input from EPRI and others.

Degraded Water Sources—EPRI has extensively studied the use of degraded water sources, including many joint studies with DOE and the CA Energy Commission. These studies have evaluated degraded water sources from the standpoint of quantity, quality, variability, treatment options and cost, transportation options and cost, and wastewater disposal issues. Many power plants have been operating for years on degraded water sources, particularly treated sewerage effluent. This degraded water source has been the most attractive source because of its year round availability, proximity to power plants, inexpensive price, relatively low cost treatment and minimal impacts to power plant operation. Even this water source is being protected in some areas of the country for use in irrigation and groundwater recharge, limiting its use for power plant cooling.

Additional degraded water sources that are being considered include:

- Brackish water from coastal areas
- High salinity groundwater
- Mine water and produced water from oil and gas wells
- Agricultural runoff
- Stormwater

Each of these sources will cost more than traditional surface or groundwater sources, with the highest costs usually a result of treating the water and transporting it to the power plant. Additional costs can come from materials of construction, chemicals to prevent scaling, fouling and corrosion, storage or backup water system costs, and wastewater treatment and disposal.

Degraded water sources typically contain suspended or dissolved solids. Suspended solids can usually be filtered or removed in clarifiers, but dissolved solids are more difficult to remove. These dissolved solids can lead to scaling and corrosion of power plant equipment, and the suspended and dissolved solids can lead to fouling. In addition, nutrients and minerals in degraded water sources can lead to biological growth that creates additional fouling issues. All of these treatments have to be incorporated to prevent operational and maintenance issues within the power plant and add to the cost of using degraded water sources.

EPRI has identified many research needs for improving the use of degraded water sources. Some of the research that EPRI has identified includes:

- Better and cheaper treatment options
- Wastewater disposal options (salts)
- Coatings to prevent scaling, fouling and corrosion
- Technologies that can better accommodate degraded water sources (like Wet Surface Air Coolers)
- Long-term experience and guidelines on using degraded water sources (example: brackish and salt water cooling towers)

Dry Cooling—Dry cooling works like the radiator on an automobile, where heat is rejected to the atmosphere by passing air over a heat exchanger, usually by using fans. There are generally two types of dry cooling. Air-cooled condensers (ACCs) are used to condense and cool the steam directly from the turbine (Figure 10). The steam is ducted to the ACC in large piping. With indirect dry cooling, the steam is cooled in a traditional condenser using a recirculating water loop. The warm water is then pumped to an air-cooled heat exchanger, where it is cooled and returned to the condenser.

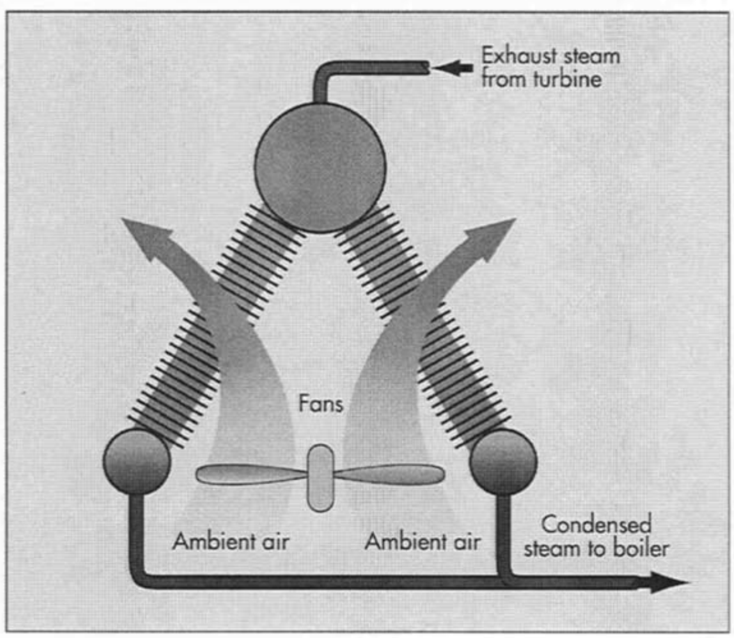


Figure 10 – Schematic of Air Cooled Condenser

While dry cooling can virtually eliminate the water required to cool power plants, it does have drawbacks.

- *Cost*—The capital cost for dry cooling systems is significantly higher, typically over 10 percent higher than wet cooling systems (Figure 11), because they require the manufacture of large finned-tube heat exchangers, large fans and drive motors, and large steel structures to provide ground clearance for proper air circulation. There are also higher operating costs associated with dry cooling. The fans needed for air circulation are much larger and more numerous than those required for a wet tower. This increases the parasitic load on the unit, and reduces the net power available from the plant. Dry cooling cools water to the *dry-bulb* temperature, which means that the water returned to the plant will be warmer than it would be with a wet cooling tower (which cools to the *wet-bulb* temperature) or once through cooling (which cools to the local surface water temperature). This higher temperature has the effect of reducing unit efficiency, which can mean up to and over a 10 percent efficiency penalty on the hottest days.

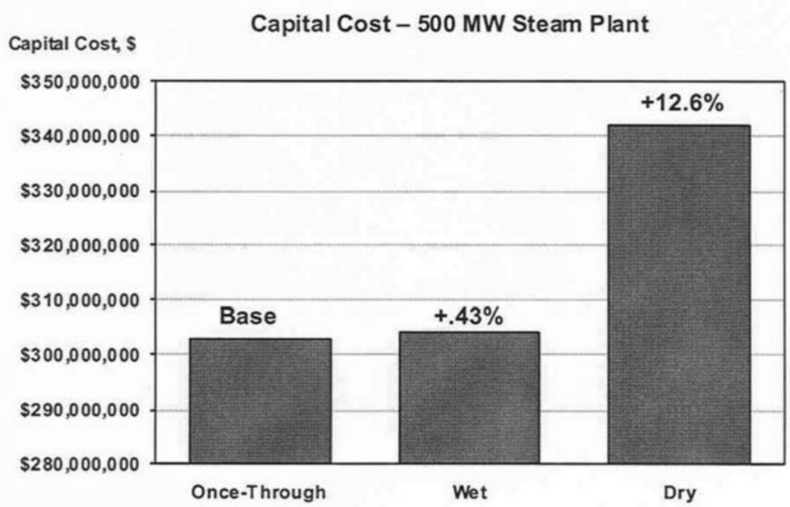


Figure 11 – Comparison of Costs for Cooling Systems

- *Size*—Dry cooling systems are significantly larger than traditional cooling towers and they require additional land space to build.
- *Noise*—The large number of cooling fans can create issues with noise for neighbors. This can be alleviated with the purchase of low-speed, low-noise fans, but this type of fan adds significantly to the cost.
- *Wind Effects*—Many utilities have experienced wind impacts on their air cooled condensers. These wind impacts have caused sudden drops in load, and in extreme cases, unit trips. High winds, especially gusty winds, can cause stalling of the air flow in leading edge fans, which causes a sudden drop in the cooling capacity. This creates higher back pressure for the steam turbine which cam lead to blade damage. If the control system is fast enough, it will be able to reduce steam flow (reducing load) and protect the turbine. If the back pressure rises too rapidly, and the control system cannot close the steam valves fast enough to protect the turbine, the unit will trip in order to protect the turbine from major damage.

EPRI has sponsored a great deal of research into addressing these issues for dry cooling. We have already investigated the wind effects and have developed a simple wind screen that should eliminate most of the wind issues. Additional research is needed to field test and demonstrate the technology and move it to commercial application. EPRI also believes that further improvements in efficiency of dry cooling could be made by improving the heat transfer characteristics of the condensing steam and the finned tubes. Significant improvements in finned tubes in recent years have resulted in better heat transfer and lower manufacturing costs, but there is still room for improvement in this area.

Hybrid Cooling—Hybrid cooling systems (Figure 12) provide a combination of a wet cooling tower and a dry cooling tower. This arrangement allows most of the heat to be rejected to the atmosphere on the cooler days, and still have high efficiency during hot days, with the wet tower taking part of the cooling load when the temperatures are higher. This system is becoming more popular because the tower sizes can be minimized to reduce additional costs, and performance is better than air-cooling only.

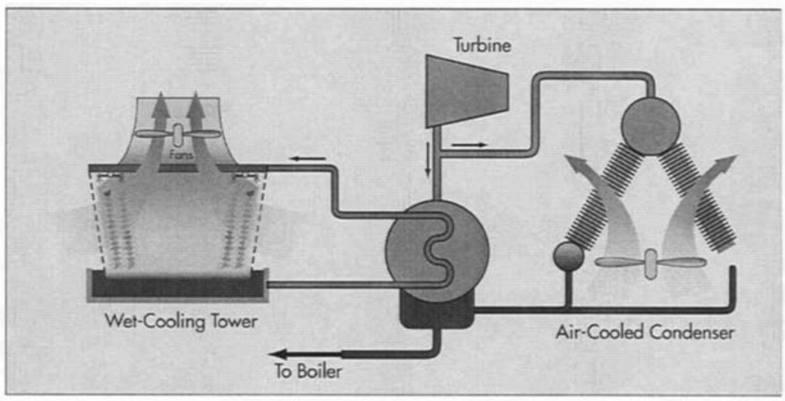


Figure 12 – Schematic of a Hybrid Cooling System

EPRI is just beginning a research program to assess the state-of-the-art for hybrid towers. There are many ways to optimize such a system, depending on the goals of the plant design and the available water sources. The guidelines EPRI will be developing will assist plant designers with this optimization process.

There may also be a research need in helping plant operators decide when to use the wet cooling portion of the hybrid system. When operators are faced with a limited water source, and the need to preserve water for the hottest operating days of the year, some sort of forecasting and optimization tool would be useful in deciding when to use the wet cooling towers for maximum benefit (efficiency, power demand and power price).

Combined Cycles/Bottoming Cycles—Natural gas combined cycle (NGCC) power plants are common in the United States and are the predominant type of plant constructed in the last 10–15 years. NGCC plants have many benefits that make them the logical choice. The combined cycle provides for much higher efficiencies that, in return, reduces the fuel costs. This also has the effect of lowering the carbon emissions for each unit of power generated.

NGCC plants (Figure 13) also can provide a large water conservation benefit. Since roughly two-thirds of the power is produced by the combustion turbines, which do not require cooling water, the cooling water consumption is reduced by an equivalent amount. In addition, the one-third of the power produced by the steam generator/turbine can be cooled by ACCs, further reducing the water usage. The ACC will be smaller, since it is only cooling one third of the total plant, and any efficiency penalties on hot days would only be incurred on that one third of the capacity.

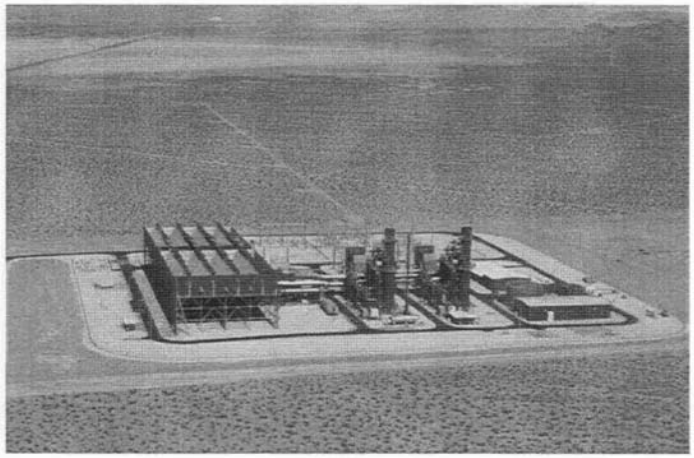


Figure 13 – NGCC Plant with Air Cooled Condenser (Structure to Left)

Bottoming cycles (Figure 14) are another way to increase the efficiency of a traditional steam plant. Such cycles were investigated by EPRI and Electricite de France (EdF) in the 1980's, and these cycles are being examined again in light of upcoming water constraints. Increasing the power output from thermal plants would provide for decreased water consumption per unit power generated. These systems, for now, appear very costly, and managing the working fluids (ammonia or supercritical CO_2) poses a potential safety risk. However, additional research into combined cycle options, including bottoming cycles, may lead to economical systems to improve power plant efficiency, reducing both emissions (including carbon) and water utilization.

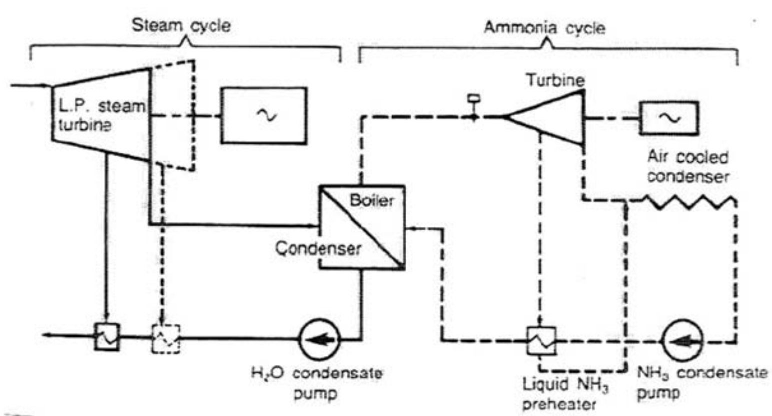


Figure 14 – Schematic of Ammonia Bottoming Cycle

Water Recapture and Water Reuse—There is a significant amount of water lost through power plant stacks (flue gas from fossil fuels) and cooling tower plumes. DOE–NETL has been sponsoring work to develop the Air-2-Air™ system (Figure

15) for capturing moisture in cooling tower plumes. Water loss could potentially be reduced by 15–30 percent.

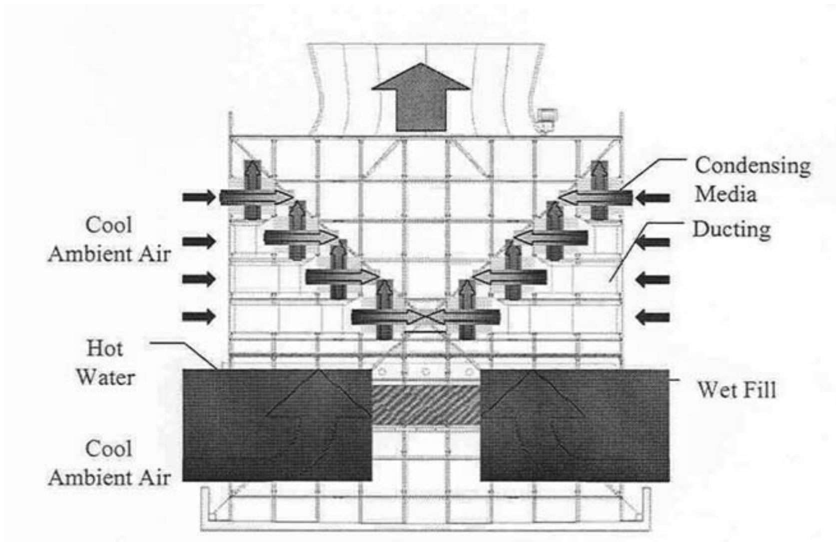


Figure 15 – Schematic of Air-2-Air ™ System

The Energy and Environmental Research Center at the University of North Dakota is pilot testing a desiccant system to recover water from flue gas. Lehigh University has also received DOE funding to develop condensing heat exchangers that will condense water from flue gas. KEMA, in the Netherlands, is developing a membrane system to extract water from flue gas. All of these technologies hold promise to replace part of the water requirements for power generation, but need additional research before they can be considered commercially available or economical.

Power plants in operation today already employ many practices to reuse water within the plant. Water is typically "cascaded" from one use to another, depending on the quality of water that is needed for each process. Some examples include:

- Fresh water that is treated and used for boiler feedwater
- Wastewater from the water treatment system is used as makeup in the Flue Gas Desulfurization (FGD) system
- Boiler blowdown is used as makeup in cooling water system
- Cooling tower blowdown is used as makeup in the FGD system
- FGD blowdown is used for ash sluicing
- Ash pond runoff is used for fly ash wetting (dust control)

By tightening the water balance in the plant, many utilities have already mastered the art of water reuse. Investments in research for more efficient and lower cost wastewater treatment systems would allow for even greater recycling and reuse. EPRI is sponsoring research in many areas of wastewater treatment, zero liquid discharge and water management toward this goal.

Role of Renewable Resources—Renewable energy from wind, solar photovoltaic, geothermal (with brine water cooling), hydroelectric, marine and hydrokinetic sources all require little to no water consumption. To the extent that these technologies can economically penetrate the generation mix, water use can be reduced. EPRI has an extensive research program into renewable energy sources, and is supporting the commercialization of new and better technologies to reduce the cost of these resources and reduce their environmental impacts.

Advanced Desalination Techniques—Sandia National Labs has had an extensive membrane and desalination program that has provided improvements in membrane technologies for reverse osmosis and other issues like salt management. As

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degraded water sources are used to replace potable water sources, economical desalination technologies will help reduce the costs of water treatment in the electric industry as well. Additional research into better membranes and new desalination concepts will have a dual effect. By reducing the cost of desalination, the use of degraded water sources in power plants becomes more economical. In addition, better technologies will reduce the amount of electricity required and the cost of desalination to meet growing population demands for fresh water. This research could have major impacts on society as a whole in future years. Additional research is also needed to address salt management, especially in inland areas where ocean disposal is not an option.

EPRI is also investigating a new forward osmosis technology that, if feasible, would be a breakthrough in desalination, and wastewater treatment and reuse. These "breakthrough" technologies could have a major impact on how we develop new water sources for everyone, not just the utility sector.

V. Research Needs

Most of the technologies described above are still in the development stage or have limits on where they can economically be applied. Additional work will be needed to develop viable options and provide solutions to water conservation needs in the electric sector. None of these water conserving options are universally applicable. Each has its advantages based on such factors as fuel type, plant design, local water sources, meteorological conditions and other factors. All of the alternative options for water conservation are more expensive than using traditional cooling towers and once through cooling using fresh water sources. However, these economics are based on the current price of raw water, and that price is expected to increase dramatically, especially over the typical 50–60 year life of a new power plant. In order to protect the capital investment that is made when building a new plant, power companies must be assured of a constant water source for the duration. The utility industry, and ultimately the rate payers, will benefit from a "toolbox" of potential solutions to allow for a best-fit solution to each plant for water conservation.

In order to reduce these costs and have a variety of options to choose from in a water constrained world of the future, extensive research is needed. These research plans have been developed in cooperation between the federal government (primarily DOE and the National Labs) and EPRI.

- **Engineering and Economic Analysis:** Although the choice among various water-use technologies depends on a variety of plant-specific considerations—including climate and the cost of available water—clear guidelines for the economic and operational consequences of alternative water conservation technologies are not available. Thus there is a need to develop an analytical framework to help guide plant decisions in the selection of equipment and approaches for addressing water needs.

  Previous EPRI research has laid the groundwork for such a framework by comparing the economics of various cooling technologies in particular circumstances for fossil plants. EPRI is planning additional research that will develop a decision framework for utility planners to readily compare costs and performance of alternative air and water cooling systems for thermoelectric plants. Follow-on work will adapt the framework for analysis of other water-conserving technologies.

- **Improving Dry and Hybrid Cooling:** Although there are currently several power plants that use dry cooling, most are gas-fired, combined-cycle units. There is only limited experience with dry cooling on a large scale and under baseload operations. In addition to the guidelines EPRI will be developing for designing and operating these systems, there is additional need for basic research to improve them. The greatest research need is to reduce capital and operating cost of these systems.

- **Reducing Water Losses from Cooling Towers:** One of the most promising ways to reduce water consumption from existing systems is to capture the evaporative losses from cooling towers, which could produce savings up to $1.2 million annually for a 350–MW plant. A number of new options are currently being explored. The Air to Air heat exchanger described earlier could recapture about 15–30 percent of water exiting the cooling tower. This technology is being prepared for full-scale field testing. EPRI is also proposing additional research into optimization of water use in existing cooling towers. While these reductions are likely to be small, the cumulative effect over entire plants could be quite significant. In addition, efficiency gains in plant operations can have a similar effect in providing additional power to the grid for the same cooling water load.

- **Use of Degraded Water:** To reduce the demand for fresh water, plants in some regions are considering the use of nontraditional sources of degraded water, such as treated municipal effluent, contaminated groundwater, and agricultural irrigation return water. A major obstacle, however, is the cost of treating degraded water before it can be used in a power plant. In addition to the technology research needs identified before, additional research is needed to develop a better inventory of potential sources and explore the feasibility of matching these sources with cost-effective pretreatment technologies.
- **Water Resources Management and Forecasting:** Episodic droughts and water shortages are an increasing problem in all regions of the U.S. An example of needed research in this arena is comparing the performance of available climate models to improve the forecasting of droughts. Additional research would also provide better decision-support tools, development of effective strategies for coping with water shortages, and integrated predictions of climate change impacts by incorporating output from climate models into watershed models to assess future water availability.

EPRI has estimated the total cost of such a research program as ~$40 million over a 10-year period. The potential benefits of using the technologies developed as part of such a program would be substantial at the plant level through improved efficiency of plant operation and significant reductions in water use. The technical potential exists to increase water use efficiency and water conservation in thermoelectric generation. Realizing this potential and the associated cost savings will require a sustained research program dedicated to water sustainability. Such a program could create a portfolio of new technologies and practices that utilities could apply in site-specific ways to achieve substantial benefits.

EPRI, the electric sector, DOE, the California Energy Commission and others have invested in decades of research to bring us to this point, and we are continuing to invest in the next generation of water conserving technologies. This research investment today will have a tremendous payoff for the industry and the country in the future.

Appendix A

Government Funding of EPRI Research on Water Sustainability and Advanced Cooling Technologies

1. Use of Produced Water in Recirculating Cooling Systems at Power Generating Facilities. NETL/USDOE. $735,000.
2. Technical Support for National Energy–Water Report to Congress. Sandia/ USDOE. $50,000.
3. Water/Energy Sustainable Residential Development. WERF/USEPA. $850,000.
4. Ohio River Basin Regional Water Quality Trading Program. USEPA. $995,000.
5. Alternative Cooling. California Energy Commission. $320,000.
6. El Dorado Spray Enhanced Cooling. California Energy Commission. $252,000.
7. U.S. Wave Energy Resource Assessment. USDOE. $500,000.
8. Eel Downstream Passage. USDOE. $50,000.
9. Lab Evaluation of Cylindrical Wedge Wire Screens. USEPA. $150,000.
10. Field Evaluation of Wedge Wire Screens. USEPA. $300,000.
11. Field Evaluation of Strobe Lights for Fish Protection. USEPA $200,000.
12. Engineering Design of Advance Hydropower Turbine USDOE. $600,000.
13. Turbine Design Support. New York State ERDA. $250,000.
14. California Hydropower Sedimentation Assessment. California Energy Commission. $50,000.
15. Hydrokinetic Turbine Testing. USDOE. Proposal under review.
16. River In-steam Resource Assessment. USDOE. Proposal under review.
17. Live Cycle Cost Assessment of Wave and Hydrokinetic Power Plants. Proposal under review.

BIOGRAPHY FOR BRYAN J. HANNEGAN

Dr. Bryan Hannegan is Vice President, Environment and Generation for the Electric Power Research Institute (EPRI). In this capacity, he leads the teams responsible for EPRI's research into technologies and practices that maintain a safe and reliable power plant fleet, develop cleaner and more efficient power generation options for the future, and reduce the environmental footprint associated with electric power generation, delivery and use.

Prior to joining EPRI in September 2006, Hannegan served in a dual capacity as the Chief of Staff for the White House Council on Environmental Quality (CEQ), and as an acting Special Assistant to the President for Economic Policy. During his tenure, he led the development of the President's Advanced Energy Initiative and assisted federal agencies in their implementation of the *Energy Policy Act of 2005* (EPACT 2005). At CEQ, Hannegan also coordinated federal agency policies and activities on a wide range of environmental issues affecting air, water, land, and ecosystems.

Between 1999 and 2003, Hannegan served as Staff Scientist for the U.S. Senate Committee on Energy and Natural Resources, where he handled energy efficiency, renewable energy, alternative fuels, and environmental aspects of energy production and use. He put together the first draft of what would become EPACT 2005, and was a principal staff member for action on energy and climate legislation during the 107th Congress.

A climate scientist, engineer and energy policy expert, Hannegan holds a doctorate in Earth system science, a Master of Science in engineering, both from the University of California–Irvine, and a Bachelor of Science in meteorology from the University of Oklahoma.

Chairman BAIRD. Thank you, Dr. Hannegan. Mr. Murphy.

STATEMENT OF MR. TERRY MURPHY, PRESIDENT AND FOUNDER, SOLARRESERVE

Mr. MURPHY. Good morning, Chairman Baird and the Committee. Thank you for giving me the opportunity to be here today.

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I am the co-founder of SolarReserve, after a 27-year career at Rocketdyne, where I was the Director of Advanced Programs. So you might be able to say that actually I am a rocket scientist. My executive responsibilities at Rocketdyne covered a wide range of advanced power systems for both space and terrestrial applications. We generated over 40 patents that leveraged aerospace technologies into clean and renewable terrestrial energy projects. So I appreciate the opportunity to give my perspective on this important issue.

As the other members have already said, power-plant cooling systems currently account for roughly one-third of our freshwater withdrawals. This is a particular problem in the Southwest where there is already a scarcity of water resources and where solar thermal plants, the things that I am working on, are expected to flourish. Solar-based electricity will be a key enabler in achieving our renewable energy goals, but water is also a key ingredient for electrical power generation, and we have got to look at that with a total approach.

CSP power plants, concentrated solar power, capture the sun's thermal energy by focusing mirrors onto thermal receivers and then transforming that energy into steam, which in turn then drives steam turbines. These turbines have an inertia in them that allows them to go through the transients that you see in photovoltaics and other types of things. So they have the thermal capability to ride that through, and the utilities like it because it matches the common stock, the rolling stock that they currently have within their inventory.

Our technology at SolarReserve takes all that to the next level in that we actually run these on molten salts, and so instead of just trying to take the thermal energy and convert it to steam, we are actually putting the energy into molten salts which can retain that heat and operate these systems on demand. And so now you have a power plant that operates like a combined cycle plant that are predictable, have zero price volatility, zero fuel costs, and can provide reasonable power for generations to come.

As discussed here, all conventional steam turbines can be dry cooled, and we have already talked about that. Most of them are wet cooled, and you have already heard of people talking about the water consumption on wet-cooled turbines. Unfortunately, the air-cooled performance gets hit when it is needed the most. And so when you go into an air-cooled system, on the hottest days is when you are really seeing the performance degradation. And so you can see up to 30 or 40 percent of degradation right when you need the power the most.

So we need to be very cautious about when we are moving forward on, you know, how we put water and the water allocation into these plants.

There is an interesting technology called hybrid technology which is a combination of wet- and dry-cooled systems, and it may be the best alternative for reducing water plant consumption. Hybrid systems operate without water when the ambient air temperature allows it to, and then if it gets really hot, only then do they start consuming water. And if you do that you can potentially have an 80 percent reduction in your water.

So you know a lot has been talked about the cost. I think one of the things the Committee has to look at is what is the public policy? You know, I have never seen a power plant that without being regulated would go to dry cooling. And so it really becomes a question of how much is it going to cost and the ability to have the rate payers pay for that. I mean, if we have got to look at water that way, that is the way we have to approach it.

There are a lot of things I can talk about through questions and answers in advanced technologies on Closed-Loop Brayton cycles, and it is a little bit intuitively backwards, but the hotter you go, the easier it is. So technologies that push temperature are a good thing for us because of the rejection temperature.

I would also like to mention there is a system on the FutureGen, on the advanced coal system, and there is maybe an opportunity for the Committee to think about looking at a FutureGen and solar on a CSP plant where I really believe we have the technology to build the ideal power plant, and maybe we can replicate something that is going on on the coal side.

So concentrated solar power is not going to solve all of our energy problems, but they do represent the best utility scale system for the American Southwest. We can run large steam turbines, and when you start looking at the types of these facilities, a single facility can generate 500 million kilowatt hours on an annual basis and do that on demand, which would reduce, you know, 500,000 pounds of CO_2. So it can definitely make an impact.

These new plants—we talked about aging plants. We could replace the coal plants with facilities like these, and many are in the works. Many are being permitted right now. You are looking at about 500 jobs per year in construction for each one of those plants.

So I look forward to answering your questions this morning and hope that a brief exchange of our ideas that we can try and put a little bit more light on this really important subject. Thank you.

[The prepared statement of Mr. Murphy follows:]

PREPARED STATEMENT OF TERRY MURPHY

Good Morning Chairman Gordon and Members of the Committee.

Thank you for this opportunity to appear before you this morning to discuss the linkage between Energy and Water. My name is Terry Murphy and I'm the President and Founder of SolarReserve.

I co-founded SolarReserve, along with U.S. Renewables Group, after a twenty-seven year career at Rocketdyne, where I was the Director of Advanced Programs. My executive responsibilities at Rocketdyne covered a wide range of advanced power systems for both space and terrestrial applications. My business unit generated over 40 patents which leveraged aerospace technologies into clean and renewable terrestrial energy projects, so I appreciate the opportunity to offer my perspective on water usage in the generation of electricity.

Solar Reserve is a U.S. company, based in Santa Monica, California, which is leveraging U.S. technology, DOE investments and local manufacturing to address our energy security and energy related environmental concerns. SolarReserve has the exclusive worldwide rights to the United Technologies, Pratt & Whitney Rocketdyne molten salt power tower technology that was thoroughly validated by the Department of Energy at the Solar Two pilot plant in Barstow, California from 1995 to 1999.

United Technologies, a Fortune 30 company, is standing behind this technology by guaranteeing the performance of the system, which is key enabler to successful project finance.

The critical components in this facility are engineered by the same team at Pratt & Whitney Rocketdyne that designed and built the International Space Station solar power systems, the Space Shuttle Main Engines, and the Apollo moon rocket propulsion systems. This is world-class American technology generating American jobs, erecting critical, desperately needed infrastructure and establishing a foothold to our permanent energy independence.

Our unique, molten salt, solar power technology solves a key fundamental challenge of renewable energy: storage. Wind only has a two percent correlation with electrical energy demand in California, so while building a wind farm may satisfy the Renewable Portfolio Standards (RPS), it does very little to satisfy customer requirements.

Conventional solar, the rooftop photovoltaic (PV) that we are all familiar with is more coincident with demand, but intermittent cloud cover can cause it to drop off in milliseconds; and what's worse, turn right back on just as quickly. While these systems have minimal water use and are great for distributed rooftops, Utility scale deployment of PV could introduce problems with grid stability and reliability due to a rapid and unpredictable intermittent generation profile.

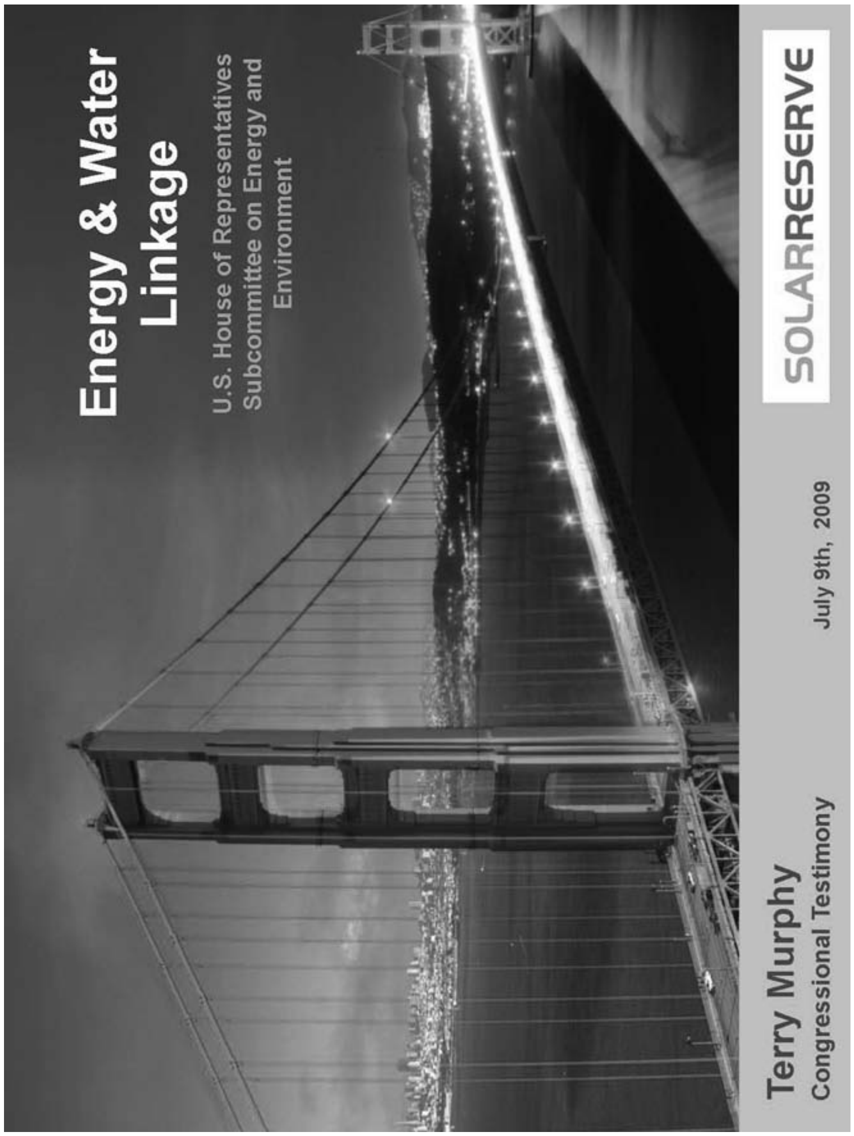
Conversely, a SolarReserve power plant generates electricity from the sun's heat; this type of solar energy is known as Concentrated Solar Power (CSP). These power plants capture the sun's thermal energy by focusing thousands of heliostats (or mirrors) on to a central receiver, converting and storing that energy in molten salt and then transforming that energy into steam, which in turn drives turbines. Unlike a photovoltaic power system, however, the molten salt CSP technology allows electricity to be generated on demand and controlled like any conventional power generator. These load following power plants operate on a highly predictable and dependable fuel supply, the sun! They have zero price volatility, zero fuel costs, and can provide reasonably-priced renewable electricity for generations to come. The technology does not require toxic operational fluids and last, but not least, SolarReserve technology does not require natural gas or other fossil fuels.

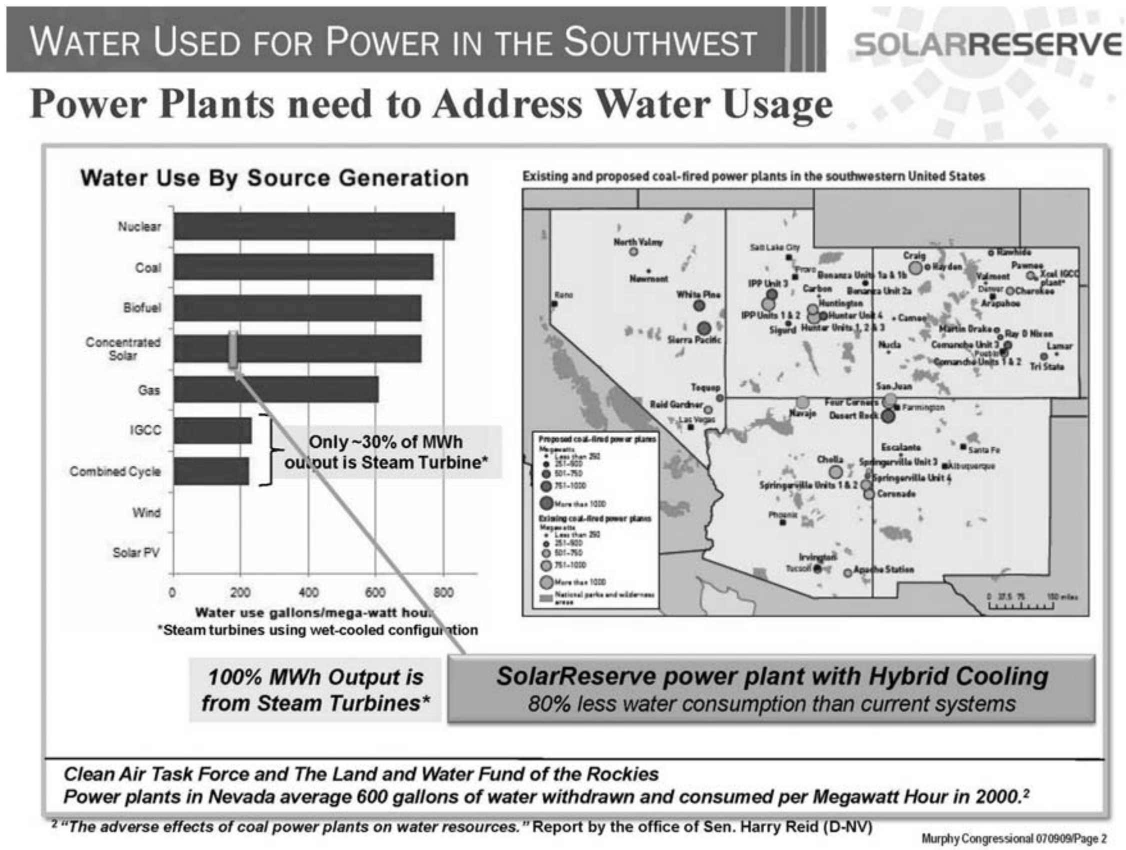
Like any power plant technology using a conventional steam turbine, our system can be Air-Cooled, reducing overall plant water consumption significantly relative to any water-cooled plant, particularly older plants which use less efficient technologies or water-saving designs. We believe, however, that we need appropriate public policy and economic incentives to realize this opportunity in the competitive marketplace since, relative to conventionally water-cooled generators, air-cooled technologies have a significant impact on electricity production efficiency and cost of electricity. In addition, SolarReserve encourages collaborative research with the Department of Energy into technologies that could further reduce our water consumption and increase our plant performance, thereby putting us on track to build the "Ideal Power Plant."

SolarReserve Power Towers can't solve all of our energy problems, but I believe that they do represent the best utility scale renewable energy system for the American Southwest. Because SolarReserve Power Towers operate on demand, they are perfectly suited to replace the aging coal-fired power plants that are currently operating in the Southwest. SolarReserve already has fifteen projects in various stages of development, with the first project in the United States slated for Tonopah, Nevada. This system will provide 500,000,000 kW-hr per year of clean, emission free, renewable energy and would abate over 500,000 tons of CO_2 when compared to a coal fired power plant over its operating life.

Our $700 million dollar Tonopah facility is scheduled to begin construction in 2010. Solar Reserve hopes that this committee will support our efforts to expedite the federal review and approval process by working directly with the Department of Defense, the Federal Aviation Administration and the Bureau of Land Management, so that this project can avoid further costly delays. SolarReserve will employ nearly 500 people during the two year construction period and will operate with 50 permanent positions. In addition to Tonopah, SolarReserve has significant development activities in California, Arizona, New Mexico, Colorado, Utah, and several international efforts, including two projects is in Spain.

I look forward to answering your questions this morning and hope that our brief exchange of ideas, along with my written testimony will provide you with a more comprehensive analysis and awareness of water usage in power plants and the true potential of Concentrated Solar Power technologies.


Energy & Water Linkage
U.S. House of Representatives Subcommittee on Energy and Environment
SOLARRESERVE
Terry Murphy
Congressional Testimony
July 9th, 2009

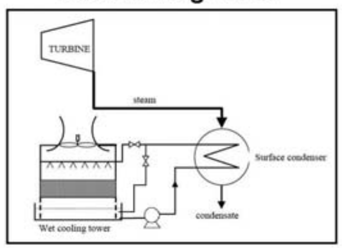

WATER USED FOR POWER IN THE SOUTHWEST
SOLARRESERVE
Power Plants need to Address Water Usage
Water Use By Source Generation
Nuclear
Coal
Biofuel
Concentrated Solar
Gas
IGCC
Combined Cycle
Wind
Solar PV
0
200
400
600
800
Water use gallons/mega-watt hour
*Steam turbines using wet-cooled configuration
Only ~30% of MWh output is Steam Turbine*
Existing and proposed coal-fired power plants in the southwestern United States
100% MWh Output is from Steam Turbines*
SolarReserve power plant with Hybrid Cooling
80% less water consumption than current systems
Clean Air Task Force and The Land and Water Fund of the Rockies
Power plants in Nevada average 600 gallons of water withdrawn and consumed per Megawatt Hour in 2000.[2]
[2] "The adverse effects of coal power plants on water resources." Report by the office of Sen. Harry Reid (D-NV)
Murphy Congressional 070909/Page 2

WET VS. AIR COOLED SYSTEMS ANALYSIS

SOLARRESERVE

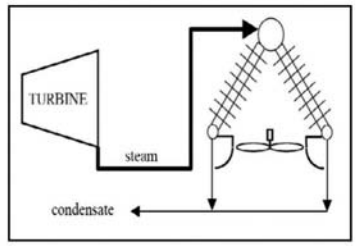
Steam Turbine Exhaust Cooling Options

Wet Cooling Tower



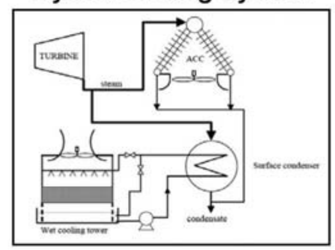
- Lowest Capital Cost
- Highest Performance
- Most Water Usage

Air Cooled Condenser



- Higher Capital Cost
- High Power Consumption
- Lowest Performance
- Least Water Usage

Hybrid Cooling System



- Highest Capital Cost
- Highest Maintenance
- Good Performance
- Best Water Usage

- Steam Turbine output efficiency is highly dependent on external temperature conditions
  - Power Plants yield the lowest output during the highest external temperatures
  - Dry cooling options very sensitive to external ambient temperatures
    - Water is a scarce resource in most CSP territories

All Plants are Site Specific and Require Detailed Technical and Economical Analysis

Rankine Cycle Cooling Options, Babul Patel, Nexant, July 1, 2009

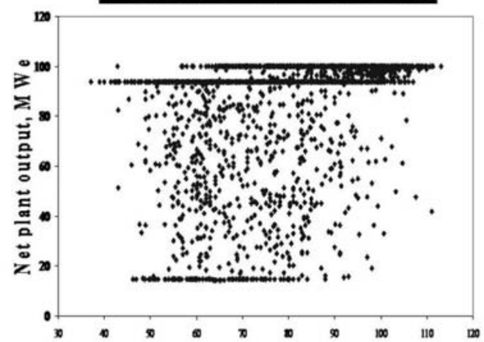
Murphy Congressional 070909/Page 3

WET VS. AIR COOLED SYSTEMS ANALYSIS

SOLARRESERVE

Fossil Fuel vs. CSP Power Plants

Fossil Wet Cooling

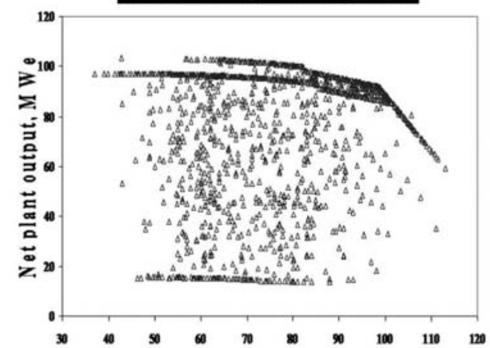


Fossil Fuel Plant

- Operates Day & Night, all year-long
- Analysis can be based on *Yearly* average

<0.5% Difference between Wet and Dry

CSP Dry Cooling



CSP Plant

- Operations coincident with the Sun
- Analysis must be based on *Hourly* average

<6% Difference between Wet and Dry

Air Cooled Systems can adversely Impact CSP Financials

Rankine Cycle Cooling Options, Babul Patel, Nexant, July 1, 2009

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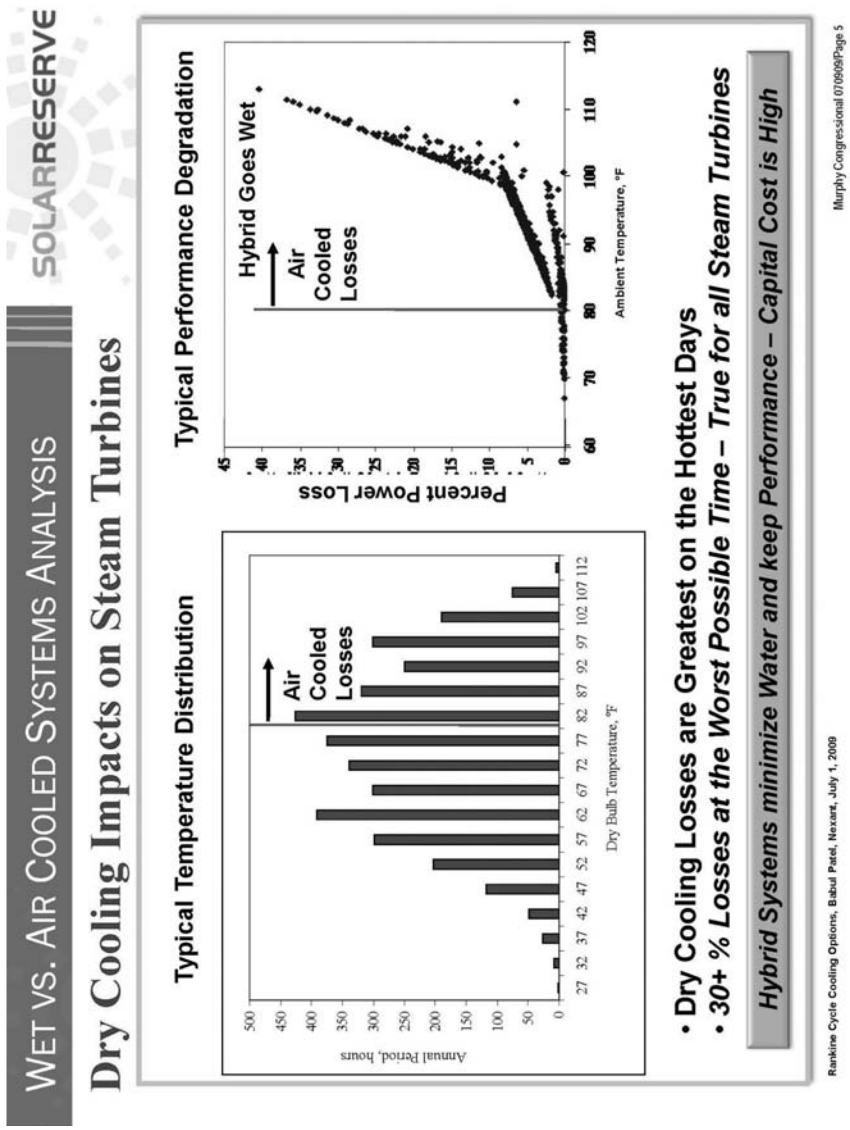
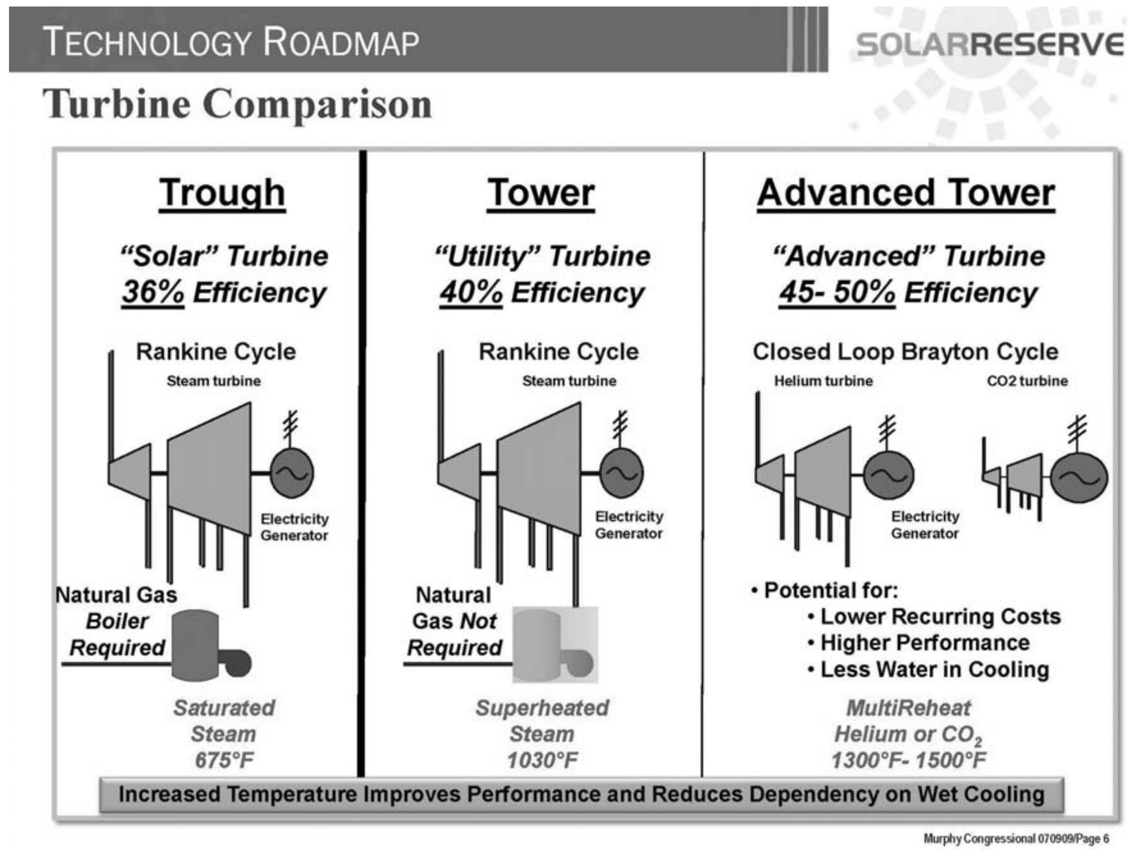

WET VS. AIR COOLED SYSTEMS ANALYSIS
SOLARRESERVE
Dry Cooling Impacts on Steam Turbines
Typical Temperature Distribution
Air Cooled Losses
Annual Period, hours
Dry Bulb Temperature, °F
Typical Performance Degradation
Hybrid Goes Wet
Air Cooled Losses
Percent Power Loss
Ambient Temperature, °F
• Dry Cooling Losses are Greatest on the Hottest Days
• 30+ % Losses at the Worst Possible Time – True for all Steam Turbines
Hybrid Systems minimize Water and keep Performance – Capital Cost is High
Rankine Cycle Cooling Options, Babul Patel, Nexant, July 1, 2009
Murphy Congressional 070909/Page 5


TECHNOLOGY ROADMAP
SOLARRESERVE
Turbine Comparison
Trough
"Solar" Turbine
36% Efficiency
Rankine Cycle
Steam turbine
Electricity Generator
Natural Gas Boiler Required
Saturated Steam 675°F
Tower
"Utility" Turbine
40% Efficiency
Rankine Cycle
Steam turbine
Electricity Generator
Natural Gas Not Required
Superheated Steam 1030°F
Advanced Tower
"Advanced" Turbine
45- 50% Efficiency
Closed Loop Brayton Cycle
Helium turbine
CO2 turbine
Electricity Generator
• Potential for:
• Lower Recurring Costs
• Higher Performance
• Less Water in Cooling
MultiReheat Helium or CO2 1300°F- 1500°F
Increased Temperature Improves Performance and Reduces Dependency on Wet Cooling
Murphy Congressional 070909/Page 6

ENERGY AND WATER LINKAGE

SOLARRESERVE

Water Impacts on CSP

- Air Cooled: Expensive and Big Performance Hit on Hot Days
  - Very Common in Western NGCC Systems – Path of Least Resistance
    - Only 30% Power is Steam Generated – Marginal Impact
  - Significant Performance Impact on CSP plants
    - 100% power from Steam
    - Deliberately located in High Heat Zones
    - System Operation is Coincident with Hottest Time-of-Day
      - Storage can shift Operation, but not Demand
- Wet Cooled: Cheapest and Most Efficient
  - Consider Water Allocation "Set-Aside"
    - Hottest Days are the Most Productive = Maximum Energy Production
      - Lowest Cost Electricity
  - Site-by-Site Analysis warranted; Potential reuse on "Gray-Water"
- Hybrid Cooling: Most Expensive
  - Big Water Savings, but essentially two systems: Wet and Dry
  - Wet only used 20% of the Time, but during the Driest Months
  - Adequate Solution for CSP, but Increases Cost
  - Could Block CSP Entry into the Marketplace

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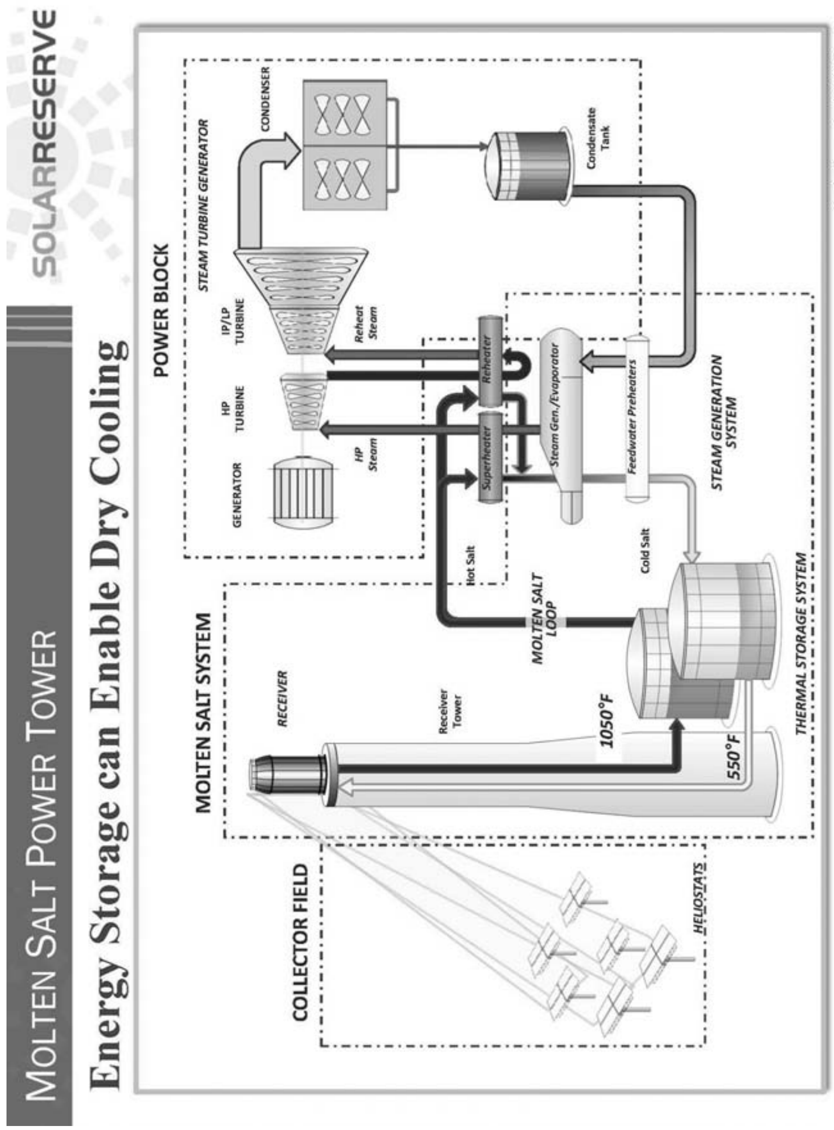
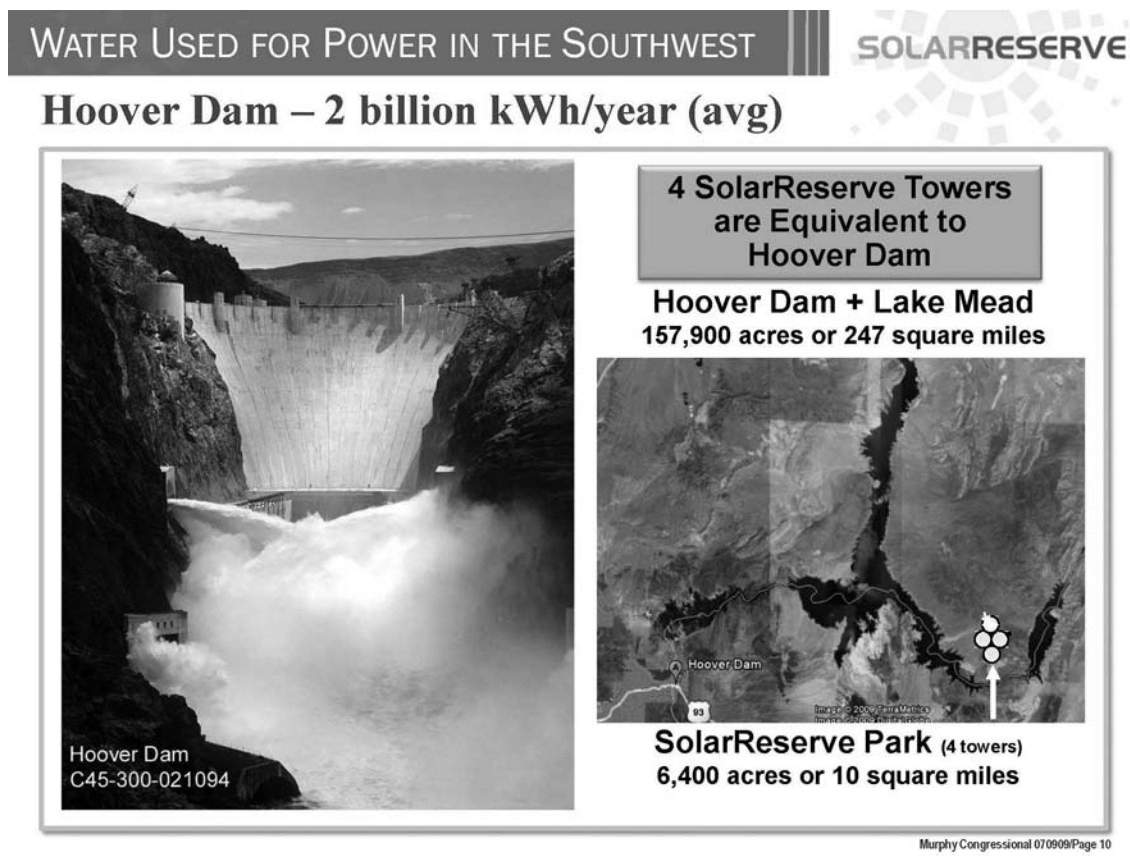
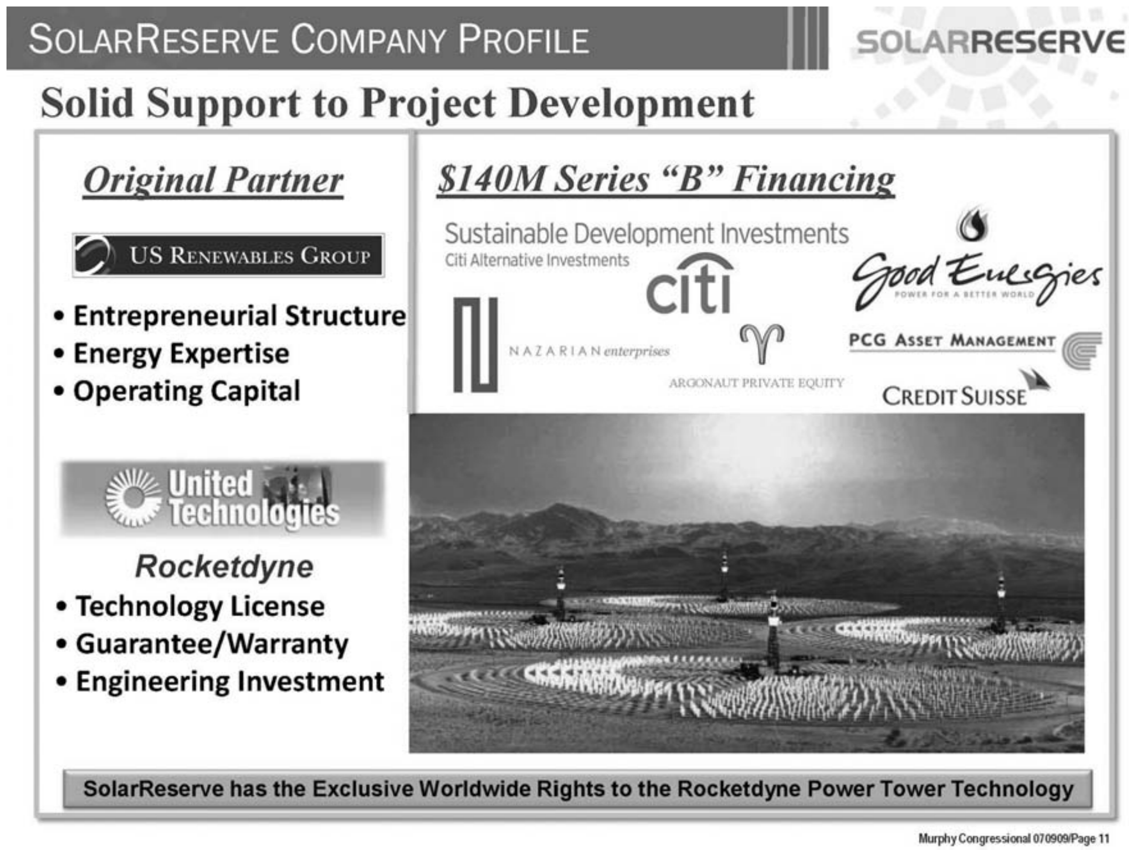
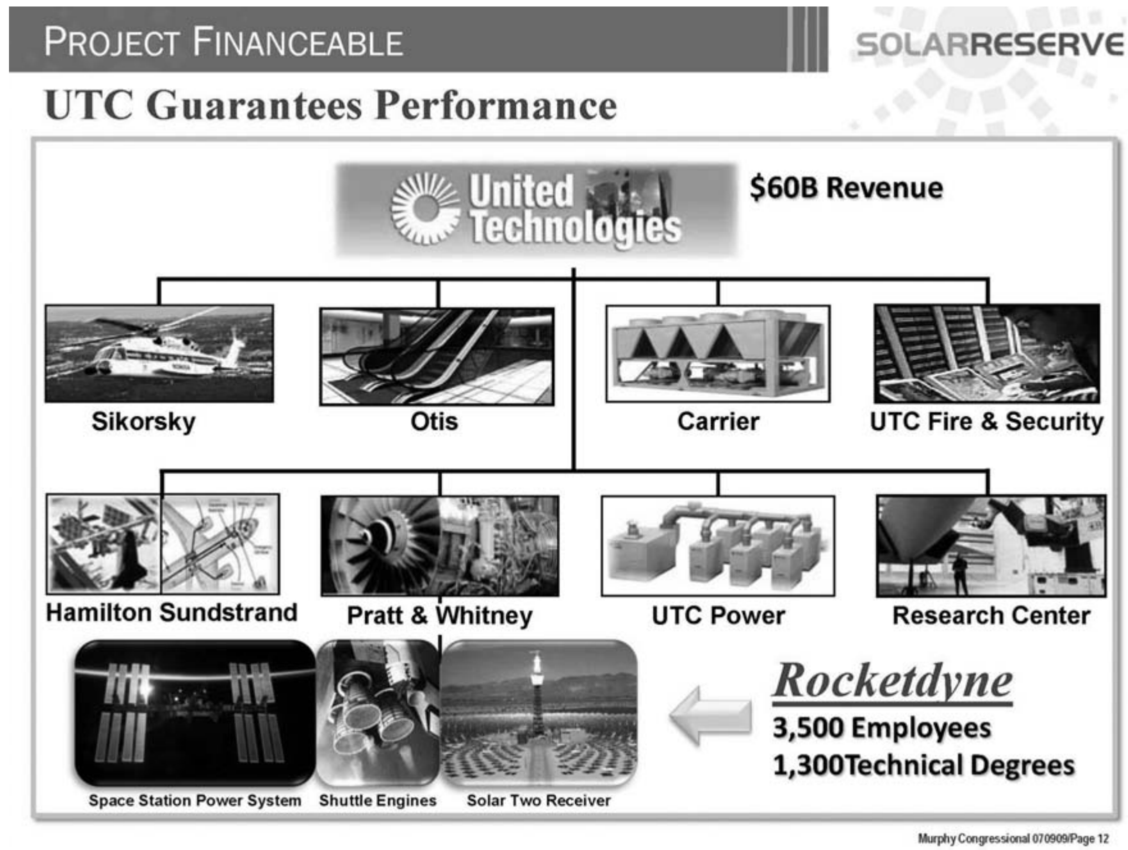
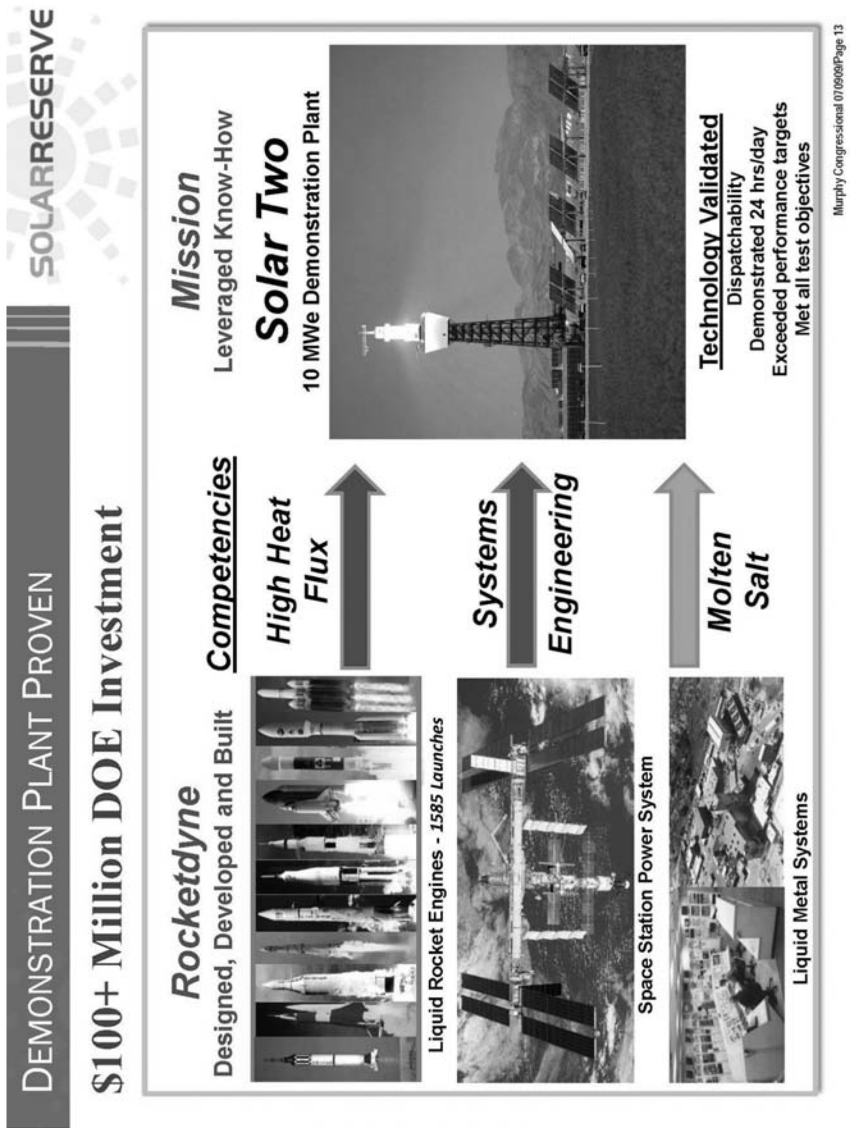
CSP MOLTEN SALT POWER TOWER
SOLARRESERVE
"Ideal" Power Plant
Low Cost Electricity
Zero Price Volatility
Zero Fuel Costs
Highly Predictable / Dependable Fuel Supply
100% Dispatchable, Load Following
Turn-down, spinning reserve potential
Limited Environmental Impact
Zero Air Emissions
Minimal Water Usage
No fossil fueled auxiliary systems
Inert materials:
Construction, Operation to Decommission
Murphy Congressional 070909/Page 8


MOLTEN SALT POWER TOWER
SOLARRESERVE
Energy Storage can Enable Dry Cooling
POWER BLOCK
STEAM TURBINE GENERATOR
CONDENSER
Condensate Tank
GENERATOR
HP TURBINE
IP/LP TURBINE
HP Steam
Reheat Steam
Superheater
Reheater
Steam Gen./Evaporator
Feedwater Preheaters
STEAM GENERATION SYSTEM
Hot Salt
Cold Salt
MOLTEN SALT SYSTEM
RECEIVER
Receiver Tower
MOLTEN SALT LOOP
1050°F
550°F
THERMAL STORAGE SYSTEM
COLLECTOR FIELD
HELIOSTATS
Murphy Congressional 070909/Page 9


WATER USED FOR POWER IN THE SOUTHWEST
SOLARRESERVE
Hoover Dam – 2 billion kWh/year (avg)
Hoover Dam
C45-300-021094
4 SolarReserve Towers are Equivalent to Hoover Dam
Hoover Dam + Lake Mead
157,900 acres or 247 square miles
Hoover Dam
93
SolarReserve Park (4 towers)
6,400 acres or 10 square miles
Murphy Congressional 070909/Page 10


SOLARRESERVE COMPANY PROFILE
SOLARRESERVE
Solid Support to Project Development
Original Partner
US RENEWABLES GROUP
• Entrepreneurial Structure
• Energy Expertise
• Operating Capital
United Technologies
Rocketdyne
• Technology License
• Guarantee/Warranty
• Engineering Investment
$140M Series "B" Financing
Sustainable Development Investments
Citi Alternative Investments
citi
Good Energies
POWER FOR A BETTER WORLD
NAZARIAN enterprises
ARGONAUT PRIVATE EQUITY
PCG ASSET MANAGEMENT
CREDIT SUISSE
SolarReserve has the Exclusive Worldwide Rights to the Rocketdyne Power Tower Technology
Murphy Congressional 070909/Page 11


PROJECT FINANCEABLE
SOLARRESERVE
UTC Guarantees Performance
United Technologies
$60B Revenue
Sikorsky
Otis
Carrier
UTC Fire & Security
Hamilton Sundstrand
Pratt & Whitney
UTC Power
Research Center
Rocketdyne
3,500 Employees
1,300Technical Degrees
Space Station Power System
Shuttle Engines
Solar Two Receiver
Murphy Congressional 070909/Page 12


DEMONSTRATION PLANT PROVEN
SOLARRESERVE
$100+ Million DOE Investment
Rocketdyne
Designed, Developed and Built
Liquid Rocket Engines - 1585 Launches
Space Station Power System
Liquid Metal Systems
Competencies
High Heat Flux
Systems Engineering
Molten Salt
Mission
Leveraged Know-How
Solar Two
10 MWe Demonstration Plant
Technology Validated
Dispatchability
Demonstrated 24 hrs/day
Exceeded performance targets
Met all test objectives
Murphy Congressional 070909/Page 13

BIOGRAPHY FOR TERRY MURPHY

Mr. Murphy co-founded SolarReserve, along with U.S. Renewables Group, after a twenty-seven year career at Rocketdyne, where he was the Director of Advanced Power Systems and Business Development. His executive responsibilities at Rocketdyne covered a wide range of advanced power systems for both space and terrestrial applications. His former organization continues to be a recognized technology leader in concentrated solar power, liquid metal heat transport, systems engineering of space power/propulsion systems, and nuclear power generation.

Prior to the acquisition of Rocketdyne by United Technologies, Mr. Murphy was the Division Director of Boeing Energy Systems. His business unit generated over 40 patents which leveraged aerospace technologies into clean and renewable terrestrial energy projects. Mr. Murphy solidified many external partnerships, which led to the redesigned and improved the reliability of gas turbines, coal gasification and hydrogen production systems. Mr. Murphy was also responsible for a host of technology contracts supporting the NASA exploration initiatives and led the capture of a deep space radioisotope thermoelectric generator power system award from the Department of Energy.

As the Director of Advanced Engine Programs and International Business Development, Mr. Murphy formulated the design of the RS–68 booster engine for the Boeing Delta IV launch vehicle and initiated several international teaming agreements for upper stage engines. The RS–68 is the largest hydrogen engine in the world and was originally developed for commercial launches, and has also been selected by NASA for their next generation launch system due to its low cost and demonstrated reliability.

Mr. Murphy earned a Bachelor of Science in Aeronautical and Astronautical Engineering from Purdue University and was honored in 2005 with their Outstanding Engineering Award. He also earned a Master of Science in Systems Management from the University of Southern California, is an Associate Fellow of the AIAA and has authored several patents relating to concentrated solar power applications.

Chairman BAIRD. Thank you very much. The tradition of the Committee is that if one of our witnesses is from the home state of one of the Members, the Member gets to introduce that witness. And I will recognize Mr. Inglis for that purpose.

Mr. INGLIS. Thank you, Mr. Chairman, for giving me the opportunity to brag on General Electric and Rick Stanley. We have 1,500 engineers and 1,500 production people in the GE facility in Greenville, and Rick Stanley is the guy in charge of all those engineers. And so he is a Notre Dame Bachelor's degree holder who then worked for GE Aircraft, got a Master's degree in aerospace engineering at the University of Cincinnati, had lots of promotions with the company, and then in 2005 came to his current post which is Vice President and General Manager of Engineering Division for GE Energy. And it is particularly exciting to have him here because he is working on power generation, gas turbine, steam turbine, gasification, controls, generators, wind, aeroderivatives, nuclear, solar and services segments of General Electric. That is quite a portfolio. He holds five patents himself, and we are very happy to have him in Greenville and very excited about having General Electric in Greenville making wind turbines and gas turbines and figuring out ways to repower our lives. So Mr. Stanley?

Chairman BAIRD. Thank you, Mr. Inglis. Before you begin your testimony, let me just share with my colleagues, we have about 12 minutes left on this vote. We will have time for Mr. Stanley's testimony. Then, my friends, we are going to have to recess probably for at least 45 minutes, possibly longer. We had some nightmarish days a while back, and I apologize for that.

So what we will do is I will tell my colleagues when we have five minutes to give us plenty of time to go get this in critical motion to adjourn vote, doubtless followed by similarly critical votes, but nevertheless, we do have to make that vote.

So Mr. Stanley, please proceed. I know you will do your best to keep within five minutes, and then we will decide where to go from there. Thank you.

Mr. STANLEY. Will do. Thank you very much, Congressman.

STATEMENT OF MR. RICHARD L. STANLEY, VICE PRESIDENT, ENGINEERING DIVISION, GE ENERGY

Mr. STANLEY. Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to testify today on the critical link between energy and water.

I have four recommendations for public-private partnerships to address this linkage. First, greater investments in water reuse technologies to facilities in pilot new technologies; second, federal support for research, development and demonstration of high-efficiency natural gas turbine technology as envisioned in H.R. 3029; third, increased research in system integration of desalination processes; and finally, additional research on large-scale demonstration of organic rankine cycle technology for waste heat recovery.

Energy and water are co-dependent, and in its simplest terms, energy is required for producing water and water is required for the production of energy. In the United States, demands for water related to electricity production are expected to nearly triple from 1995 consumption levels. Significant quantities of water are used throughout the power generation cycle in boilers, cooling towers, and fuel gas and emission treatments. With water treatment and reuse, important reductions could be made in the amount of water consumed in power generation.

GE is working to develop high-efficiency membrane materials that will allow for through-puts that increase water flow by a factor of 10-plus and further reduce energy costs. Achieving these results requires advances in manufacturing technologies, materials and processes, as well as the establishment of facilities to pilot new technologies.

We can accomplish this most effectively through joint government, industry and university initiatives. Wider deployment of less water-intensive power generation technologies and improving the efficiency of these technologies represents another important opportunity to reduce water consumption in power generation.

Currently natural gas combined cycle power plants represent about 20 percent of the country's electric generation. Now, on a per-megawatt basis, natural gas combined cycle plants utilize less than 50 percent of the water used by our pulverized coal plants which comprise the largest percentage of U.S. power generation capability today.

Today's most advanced gas turbines are capable of reaching up to 60 percent efficiency. Aggressive technology advancement can lead to 65 percent efficiency. Now this is a stretch goal, but one that is worth aiming for because a one percentage point improvement in efficiency applied to GE's existing F-class fleet in the United States would result in CO_2 emission reductions of 4.4 million tons per year while providing savings of more than $1 billion per year in fuel costs, all while using far less water than alternate technologies.

GE Energy has invested over $1 billion in the gas turbine technology during the past three years, but more work is needed. The Department of Energy can partner with U.S. private industry to reduce the inherent risk in the required research and development efforts. H.R. 3029, introduced by Representative Paul Tonko and referred to this committee provides the basis for such a partnership. GE commends Representative Tonko and applauds the House of Representatives for including this proposal in the recently passed *American Clean Energy and Security Act.*

For desalination applications, GE's LMS 100 aero-derivative gas turbine has heat rejection that can ideally be integrated with a desalination process to produce clean water as well as power while achieving substantial savings in total power usage. Further research is needed in system integration to achieve these benefits at a low cost.

The organic rankine cycle offers the opportunity to reduce dramatically the need for water and energy production. This technology utilizes an organic solvent as a working fluid to extract power from low-grade waste heat in a gas turbine. The key advantage is that it is a closed cycle, and it does not utilize water. GE is working to evaluate this technology. However, there are significant needs for development and demonstration on a large scale before this opportunity can become a reality.

In summary, Mr. Chairman, the nexus between power generation and water usage is one of the world's most complex and critical public policy challenges. GE believes that the Congress can play an important role in bringing focus and facilitating partnerships between the U.S. Department of Energy and the private sector in areas including water reuse, gas turbine technology advancement, integration of desalination, and organic rankine cycle technology for gas turbine applications.

Thank you, and I would be pleased to answer any of your questions.

[The prepared statement of Mr. Stanley follows:]

PREPARED STATEMENT OF RICHARD L. STANLEY

Mr. Chairman and Members of the Subcommittee, I am Rick Stanley, Vice President of GE Energy's Engineering Division. I appreciate the opportunity to testify today on the link between energy and water and technologies that can enable us to better manage these interrelated resources. GE has long recognized the connection between energy and water, and commends the Committee for its efforts to explore and make progress on this critically important topic. In my testimony today, I will address three major points: the depth of the challenges surrounding the use of water in power generation, the role of current technology in addressing these challenges, and the need for targeted research and development through public-private partnerships.

Background

GE is a global leader in power generation technology and products with more than 100 years of industry experience. In 2008, GE's water and power generation businesses were integrated to better meet customer needs and address significant global challenges. Our team of more than 30,000 employees operates in 140 countries around the world, and had 2008 revenues of $23 billion. GE Power & Water offers a diverse portfolio of products and services, including renewable energy technologies such as wind, solar, and biomass, and fossil power generation, gasification, nuclear, oil & gas, transmission, and smart meters. GE Power & Water likewise has technologies for water treatment and use, including process chemicals, water chemicals, equipment and membranes.

At GE, we see the importance of achieving water and energy efficiencies across our own portfolio of businesses. In 2005, GE launched a global environmental initiative called ecomagination. We have committed to reduce our greenhouse gas emissions by 30 percent on a normalized basis (allowing for projected growth of GE's businesses), or one percent in absolute terms from 2006 to 2012. In addition, we have committed to reducing our water consumption by an absolute 20 percent during the same time frame. At the same time, we're working with our customers around the world to help them achieve similar efficiencies.

In addition, GE is doubling its level of investment in clean research and development from $700 million in 2005 to more than $1.5 billion by the year 2010. This research effort is focused on helping our customers meet pressing energy and water challenges.

The Energy-Water Nexus

It could be said our economy runs on water. Unfortunately, water demand already exceeds supply in many parts of the world. And, as the world's population continues to grow at an unprecedented rate, many more areas are expected to experience this imbalance in the near future.[1] The situation is no different here in the United States, where most states expect water shortages during the next decade.

Energy and water are co-dependent. In simplest terms, energy is required for producing water and water is required in the production of energy. Globally, the demand for both of these crucial resources is projected to grow at an alarming pace, with energy demand doubling[2] and water demand tripling[3] in the next 20 years.

As we prepare to meet the future electricity demands here in the U.S., corresponding demands for water related to electricity production are expected nearly to triple from 1995 consumption levels. In addition, the deployment of technologies to meet expected carbon emission requirements will increase water consumption by an additional one to two billion gallons per day.[4]

Water reuse represents a significant opportunity to achieve reductions in water consumption for power generation. It is estimated that 45 percent of freshwater withdrawals in the United States is used for industrial purposes.[5] And nearly 90 percent of all industrial water—or 39 percent of all freshwater withdrawals—is used for the generation of power.[6] Although power generation facilities in the United States today withdraw 136 billion gallons per day (GPD), they only consume four billion GPD through evaporation and other means. The vast majority of the water is used for once-through cooling water applications, and then returned to the receiving stream. Once-through cooling, however, consumes large amounts of energy to pump the water, and it also elevates the temperature of the receiving stream.[7] It is often less expensive to pull water from a river or the ground than it is to reuse it.[8] In addition, many power plants in the United States use potable water from municipal systems to meet their cooling and other needs.[9] This places strains on community systems. If the cooling water needs could be met with reused wastewater, significant benefits would result.

Another opportunity for reductions in water consumption for power generation is in selection of less water-intensive power generation technologies and in improving the efficiencies of those technologies. For example, the use of advanced gas turbines in power generation applications contributes to water savings. Key applications include the use of natural gas combined cycle (NGCC) power plants and integrated gasification combined cycle (IGCC).

NGCC plants currently account for about 20 percent of total electric generation in the United States. They are a highly efficient, flexible source of clean and reliable electric power, and can be constructed and installed in relatively short periods of time in comparison with other forms of electric generation. On a per megawatt

[1] *Greenfacts.org*
[2] DOE/EIA–0384 (2004).
[3] NETL 2006.
[4] NETL 2006.
[5] USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004.
[6] USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004.
[7] USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004.
[8] USGS, Estimated Use of Water in the United States in 2000, USGS Circular 1268, March 2004.
[9] Wade Miller, Executive Director, WateReuse Association (2009).

basis, NGCC plants utilize less than 50 percent of the water used by pulverized coal power plants—which comprise the largest percentage of U.S. power generation capability today. Wider deployment of natural gas combined cycle plants—and technology advances to make those plants more efficient—will have a dramatic impact on water usage for power generation in the United States.

IGCC is a power generation technology that gasifies coal to remove pollutants and capture carbon prior to combustion. IGCC technology is commercially ready to utilize the abundant coal resources here in the U.S., with both lower emissions and reduced water consumption. GE is building the first fully commercial IGCC plant at Duke's Edwardsport, Indiana facilities. This new GE IGCC generation plant will utilize 30 percent less water and offer significant emissions reduction benefits in comparison with a traditional pulverized coal facility. GE also is working with the University of Wyoming to develop advanced coal gasification technology, including a unique dry feed injection process. The development of this dry feed process will deliver IGCC's environmental benefits utilizing lower rank coals from Wyoming, Colorado, Montana, Utah, and South and North Dakota, while capturing the 30 percent reduction in water consumption.

Beyond the fact that NGCC and IGCC have less intensive water consumption, continued advancements in gas turbine technology to achieve greater fuel efficiency will also reduce water consumption per megawatt of power produced.

The following sections discuss the challenges and research being performed to enable cost-effective water reuse and improved gas turbine efficiency.

Water Reuse Challenges

Throughout the cycle of power generation, significant quantities of waters are used in boilers, cooling towers, and gas fuel and emission treatments. Throughout this process the temperature, pH and contaminant levels of the water change significantly, bringing tremendous challenges to any water treatment scheme. The waters can contain a significant amount of oils, dissolved solids, minerals, and potentially ammonia, heavy metals and selenium. In order to reuse the waters in the process systems without damaging equipment, the waters must be cleaned to appropriate levels. This typically involves chemical treatments, water filtration, biological processes to purify the water, and often a thermal treatment to clean the waters. GE is investing in technologies throughout this cycle to make water treatment more cost-effective and robust, encouraging reuse and/or ecologically-friendly discharge. These treatments must be able to handle wide variability in water conditions, and be reliable and easily maintained.

During fuel preparation and emission cleaning, waters utilized undergo significant change in temperature and pH, and pick up contaminants that may include mercury, nitrates, salts, metal compounds, and selenium. Broad portfolios of technologies must be developed to allow customers to find the appropriate solution for their process in order to effectively reuse the water.

Water Reuse Technology

Technology used to treat water includes filtration products to remove particulate and organic matter, and membranes to remove dissolved minerals and organic matter that are present in essentially all natural water sources. State-of-the-art filtration products include hollow fiber microfiltration (MF) and ultrafiltration (UF) as well as spiral-wound nanofiltration (NF) and reverse osmosis (RO) membranes. In order to drive cost and energy efficiencies, investment in technology development will be required to meet future demands on water resources to meet growing needs in industrial and energy applications. In the near-term, significant focus is being applied to higher-flux membrane systems that will enable larger water production for each unit area of membrane. This will result in lower energy consumption per unit volume of water treated. The integration of advanced filtration systems for pretreatment for RO systems will further enable reductions in plant footprint, while simultaneously allowing for higher-throughput due to an improved ability to remove contaminants that are harmful to RO systems and currently require more conservative designs.

Water scarcity requires high-recovery of product water in the removal of dissolved minerals from stressed, saline aquifers, such as in the Southwest USA, or for water reuse applications. GE is developing advanced technologies in electrically-driven processes for the removal of dissolved ions from these water sources that will allow for recovery of greater than 85–90 percent of feed water as product water. Not only will these systems enable improved efficiencies in water-management, they will also accomplish this at significantly reduced energy consumption as compared to current electrically-driven systems. This is being accomplished through advances in power electronics and novel energy-conversion systems. Furthermore, integration of renewable energy sources and advanced energy recovery devices will further reduce environmental impact and overall cost of operation by significantly lowering energy requirements.

Anticipated increased water needs, coupled with projected shortages, require innovations that enable substantially higher efficacy in wastewater recovery and reuse. GE intends to address these needs through the development of high-efficiency membrane materials that will allow for throughputs that increase water-flux by a factor of 10+, and further reduce energy costs and system footprint requirements. These innovations will be achieved through advances in manufacturing technologies and processes, as well as materials of composition, including advances in nano-materials. A major barrier to continuous operation and maintenance of water flux is membrane surface fouling by organic matter and mineral deposits. These effectively blind the surface and prevent flow through the membranes, which also leads to increased energy consumption. Advances in nano-materials can increase membrane capabilities in fouling control and increased flux with reduced energy consumption for water produced. Through novel incorporation of nano-materials into a membrane matrix, it is anticipated that biological growth can be mitigated. It is also expected that significant increases in membrane surface areas can be achieved with no increase in device size. Specifically designed and tailored nano-materials that can prevent mineral deposits from forming could also be envisioned. There are currently joint industry/university research programs in this highly-specialized technical area in Europe and other parts of the world. It is imperative that these capabilities be developed here to ensure that the United States remains at the technical forefront of this vital high-technology industry.

Investments in the technologies and establishment of facilities to pilot new technologies will be needed to advance the state-of-the-art. The complexity of the waters and resulting complexity of the treatment systems will continue to be a barrier to broad adoption of water reuse. Joint government-industry-university initiatives will allow the power generation community to advance the knowledge of solution effectiveness, cost and reliability, allowing adoption to be more rapid and widespread.

Advanced Gas Turbine Technologies

As the world leader in industrial gas turbines, GE has always been at the forefront of technology advancement that improves gas turbine efficiency. As efficiency is improved, more output is achieved for the same fuel consumption and water usage. Therefore, improvements in gas turbine efficiency yield reduced water consumption per MW of power output. To improve gas turbine efficiency, GE conducts research in technologies such as aerodynamics, aeromechanics, compressor, high-temperature materials and coatings, heat transfer, combustion, controls, and manufacturing. In a current cost share program with the U.S. Department of Energy, GE is working on technology advancements for hydrogen fueled gas turbines that will be used when carbon capture is used on IGCC coal power plants.

Current NGCC power plants are capable of reaching up to 60 percent efficiency. That means 60 percent of the thermal energy contained in the fuel is converted to useful power output. Aggressive Gas Turbine technology advancement can lead to 62 percent efficiency and define future technologies needed to get to 65 percent efficiency. The efficiency gain would not just apply to future power plants, but many pieces of the new technologies could be retrofitted into the existing gas turbine power generation fleet. General Electric's E and F class turbines are two of the backbones of the installed U.S. fleet, with about 450 E class and 560 F class units deployed throughout the country. A one-percentage point improvement in efficiency applied to GE's existing F Class fleet would result in CO_2 emissions reductions of 4.4 million tons per year while providing savings of more than a billion dollars per year in fuel costs.

Today, GE Energy is making significant investments to advance technology and develop new products and capabilities. Over the last three years, GE Energy has invested over $1 billion into gas turbine products and technology. However, much more is needed to develop the new technologies to reach the game changing level of 62 percent efficiency. There is a distinct role for government, specifically the Department of Energy, to partner with U.S. private industry to reduce the inherent risk in the research and development efforts required to reach such an aggressive target. Besides the national benefits that will be realized for the U.S. in terms of water usage and emissions reductions, a public-private partnership on gas turbine efficiency will likewise have substantial economic and employment benefits, as well as benefits for our national competitiveness in the global market for new technologies. The fact that GE's foreign competitors receive funding from their governments poses a significant challenge to the United States' traditional preeminence and leadership in gas turbine technology development.

H.R. 3029, introduced by Representative Paul Tonko and referred to this Subcommittee, provides the basis for a future partnership between industry and government to make the next big leap in gas turbine efficiency. GE commends Rep. Tonko for his efforts, and also applauds the House of Representatives for including this proposal in the recently-passed *American Clean Energy and Security Act of 2009,* H.R. 2454. Because of the magnitude of the technological risks, a government-industry partnership is needed to address challenges inherent in moving the efficiency benchmark to 65 percent, in areas including development of high temperature materials, improvements in combustion technology, advanced controls, and high-performance compressor technology.

Highly skilled engineers located at GE's Global Research Center and GE Energy facilities in Schenectady, NY, Greenville, SC, Houston, TX, and Cincinnati, OH will remain at the forefront of GE's efforts to advance gas turbine technology. GE Energy has had an outstanding collaboration with the U.S. DOE Fossil Energy team, including the National Energy Technology Laboratory. Our recommendation in the area of gas turbine technology is that the DOE, in addition to its current coal/IGCC gas turbine focus, be authorized and funded to also pursue advances in natural gas fueled gas turbine technologies.

The remainder of the testimony will focus on specific technologies identified by the Committee as areas of interest.

Production of Clean Water—Desalination

Desalination refers to any process that removes excess salt and minerals from water. Water desalination and its integration with power plants is an economically attractive approach to improving overall system efficiency. There are, in general, two approaches to desalination—Reverse Osmosis (RO) and Multi-effect Distillation (MED). Both processes can utilize waste heat from power plants to operate more efficiently in producing clean water.

GE is taking leadership role in integrating desalination with power generation equipment. GE is working with external partners to promote use of gas turbines for use in desalination applications for both MED and RO processes. For example, GE's LMS100 aeroderivative gas turbine has heat rejection that can be ideally integrated with a desalination process to produce clean water as well as power. GE's Global Research Center has also developed low cost approaches to desalination that can be utilized in next-generation desalination applications.

The main short-term technical challenges are in optimizing the overall system efficiency to produce power and water at the lowest cost. The MED process requires significant heat input, and proper integration with gas turbines can mean substantial savings in total power usage.

GE would support research in system integration of desalination and power generation processes and development of the next generation technologies required to achieve this integration at low cost.

Organic Rankine Cycle—Power From Waste Heat Without Water Usage

Organic rankine cycle technology utilizes an organic solvent as a working fluid in a rankine thermodynamic cycle to extract power from low-grade waste heat. This is similar to a steam cycle, but can recover lower grade heat since the organic solvent has a lower boiling point. There are several organic rankine cycle applications for heat recovery in geothermal and gas turbine applications. The key advantage is that it is a closed cycle, and it does not utilize water.

GE is working with external industry leaders in evaluating this technology for gas turbine applications. Internally, GE is trying to develop next-generation organic rankine cycle technology that can be more efficient and also less expensive. This technology is already being used in the Oil and Gas industry for power generation in pipeline applications. For simple cycle gas turbines used in peaking applications, this technology can potentially recover heat to produce electricity without using incremental water.

The key technology hurdle is reducing the capital cost of the equipment. Currently, the capital cost is 20–30 percent higher than a steam cycle. Current technology utilizes one fluid to recover waste heat from gas turbines and a second fluid to serve as the working fluid. Future systems may utilize a single organic solvent to recover waste heat and serve directly as the working fluid. Technology also needs to be demonstrated in a bigger scale for gas turbine applications.

Use of GE Jenbacher Gas Engines In Wastewater Treatment Systems

The process of treating municipal and industrial wastewaters from homes and facilities across the United States is a tremendous undertaking, involving complex operations and processes to treat flows and return treated water to the environment. During these processes, chemical and biological constituents are removed and separated from wastewater, producing treated effluent that often is cleaner than the bodies of water into which it is discharged. The removed constituents, energy-rich biosolids, are then subsequently treated, in some cases anaerobically (without oxygen) to be used in various manners. The by-product is a methane-rich biogas that can be used to produce electricity and heat.

There are over 16,000 municipal wastewater treatment plants (WWTPs) in the United States, and approximately 540 of these plants anaerobically treat their biosolids.[10] The biogas produced by this treatment process is most often flared at the facility. The United States Environmental Protection Agency published a report in April 2007 that stated that less than 20 percent of the facilities with anaerobic digestion used their biogas for electricity or heat production.[11] The USEPA estimated that if each of these plants were to convert the biogas to electricity, it would produce 340 MW of renewable energy and remove 2.3 million metric tons of carbon dioxide—the equivalent of emissions from 430,000 automobiles—from the atmosphere.[12]

General Electric's Jenbacher gas reciprocating engines provide an effective solution for wastewater professionals looking to optimize efficiency through the production of renewable energy. With more than 50 years' experience, GE Jenbacher has an extensive installed base of over 460 units running at WWTPs, primarily in Europe where this technology application has been used for years. The GE Jenbacher gas engine product portfolio includes a wide variety of engine sizes ranging from an electrical production of 0.33 MW to 2.70 MW on anaerobic, digester gases. Additionally, the GE Jenbacher gas engines present some of highest electrical and thermal efficiencies along with lowest emissions available. Combined with the use of waste heat from the engines, the total electrical and thermal efficiencies from GE Jenbacher gas engines can exceed 85 percent.

Depending on a wastewater treatment plant's processes and operations, the conversion of biogas to electricity and heat can amount to a reduction of 30 percent—70 percent of a plant's energy costs—the second leading cost (after personnel) facing wastewater treatment operators today. By way of example, the Strass Plant in Austria, located approximately four miles from the GE Jenbacher factory, is the shining star for energy efficiency at WWTPs—currently producing 120 percent of the energy demand at the plant. The Strass Plant produces electricity to power all of its processes, and returns 20 percent of its demand to the grid from electricity produced by one GE Jenbacher J208 engine.

As this technology continues to gain interest in the United States, GE Jenbacher gas engines will continue to be a leader in technology and research improvements. Future research will be dedicated to increasing electrical efficiencies, improving engine heat rates, and reducing emissions, such as Nitrogen Oxides (NO_X) and CO_2. A commitment to these endeavors will allow wastewater professionals to continue to protect their citizens by focusing on meeting their wastewater treatment requirements while saving millions of dollars on energy costs.

Conclusion

In summary, Mr. Chairman, the nexus between power generation and water usage is one of the world's most complex and critical public policy challenges. GE commends you and your colleagues for your leadership in exploring the issues, and for your particular emphasis on the role of technology solutions. GE is proud of its work in this area, and we believe that the Congress and this committee can do a great deal to promote progress by bringing focus and facilitating partnerships between the U.S. DOE and the private sector. Our specific recommendations are:

- Greater investments in water reuse technologies and establishment of facilities to pilot new technologies to advance the state-of-the-art in membrane capabilities.
- Additional research, development and demonstration of high efficiency natural gas turbine technology, as envisioned in H.R. 3029.

[10] United States Environmental Protection Agency Combined Heat and Power Partnership, "Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities" at page 1 (April 2007). This report is available at: *http://www.epa.gov/CHP/documents/wwtf_opportunities.pdf*

[11] *Id.*

[12] *Id.* at pages 7–8.

- Increased research in system integration of desalination and power generation processes and development of the next generation technologies required to achieve this integration at low cost.
- Additional research on and larger scale integration and demonstration of organic rankine cycle technology for gas turbine applications.

Thank you, and I look forward to your questions.

BIOGRAPHY FOR RICHARD L. STANLEY

A graduate of the University of Notre Dame with a Bachelor's degree in Mechanical Engineering, Rick joined GE Aircraft Engines in 1980. With GE, he pursued his Masters Degree in Aerospace Engineering from the University of Cincinnati and is a graduate of GE's Advanced Engineering Program. During his career, he has held numerous assignments in turbomachinery blade, rotor, structures and combustion design and systems engineering. He has participated on many GE Aviation product designs, including the F110, F120, CF34, CF6, GE90, GEnx, T700, and F404 aircraft engines.

Increasingly responsible roles include Engineering Manager for the Structures Center of Excellence, General Manager for the Combustion & Configuration Center of Excellence, General Manager for Engine Systems Design and Integration Department, and General Manager of the CF6 Project Department. In 2003, Rick was elected a corporate officer of the General Electric company and promoted to Vice President and General Manager of the Aviation Engineering Division.

In November 2005, Rick was appointed Vice President and General Manager of the Engineering Division for GE Energy, with responsibilities for research, development, technology and product design activities spanning the Power Generation Gas Turbine, Steam Turbine, Gasification, Controls, Generator, Wind, Aeroderivatives, Nuclear, Solar and Services segments.

He has been awarded five patents, is an Associate Fellow of the AIAA, and is a member of the ASME. He is the 2005 recipient of the Distinguished Alumni Engineering award from the University of Notre Dame.

DISCUSSION

Chairman BAIRD. Thank you, Mr. Stanley. Here is our situation. This is a motion to adjourn. We have seven minutes left to go, and out of respect for the witnesses, I am going to stay here and miss this vote. I will suffer the consequences of missing a motion to adjourn vote, but I recognize my colleagues may wish to make this vote if they want. My understanding is the next vote will likely be a 15-minute vote, so my choice here by sticking, I get 20 minutes with the witnesses. Now Mr. Inglis is going to go do this. With his consent, we will just continue the hearing. If my colleagues want to go, that is fine. We will then reconvene after this series. So when I finally have to go to the first vote, we will reconvene after this here. So we have about 15 minutes or so at least to have a discussion. Again, it is up to each individual Member whether they want to head for this vote or not.

I want to thank Mr. Stanley for acknowledging Mr. Tonko's excellent work on the legislation referred to, and we are thrilled that it was included in the energy bill. His long and distinguished background in energy has served this committee and this country well. Mr. Luján, thank you for your presence as well.

So Members are free. We have six minutes to go if you feel you want to make the vote. I will see you over there. But I will proceed with questioning at this point.

THE EFFECTS OF POPULATION GROWTH

Again, thanks to all the witnesses for your outstanding comments. Let me introduce another variable that hasn't I don't think been mentioned to a great degree, and I am very curious about it. If memory serves me correctly, the recent census data suggests that the population growth in the next 40 years, U.S. population growth, is projected at around 139 million. That is an enormous addition in terms of demand on every portion of our infrastructure. And yet, I almost never hear it factored into energy, and in this case energy-water calculations, and it seems to me that the combination of just consumption for housing, for hydration, for irrigation and then in this point here, the nexus between energy and water, to what extent is this projected population growth being factored into our energy projections and/or our energy-water consumption projections and availability projections?

Dr. HANNEGAN. Mr. Chairman, thanks for that question. It is really at the heart of the challenge when we look at water sustainability. One of my comments in my testimony was that at a fundamental level, in addition to the amount of water use by the population themselves, there is water use by the energy production that's demanded, in the base line that EIA puts forth, they project an increase in generation. That has to be met by an increasingly cleaner mix of resources. Many of those, including central station solar, nuclear, coal with carbon capture and storage, biofuels, both for transport and power, we are talking about some fairly thirsty applications. And so I think one of the challenges to the power sector is we recognize that people need water. We recognize that agriculture and food production needs water. Power generation tends to come at the end of the line. And so it really places an imperative on the need to get advanced cooling and waterless cooling technologies right for cooling power plants, and I think that adds urgency to this issue and the need to get the research and development going at a much faster rate than it is today.

Chairman BAIRD. Would it be fair to also suggest that the increase in human direct demand, and indirect through agriculture for water, would produce an additional incentive for less water-intensive energy generation?

Dr. HANNEGAN. Absolutely. I think if you look at what is going on in the Colorado River Basin out in the Southwest, you see that happening today. We saw that in the Southeast during the difficulty, the droughts in 2006, and we see it anywhere in the world that water resources are placed under pressure. It is generally the energy production that has to adjust. If you look at the power plants in South Africa where water is at a premium, nearly all of them operated by Eskom operate on dry cooling technologies but at a much higher cost, and that obviously impacts job creation, economic development and availability of power for people to live their lives.

Chairman BAIRD. Any other person wishing to comment on that line of questioning?

Mr. MURPHY. Well, yes, I just would—you know, not only do you have that, but it is exacerbated by the fact that you do have some of the old facilities. So you have this double thing going on. But I think it is also a great opportunity that you can replace the coal plants and do this build-up as this country moves forward. The technologies are there as, you know, everyone talked about. There are improvements that can be made, but we can put together sensible systems and approach this thing.

You know, up until now people haven't put that water equation really into the power plants, and it is great that the Committee is putting some light on that and that if we really start thinking about that, we can design power facilities with, like I said, hybrid-type cooling. And it is a cost issue. It is not really as much really a technical issue as it is, how do new facilities get permitted and how does that additional cost as a power developer, how does that get factored into saying, okay, you know, that has to go to the rate payer?

CONSIDERATION OF WATER IN ENERGY LEGISLATION

Chairman BAIRD. As you know, we passed through the House the major energy bill right before the July 4 recess focused predominantly on carbon. There is obviously offered by your testimony today to the degree that the new energy bill incentivizes renewables, wind, photovoltaic, and others, the water demand may be somewhat lessened naturally versus, say, a thermal-based coal plant. Would we have been wiser or would we be wise as we move through the conference and the work with the Senate to add some factor, a greater discussion of water consumption? I don't know how we would do it, but I just put this out there as a thought question. What would that look like if we did that?

Dr. JOHNSON. Mr. Chairman, if I might comment.

Chairman BAIRD. Please, Dr. Johnson.

Dr. JOHNSON. First of all, I think it is an excellent point you raise, and I think globally if you look at where the population of the world is going by the mid-century, it is supposed to be up to I think around nine billion, which I think will place a tremendous pressure on these resources. Plus if we don't do something, which we are taking the first step with the bill in terms of carbon emissions, that is going to impact the climate change tremendously as well. I think in your second question, thinking about how we might do that, some of the recent appliance standards with regard to dishwashers and washing machines have both energy and water usage in them, and I think that is important.

I think the biggest thing is figuring out how we can change behavior in terms of capturing the waste, the amount of water that we use, you know, from toilets to running faucets with toothbrushes. It is a significant amount of water that we waste and a significant amount of lighting and electricity that we waste that is not needed. And I think that that is the low-hanging fruit that we have to figure out a way to get after. And I think standards, building standards, that affect energy use as well as water use are important, and we are moving in that direction trying to establish these standards. But that would be very helpful to have policies in that direction.

Chairman BAIRD. Thank you.

Dr. HANNEGAN. Mr. Chairman, related to that, there is an awful lot of inefficiency with water use in today's existing plants as my colleague, Mr. Murphy, has put forward. A lot of these existing plants are also going to be looking at new pollution controls to meet more stringent air quality standards. If there are changes in the way that we are dealing with coal combustion products as a result of recent incidents, that also is going to be an opportunity to modify those facilities. These facilities are going to have a number of different things that are going to be happening concurrently, we hope, but maybe separately and on different time scales. It is worth thinking about how do we treat those existing units as we move from where we are today to the low-carbon future we all want to get to in the future and whether there is an opportunity to look at sort of an integrated redo of some of these existing units. We are looking at bringing concentrated solar right onto an existing facility as a way of kind of hybridizing that power plant. Well, while you are making that modification, you might want to do something to improve your water use efficiency. And there are technologies that are on the shelf today that we can do and there are tests of technologies that are right at the cusp of being commercializable that we can do as well.

So I think you have an opportunity. I know Senator Bingaman and the Energy Committee staff on the Senate side have energy and water-related provisions in the bills that they have been working on, and so there may be an opportunity when you ideally get to conference to have a good conversation about how you put it all together.

Ms. MITTAL. Mr. Chairman, our work on biofuels and electricity basically tells us that there are three trade-offs that you are making. This is a three-dimensional equation. You have got energy trade-offs, you have got water trade-offs, and you have got carbon trade-offs. And the choices that you make, you are either going to be positive on one, negative on another. There is no perfect equation because in each choice that you make, you are either positive on one front and negative on another. So these are the types of things that our work is showing, and that you do have to factor water in.

One of the things that we are looking at in our thermoelectric work is that states that have primary responsibility for siting power plants are starting to take a harder look at their water impacts, especially in those states where there are long-term water shortages, where they are dealing with water constraints. Whereas other states where they have not had a history of water shortages, they don't have the more detailed processes to look at the water impacts of power plants. So it is again, as water supplies become more constrained, we think people are going to become more aware of how important it is to look at these three aspects.

Chairman BAIRD. Excellent point.

Mr. STANLEY. Let me just say one last comment on that. I think at the highest level, having a national water reuse initiative would be something worth considering. Other countries have done this. I believe Israel has a 70 percent goal for water reuse. Singapore just passed an initiative for 30 percent as their goal for water reuse. Having a national goal for water reuse at whatever level it is—I think we are at six percent today as a country—would drive more technology toward water reuse, that would accelerate technology, I think, into water reuse and a study of how we do waste water and how we can bring some of that back. I do think it is a worthy discussion and a worthy goal that ought to be addressed.

CLIMATE CHANGE IMPACTS

Chairman BAIRD. I appreciate that. There is this relationship between what I refer to lethal overheating of the planet—I have said many times in this committee that global warming sounds like a nice thing and lethal overheating sounds like a bad thing, and acidification of our oceans, as Dr. Johnson said, is also a bad thing, especially when one considers that the oceans provide 50 percent of our oxygen. Lest anybody think this climate change thing is insignificant, ask yourself how you would like to do without 50 percent of your oxygen, and it is not a good thing. But one of the impacts is clearly availability of water. As we see, and we moved through this committee legislation to establish a National Climate Service, the idea being we would use our best available knowledge to try to make predictions about climatic events and how they would impact various aspects of our lives and our economy. And it seems that energy, particularly in light of this hearing, is critically impacted by that. You, in your testimony, several of you offered images where water levels in lakes or rivers, et cetera, had declined, and hence, the available energy production which is water dependent also declined. How is that being factored in as we look at—you know, we are trying to reduce those impacts, but how is that being factored in?

I tell you what. I am going to ask you to hold that question, and I am going to recognize my colleague. Mr. Luján has returned from the vote. I am grateful that he did, and so please hold my question and I will recognize Mr. Luján for five minutes. Thank you.

Mr. LUJÁN. Mr. Chairman, thank you very much. We can see the efficiency of being able to move back and forth quickly and sometimes the benefits that it pays.

I can't thank you enough, Mr. Chairman, for holding this hearing. Coming from New Mexico and understanding the importance of being able to support a generation thinking outside of the box and looking to how we can embrace innovation as we move forward in each of these areas, especially the importance of water in the part of the country that I represent and what we can do to help accelerate this.

FUNDING PUBLIC-PRIVATE PARTNERSHIPS

One question that I have, Dr. Johnson, is having had a chance to visit with Secretary Chu and understanding the importance of moving forward Centers of Excellence and really embracing the technology, the breakthroughs that are taking place at our National Laboratories, the collaboration that is taking place at Sandia National Laboratories already, some of the explorations taking place up in Los Alamos, whether we are looking to see what we can do to be able to recycle water through exploration for oil and gas, some of the breakthroughs associated with storage and to truly understand what Mr. Murphy has done with storage capabilities and how that can break through, but you can tell me, Dr. Johnson, is there any thoughts as to how we can move forward without the existing requirements of the private match? You know, there is a 20 percent match that is required from the public-private partnership to support the laboratory's research in many of these areas. Understanding that these breakthroughs will be game-changing for everyone, is there any thought to how we may be able to use that program or modify it so that we can encourage some of the partnerships in the event that we don't have that, the ability for some of those collaborations?

Dr. JOHNSON. Thank you very much for the question. First of all, I firmly believe that these problems are so complex that we need to bring together the best and the brightest from the labs, from the private sector, from the universities, and to that end, we need to encourage them as much as possible. The work going on in the labs is not subject to the 20 percent match. The universities would be and industry would be as well. So it is not an issue for the labs, per se, but in terms of bringing together these teams and partners, sometimes it can be an issue, and we will be looking at what is appropriate to encourage these kind of relationships as we move forward.

One of the ways that we are trying to bring together all the best and brightest in one place to address these very complicated issues are through the energy innovation hubs that have been proposed, and I think that will certainly help move some of these issues forward to be solved because it is critically important we get industry, the universities, the labs together to try and solve these critical issues, whether it is, you know, fuels from sunlight or solar electricity or batteries in storage. All the things that are related to how we use energy and how we use water for the betterment of society. So I am pleased that we will be hopefully moving forward with some of those initiatives as well.

INCREASING EFFICIENCY

Mr. LUJÁN. Thank you, Dr. Johnson. And Mr. Murphy, Mr. Stanley, in the area with what you have been able to see and prove from every increase of percentage in energy efficiency and even the importance of storage, your thoughts on how we can accelerate. Going back to 2007, some of the legislation and acts that were moved forward by the Congress to encourage more storage exploration and how that will decrease the amount of water that is needed to be able to move to the energy that is being stored to make sure that it is fully dispatchable and the impact on energy as a whole in those areas.

Mr. MURPHY. Yes, that is a great point. I mean, when you look at the real demand, as we move forward, if we can get the power plants to be much more coincident with the demand. And so what you're looking at with some of the power plants on base load, particularly for example on a coal plant, it might be running all night long and using these valuable resources, and there may not be a demand that is necessarily justifying that.

So the idea of having storage—there was a discussion about, you know, you have to trade water versus carbon dioxide versus energy—I think you can get all three and I think there are systems out there that exist today that we can achieve reductions in all of those, but it comes at a price. So that is the other dimension that, you know, happens.

But you know, the reality is, you know, you pay for it now or you pay for it later. There is really not—it is just something that we have to move forward with.

Mr. STANLEY. I will add to that from a standpoint of the machinery itself, having the machinery operate more efficiently at part load, like nighttime. as opposed to being optimized at full load and then not optimized at part load, is a big technology as we move forward. Having optimized at part load, even in these areas that need electricity but they don't need it at nighttime, where storage is one option. Another option is also just reduce the amount of fuel that is required for these part-load periods during the day when a gas turbine, for example, still can be run but run very efficiently. Right now in some of the older technologies in our fleet of turbines that are out there, they are not very efficient during nighttime. They weren't designed that way. They were designed to run at full speed, full load during the day at peak load. And some of the new technologies which are actually being translated from the aviation world down into land-based gas turbines actually address those issues including the different temperatures during the day. A hot day is very hard on the efficiency of a turbine versus a cold day.

So just looking at the design of the machinery itself and advancing that technology can have a big impact on reducing fuel and water use on these systems, even in these areas that have very low water areas to begin with.

Mr. LUJÁN. Thank you very much, Mr. Chairman. I know my time is expired, and Dr. Hannegan, if you have an opportunity, if you can respond to that later, whether it is through questions today or in writing, I would be very interested to hear your thoughts on that a little.

Thank you, Mr. Chairman.

Chairman BAIRD. Thank you, Mr. Luján.

Dr. HANNEGAN. I would be happy to do that.

Chairman BAIRD. Mr. Inglis is recognized for five minutes.

WATER AND NUCLEAR POWER

Mr. INGLIS. Thank you, Mr. Chairman. It is my understanding that nuclear power I believe is a wonderful way to make electricity, but it also has a trade-off, not just the waste but also uses a lot of water as I understand it. Some talk—I think I have heard this—of using it in combination with desalinization, is that a matter of heating up the wastewater and using that? Have you all been working on that, Mr. Stanley, or is that——

Mr. STANLEY. We are doing some research on that. It is usually in the waste heat of it. You can do it on a nuclear plant or even a gas turbine plant. But it is using the waste heat, the leftover heat, to basically evaporate the water if you will, leaving behind the solids in the waste water but evaporating the water and recovering, reusing the water in the cycle. So as opposed to taking it into the plant, using it and then discharging it away from the plant, it is a way to use the water in what we call a closed circuit so that we are not taking as much water from the stream but keeping it inside the plant.

Many nuclear plants today use water. If they use it in a closed system, they lose a lot of it to evaporation during the evaporation process. And so they do consume a lot of water, a heavy amount of water, and this would help reduce that consumption.

Mr. INGLIS. Yes. I guess of course it is not really consumed, it is just moved from one state to another and then dropped somewhere else, right? But I guess it does have a local impact in that you are withdrawing a fair amount of water out of a stream. It will fall somewhere else, but the question is how far away, right?

Mr. STANLEY. That is correct.

Mr. INGLIS. So is it something that you would put on a list of real, feasible things about using seawater basically in that process? We have got a lot more of that than we do fresh water. We got a lot of population close to the shoreline in the United States. Does that make that attractive or is that questionable?

Mr. STANLEY. I think it is. No, I do believe it is possible. It is still early in the stage of system integration and simply cost, and the trick is getting the cost down to do that and the cost of the systems it takes to use that type of water, clean it and return it.

Mr. INGLIS. Does anybody else want to comment on that?

Dr. HANNEGAN. Yes. Congressman, a number of nuclear plants, particularly those in California, my home state, do intake sea water as a method of cooling their activities. The challenge associated with that is the impact on marine organisms, on fish larvae and other species of concern, and one of the things that we are working on at EPRI are protective measures and alternative ways of getting the water into the plant that don't have as much impact on the marine environment. That is a big concern for EPA currently in the rule-making around the Phase II rule, the 316(b) provisions, and the *Clean Water Act*. We have done a lot of work looking at screens and intake mechanisms and different conduits to get the water into the plant.

So that is one thing to keep in mind when you are thinking about seawater as an intake. Particularly in the coastal zone, it has the potential for some significant impacts.

Mr. INGLIS. If you take in a very large amount of water, I guess you don't raise the temperature as much. Is that another strategy is to cycle through a great deal of water and then——

Dr. HANNEGAN. Yeah, that is—in fact, where nuclear plants take in a considerable amount of seawater, that is the goal, to reuse and recycle within that plant through a number of different cooling cycles. Each of course is progressively less efficient because of the difference in the temperatures. You can't extract as much heat each time through as the water gradually warms and warms and warms, and then you exhaust it to a cooling pond, if you will, where the water can then equilibrate with the atmosphere before being discharged back in the ocean. Section 316(a) of the *Clean Water Act* actually puts limits on the thermal differences in the water that you discharge back into the environment, whether it is a lake or an ocean body. Having thermal shock can be just as impactful on organisms as the physical shock of going through the system. So we have to work on getting as much cooling value out of that water but ultimately discharging it back into the environment in largely the same state in which we took it. And it is a matter of cost. In many cases, it is a matter of performance of the unit. As you use more and more of the water, you leave behind more and more of the stuff that was in the water, and so it can cause scaling and fouling and different impacts on the plant itself which are an issue of operations and maintenance.

There are no easy solutions, sadly. Otherwise, we may not be having this hearing.

Mr. INGLIS. Thank you, Mr. Chairman.

Chairman BAIRD. Thank you, Mr. Inglis. Mr. Luján had a question he wanted to follow up on. I'll recognize him for the opportunity to do so.

MORE ON EFFICIENCY PRACTICES

Mr. LUJÁN. Dr. Hannegan, along the same lines of the question to Mr. Murphy and Mr. Stanley?

Dr. HANNEGAN. If you could just recapture that for me?

Mr. LUJÁN. Some of the benefits associated with the efficiency practices and I guess in your instance, the efficiency practices that invest your own utilities or generation or transmission companies are adopting, and even with how firm the utility commissions around the country are being with adopting those practices and to future generation and the possible benefit associated with utilities moving forward with more efficient approaches with consumption of water as they are generating power.

Dr. HANNEGAN. Right. Thank you, Congressman. That is a very important issue for siting a new generation of plant. You hear it coming up more and more with utility commissions and even local communities. When you look at new generation in your back yard, one of the impacts in addition to the myriad others that are of concern is the water consumption and where is that going to come from. I think this is an opportunity for looking at co-benefits. As I mentioned, these plants are also looking at a bunch of other different obligations in terms of their environmental footprint, and there are a number of technologies that can be employed in a new plant which give you multiple benefits: reducing air pollution, improving the efficiency of the thermal plant as far as greenhouse gas emissions is concerned, and then water consumption as well. Even as I mentioned before, if you've got a fossil unit with CO_2 capture and storage or if you have got nearby oil and gas operations that are creating produced waters, there is the possibility for new technologies to be involved there. Through some of the work that Mr. Stanley is working on with desalinization, it would be quite possible to use those produced waters or to use degraded sewage from the nearby community. The Palo Verde Nuclear Power Plant in Arizona does just that. It runs entirely off of the treated sewage waters coming from the nearby communities.

So I think there are a lot of opportunities. Sometimes the challenge though is the utility commissions, as Mr. Murphy indicated, look at it strictly through the lens of lowest-cost power, and they are not looking perhaps at the whole lifecycle cost when you think about the impacts and the overall impact both economically and environmentally.

Mr. LUJÁN. Thank you very much, Dr. Hannegan. Thank you, Mr. Chairman. I yield back my time.

Chairman BAIRD. Excellent line of questioning. Thank you very much.

WATER IN COAL CARBON SEQUESTRATION

My understanding is Mr. Tonko, we hope, is returning. We have got yet another vote call, but what I will do is ask a brief question on coal carbon sequestration. Hopefully Mr. Tonko will return, and then we will actually probably adjourn the hearing because there is a long series of votes and rather than making you folks wait that unpredictable amount of time.

With that, talk to us a little bit about what the likely water demands would be if we had widespread coal carbon sequestration, and help us understand the distinction between use and loss of water in that process.

Dr. HANNEGAN. I will take that one, Mr. Chairman. The likely impact, if you add in CO_2 capture technologies on today's power plants, you are looking at about a 30 percent reduction in both the power production and the thermal efficiency of that unit. And so as a result, you have to combust more coal or more natural gas to create the same amount of power output. That means you are pushing more heat overall through the system which results in a greater use of water for cooling. When you then talk about the compression, the clean-up of the gas on the back end, all of the other things that you have to do to get the CO_2 that has been captured ready for pipeline-quality specifications for transport and ultimately, you know, the kinds of specifications we are looking at in the underground injection program for disposal in the geologic reservoir, you are looking at about a doubling of current water use throughout that process. Now, much of that water goes through the normal cooling cycle, so it is ultimately recoverable. And if you are condensing out the evaporated water and reusing that in the plant, the consumption doesn't go up nearly as much. It is not a one-to-one relationship. But certainly the widespread adoption of CO_2 capture and storage, which we think is a key part of any climate mitigation program, is going to lead to increased demands by the electric sector for water in the decades ahead. Some of that can be mitigated through the new technologies that we have been talking about, but there again, it is the matter of getting those cooling technologies integrated with the new technologies we are employing for pollution control, the new technologies we are employing on the turbines themselves and the balance of the plant. I mean, we have a lot of things that work separately, but it is really the integration challenge that I think would be a center pole tent to any aggressive research program going forward.

We have outlined in EPRI documents, which I am happy to provide for the record,[1] you know, a fairly modest, if you look at other research activities going on presently throughout the Federal Government, a fairly modest $40 million that would get us started on those things, and we think that that would be a good investment.

[1] See Dr. Hannegan's submission for the record, the EPRI report program on technology innovation: *An Energy/Water Sustainability Research Program for the Electric Power Industry* [*Appendix 2: Additional Material for the Record*].

Chairman BAIRD. I will personally look into that given the importance of the issue before us today and the relative amount of $40 million versus NextGen costs.

My own personal belief is that we have staked a tremendous amount of our wager on first of all biomass in the area of ethanol which has huge, to my knowledge of the issue and it sounds like the GAO report confirms that, huge water consumption issues to grow the crops. And given the graph we saw earlier of the amount of water that goes through irrigation, that is not going to be reduced if we put ethanol from corn base with switchgrass as the Secretary mentioned. But I also think we have staked an awful lot on coal carbon sequestration, I personally think too much, and I will point for the record that we had testimony in our committee suggesting that likely commercial feasibility was not going to happen for 25 years and that a much more optimistic scenario is banked on as a predicate for the energy bill we passed. And I have really quite a bit of concern about that. And then when you add this water notion, 50 percent increase? Did I get that?

Dr. HANNEGAN. Well, in some cases. There is a chart in my written testimony that is a result of some work that we have done with the National Energy Technology Lab. In some cases, particularly for an ultra super-critical pulverized coal plant, it is almost a doubling.

Chairman BAIRD. I will be certain to look at that. I will ask the staff to make sure I get that. Mr. Inglis had a question.

PRICING CARBON

Mr. INGLIS. Thank you, Mr. Chairman. Mr. Stanley, GE was in favor of the cap-and-trade bill as I understand it, and of course, it may have the advantage of changing the economics, some of the economics, around. That is my hope. If it doesn't make it through the Senate, I hope we can talk about an alternative which is a revenue-neutral tax swap. It can be done in 15 pages, whereas this one is 1,200 pages. But in both cases, what we are attempting to do I suppose is attach a price to carbon because what I am gathering is you have got a lot of products that you could sell but the economics don't work because if you can belch and burn for free, why pay for the more sophisticated machinery, right? So IGCC, for example, why pay for that if you can get a freebie in the air and there is no accountability for the emissions, then belch and burn. I guess that is more of a statement than a question. It will give you an opportunity though to say that, yeah, we have got products that we can sell if the economics work, but you have got to attach a price to carbon in order to make the economics work. And that is a conservative concept it seems to me because what you are saying is no, we are not going to allow people to have a free good in the air that causes a market distortion. If you insist on accountability and say, listen, be accountable, this is a conservative concept. Then what you have is the economics change, and we sell a lot of product I think from Greenville which would be exciting.

Mr. STANLEY. We do, Congressman, and you are right. The theory I think that you are talking about is buying carbon, much as you have to buy fuel if you have a power plant that produces electricity. And if that becomes the case, whether it is a carbon cap or other means, if there is a value with producing carbon dioxide that we want to reduce, we have a broad range of products that make that a better situation, economic situation. IGCC, certainly one of those, it is a way to use our vast resources of coal and still be able to use that resource in a less water-intensive way and less CO_2-producing way than a pulverized coal plant, which as you say produces quite a bit of carbon dioxide. Gas turbine and gas turbine technology, for sure. Wind turbines, absolutely. Solar, and the next generation of solar which we haven't talked about today, but thin film solar which is coming and will be as my belief as pervasive as flat-panel TVs that you see today in the store, is coming. That technology is coming, and again, as the costs come down with scale, that will be affordable, and carbon policy will drive that even more rapidly. So we are absolutely in favor of some type of value for carbon.

Mr. INGLIS. That is great. Thank you. Thank you, Mr. Chairman.

Chairman BAIRD. I thank Mr. Inglis. We are down to about 5:48, but Mr. Tonko has got such an interest in this, I want to recognize him for some final questions if we can.

GREATEST IMPACT TECHNOLOGIES

Mr. TONKO. Thank you, Mr. Chair, and thank you to the panelists. Your information is of great assistance to us as we go forward with sound policy, and thank you, Mr. Stanley, for your kind comments.

My question to you is, Mr. Stanley, of the energy technologies that you are ready to utilize, embrace, if the funding comes the way of GE. Are there ripple effects that you can imagine in those technologies that will come even beyond those first plans that you have for efficiency with the natural gas turbines?

Mr. STANLEY. There are ripple effects in many of the technologies. There are effects if we advance for example gas turbine technology. There are improvements that cannot only and not only will help land-based gas turbines but will also help aerospace turbines which use a lot of turbines and increase fuel efficiency.

As we develop new materials, such as carbon matrix composites, a new material that we can use in the turbines, as was mentioned earlier today, turbines become more efficient the hotter that they operate. So the hotter that we can operate the turbine in temperature, the more efficient it becomes. Now, I will give you an example. Today's turbines, the metal inside the turbine bucket of a current generation turbine operates in an exhaust gas that is 500 degrees hotter than the melting point of the metal itself. So heat-transfer technology is vitally important just to make today's turbines survive. We want to push that temperature even higher, 500, 600, 700 degrees higher than it is today. New materials like ceramic matrix composites will be the way there. Now, today they are very expensive, they are hard to make, they are hard to develop. We know very little about them, really. But if that technology succeeds, and it will, I fully believe that it will, that is not only good for land-based gas turbines, but it has direct application to aircraft turbines in aircraft around the world. Higher temperatures, better efficiency for aircraft as well as for land-based power plants.

Mr. TONKO. Thank you. So what I am hearing here is that this may be a down payment for a lot of lucrative investments that can be made for efficiency sake or for development of emerging technologies that can be applied to the broader turbine environment?

Mr. STANLEY. That is correct, Congressman. The many other ripple effects will help the United States to maintain our leadership in high-temperature gas turbine design and aircraft turbine design. Jobs that are created at GE—we have an estimate, every job that we create in gas turbine technology manufacturing leads to five more jobs in our suppliers and contract engineering and other places in the economy. So it is a very powerful ripple effect, not just economically but also with jobs and——

Mr. TONKO. Well, the energy self-sufficiency and job count is what is driving this great legislation, and I am just happy to hear the feedback from the industry and from those who will help lead us in this effort. So thank you so much. Thank you, Mr. Chair.

CLOSING

Chairman BAIRD. Thank you, Mr. Tonko. We have got two minutes to go. We are going to have to hurry. I want to thank our witnesses for outstanding input today. The record will remain open for two weeks for additional statements for the Members and for answers to any follow-up questions that the Subcommittee may ask of the witnesses. I thank you for your testimony and for your indulgence as we were interrupted by votes. I appreciate very much your expertise and insights. Thank you, and with that the hearing stands adjourned.

Mr. INGLIS. Thank you, Mr. Chairman.

[Whereupon, at 11:15 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

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ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Kristina M. Johnson, Under Secretary of Energy, U.S. Department of Energy

Question submitted by Chairman Brian Baird

Q1. One cane effect of global climate change is a declining level of fresh water availability. How is DOE addressing the anticipated impacts of an increasingly burdened water supply and the consequent challenges to energy production?

A1. Much of the current domestic energy resource development and production depends heavily on the availability of adequate water resources, and it will take a concerted effort to address the impacts of climate change on water quality and availability. Legislation in the last thirty years has limited the thermal discharges and other environmental impacts from power plants, which has already placed a premium on regulatory agencies mandating—and industry adopting—lower fresh water usage technologies for new generation capacity. Climate change and even decadal scale climate variability (e.g., El Niño and La Niña cycles, which bring periodic droughts to different areas of the United States) also place a premium on fresh water usage. DOE is assessing energy efficiency measures and the role of alternative energy technologies, such as wind and wave power, that require less water resources in order to augment the traditional sources of domestic energy supply that require more water-intensive development and production.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Bryan J. Hannegan, Vice President, Environment and Generation, The Electric Power Research Institute

Question submitted by Chairman Brian Baird

Q1. During our discussion on the water use of carbon capture and sequestration technologies, you referred to an EPRI $40 million research and development proposal to address the adoption and integration of new pollution control technologies with existing power plant cooling technologies. Please provide this information for the Committee record.

A1. In response to the Chairman's question for the record, please see EPRI's report outlining a $40 million, 10-year research program focused on reducing water consumption in thermoelectric power plants:

Electric Power Research Institute. "Program on Technology Innovation: An Energy/Water Sustainability Research Program for the Electric Power Industry," EPRI Report #1015371. Palo Alto, CA: July 2007.

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