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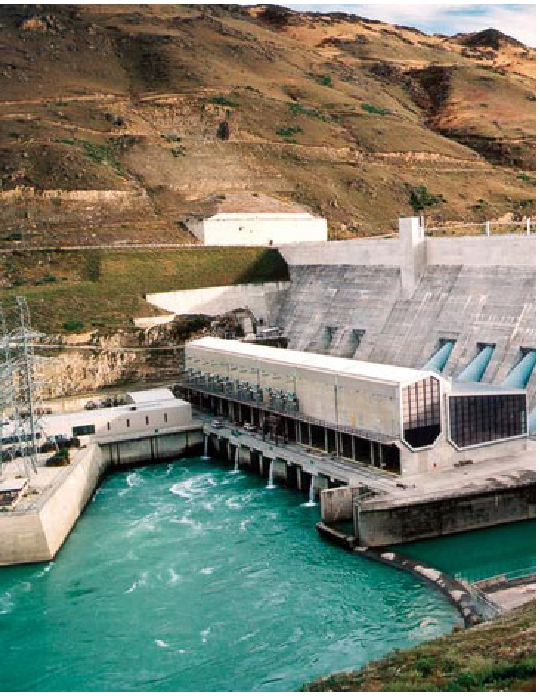

SUMMARY: WATER AND ENERGY WORKSHOP—UNDERSTANDING IMPACTS AND TRADE-OFFS TO FACILITATE TRANSITIONS

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"Summary: Water and Energy Workshop—Understanding Impacts and Trade-Offs to Facilitate Transitions"

Water and energy are intimately linked. Water is needed to extract, refine, and produce fossil energy resources and is a by-product of the oil and gas extraction process. Water is also important for electric power generation, where it is the primary source for hydropower and is sourced for steam and used for cooling in nuclear and other electricity generation processes. In turn, energy is consumed in extracting, treating, and transporting water. This complex relationship is referred to as the water-energy nexus. It is often also considered alongside questions of competing land use, agriculture, and food, which is the broader "water-energy-food nexus."

Population growth and rising income levels are increasing global demands for water and energy to the point that water access and availability concerns are affecting the energy industry. The challenges to a sustainable water-energy future presented by growing populations and expanding economies can become exacerbated when regions experience extreme climate conditions, such as drought, or when economic growth puts industrial activity and resource development in competition with local municipalities for water.

On May 14, 2015, the Center for Energy Studies (CES) at Rice University's Baker Institute for Public Policy and the Texas A&M University Nexus Research Group convened a workshop discussing the water-energy nexus to advance the understanding of water-energy interdependency and related issues. The nexus presents a challenge that has generated vigorous debate around the globe. Solutions vary with specific circumstances and may be transitory, making it an issue without a clear path forward. As a result, initiatives that bring together experts representing diverse sectors and interests, like this workshop, are particularly valuable when considering such a complex topic.

Dr. Ken Medlock, Senior Director of CES, opened the workshop by commenting that "human civilization stands on the three pillars of food, water, and energy for all modern economic activities." Recognition of the intertwined nature of these building blocks has grown in the last decade. Academia, government, and industry are focusing more than ever on public policy and the intersection of these pillars. Medlock announced that the workshop marks the expansion of CES into this important new area of research and will be the first in a series of CES events looking at the intersection between water and energy.

Dr. Linda Capuano, CES Fellow in Energy Technology, moderated a government and industry panel highlighting the strain on global water-energy resources. Panelists Clay Bretches, president and CEO of Sendero Midstream LLC, Michael Hightower, distinguished member of the technical staff of Sandia National Laboratories, and David McBride, vice president of Anadarko Petroleum Company, each shared perspectives on how supply and demand forces are driving the issue, including actions that industry is taking to alleviate the strain on water resources while meeting growing demand for energy.

Regina M. Buono, CES Fellow in Energy and Environmental Regulatory Affairs, moderated a panel that considered an array of technical, agricultural, and policy solutions with possible application to water-energy nexus issues. Panelists Dr. Rabi Mohtar, professor at Texas A&M University, Dr. Qilin Li, assistant professor at Rice University, and Dr. Caroline

Masiello, professor at Rice University, shared insights on potential policy tools and technological innovations being developed to maximize the use of water resources.

Keynote speaker Kathleen Jackson of the Texas Water Development Board (TWDB) provided an overview of the future of water in Texas and offered examples highlighting the successful application of innovative policies and technologies to water conservation and reuse in the state.

A number of common themes emerged from the workshop presentations and ensuing conversations. In what follows, we highlight these themes in the context of the various presentations.

1. Water is crucial to long-term energy stability.

Stability in the energy sector drives economic stability in other sectors that require energy to operate, for example in the transportation, agriculture, water, and other industries. Stability in energy supply and pricing is an important part of a strong, resilient, competitive economy that encourages prosperity, but it is impossible to achieve without adequate water supplies. Energy production depends on water, which is needed for hydraulic fracturing, refining, electric power generation, and biofuel production, and the water sector simultaneously depends on activities that require energy input, such as pumping, transport, and treatment.

Despite this intertwined existence, the next 20 to 30 years will be marked by water shortages rather than energy shortages, making water an issue of national and global security. Some scholars believe that water will be the centerpiece of security; for example, the World Economic Forum recently identified water as the top global risk in 2015.[1]

2. Freshwater supplies are already strained globally.

Surface water limitations and the reduction in available groundwater are creating stress in regions of the U.S. not usually associated with water problems, such as the northeastern United States, Wisconsin, Minnesota, Washington, and Oregon. Water stress can be driven by a variety of causes, including weather patterns, crop irrigation, and the production of biofuels as well as oil and gas. Water stress, in turn, has broad heterogeneous impacts on the energy and electric power production sectors—including nuclear plants, hydropower dams, coal plants, and oil and gas operations—as each is being impacted in different ways.

Projections indicate this trend will continue globally with significant reductions of water availability in the mid-latitudes,[2] which are also areas with fast-growing economies. These regions include the southwestern and southeastern United States, northern Mexico,

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[1] *Global Risks 2015* (Geneva, Switzerland: World Economic Forum, 2015), http://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf).

[2] Elizabeth Kolbert, "Changing Rains," *National Geographic*, April 2009, http://ngm.nationalgeographic.com/2009/04/changing-rains/kolbert-text.

northern Africa, southern Europe, China, India, the Middle East, Brazil, Argentina, South Africa, Australia, and Southeast Asia. This trend is revealed through regional conflicts, such as when the state of Georgia sought help from the US Supreme Court and the US Army Corps of Engineers to resolve transboundary water issues with neighboring states. The challenge for entities such as the Baker Institute is to make recommendations based upon local and regional challenges that will assist policymakers to conceive of programs that can be applied globally.

3. *Trends in demand and the limits on fresh surface and ground water availability are limiting shale development and putting energy in competition with agriculture for access to domestic freshwater supplies.*

Energy and agriculture are the two largest water withdrawal sectors in the US and in most other developed nations. Irrigated agriculture is the largest consumer (~82%) of US freshwater supplies. Energy generation and production consumes 4-5%, which represents approximately 27% of all non-agricultural freshwater uses. Regional demand varies; in Colorado, agriculture uses 85% of water while the oil and gas industry uses less than 0.1%.[3] There are opportunities within the energy sector to help water-stressed regions, including improving water treatment technologies, reducing the cost of water treatment, and using brackish water, recycled water, or produced water. While these options are possible in virtually every shale basin, there are economic hurdles and other barriers to implementation. A broad dialogue between stakeholders and policymakers is necessary to support water reuse.

The findings of the National Petroleum Council's study on the prudent development of North America's oil and gas resources[4] indicate the presence of a far larger resource base than was thought a decade ago. North America is projected to become the world's largest oil producer by 2025. Moreover, the enormous gas resources in the US could transform not only its domestic market, but also the world as a whole. However, under the status quo, current trends of increased water stress will be aggravated by the future development of oil and gas reserves.

Today, shale resource development requires 2-5 million gallons of water per well. Importantly, water use per well is not increasing, but total water use for oil production is rising due to overall increases in total production. At the time of the presentation, the Eagle Ford Basin in Texas was noted as having the highest total water use at over 19 billion gallons (bgal), followed by the Marcellus (>13 bgal), Permian (>10 bgal), Barnett (>9 bgal), and Haynesville (>8 bgal) shale basins.[5] While 20-70% of the volume of water used in production can be recovered, produced water quality can vary from 10,000 to 100,000 ppm total dissolved solids (TDS). Because shale development tends to be concentrated in

[3] "Water Use Fast Facts," COGA, 2012, http://www.coga.org/?cpt_energy=/water-use-2/.
[4] National Petroleum Council, *Prudent Development–Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, National Petroleum Council 2011, http://www.npc.org/NARD-ExecSummVol.pdf.
[5] Ceres analysis using PacWest FracDB from FracFocus data from wells drilled January 2011 to May 2013.

the more productive zones of a shale play (the so-called "sweet spots"), field development activities impact a relatively small number of counties within each basin. For example, almost 50% of wells in the Eagle Ford have been drilled in Karnes, La Salle, and Dimmit counties.[6]

4. *Treating and using produced water presents real challenges, and may result in water treatment becoming the largest electricity-consuming sector in the US and globally.*

Produced water from an oil and gas operation represents the largest volume of a product or waste stream associated with exploration and production.[7] Furthermore, pumping, moving, and treating surface and groundwater consumes large amounts of energy. Population and economic growth are the main drivers of increased treatment and use of brackish water, seawater, and other non-freshwater sources of water supply. This could result in the water and wastewater sectors expanding to the point that these industries consume significant quantities of electricity in the US and even globally.

Speakers noted the deep interdependencies between the water and energy sectors that need to be addressed, describing opportunities in water sourcing, management, and disposal, improvements in water treatment, and the need for improved policies and regulations that support beneficial reuse of water produced during oil and gas production. There are opportunities for new technologies and intelligent policies to help conserve and minimize the disposal of useful water resources and facilitate water treatment. Moreover, innovations employed in the US could help other nations.

5. *Policies to facilitate lower-emissions in power generation and transportation must also consider water consumption.*

As we move forward to reduce our impact on the environment through energy efficiency and "green energy" technologies, we must ensure these technologies do not negatively impact water supply and availability. "Green" needs to mean low emissions coupled with low water use. The US could potentially become the largest oil-producing nation in the world, with North America the second largest oil-producing region. The United States also has the potential to be the world leader in reducing its carbon dioxide (CO_2) emissions from 5,300 million metric tons per year[8] to 1,800 as compared to 4,400 million metric tons in China, 2,100 million metric tons in India, and 11,400 million metric tons per year globally. The desire to reduce emissions will inevitably lead to the implementation of alternative energy technologies.

[6] Ceres analysis using WRI Aqueduct Water Risk Atlas in combination with well data from PacWest FracDB from FracFocus.org between January 2011 and May 2013.
[7] Ground Water Council, U.S. Produced Water Volumes and Management Practices in 2012, April 2015, http://www.gwpc.org/sites/default/files/Produced Water Report 2014-GWPC_0.pdf.
[8] See The World Bank website at http://data.worldbank.org/country/united-states.

Biofuels and other alternatives to fossil fuels, while "green" in terms of CO_2 emissions, can be particularly water intensive if the crops from which they are produced require irrigation, or if significant amounts of water are used in their production. Water consumption currently varies widely in the production of transportation fuels. Conventional and unconventional oil and gas average less than three gallons of water consumed per gallon of fuel. Biofuels can use over 900 gallons of water per gallon of fuel if irrigated corn is used for ethanol production, and over 6,000 gallons of water per gallon of fuel if irrigated soy is used for biodiesel.[9] Policymakers need to ask if this rate of water consumption is sustainable and consider policies that balance these competing priorities until technologies can be developed to reduce the water requirements of biofuel crops.

Speakers addressed the need of the United States to be environmentally responsible as it achieves its domestic production potential and realizes the benefits of becoming one of the world's largest oil and natural gas producers. This is especially important with respect to water since current shale development practices require approximately seven times more water than conventional well development, and when production growth is in a location where water is already scarce.[10] Operators in shale plays who experience extremely high production activity and intense water use must think about using and conserving water in a way that will allow the activity to flourish for decades. An approach tailored to local needs and circumstances must be developed since not all areas in oil producing states are equally affected by water withdrawals. Usually, only a few counties where the activity is taking place are affected, so it is important that policies consider local solutions. A similar point may be made with regard to the management of produced water.

6. *Decision-support tools are needed to assist policymakers in choosing the appropriate balance of carbon emissions and land and water use impacts under specific regional energy and power-generation conditions.*

Decision-support tools are needed to understand the optimal balance of CO_2 emissions and water use when considering the deployment of alternative energy technologies. For example, there is a wide variation of water consumption between different methods of electric power generation. Wind and photovoltaic solar combine low water use with low emissions. Natural gas and integrated gasification combined-cycle power generation use significantly less water than do geothermal, concentrating solar, and fossil/biomass steam turbines. However, adding carbon sequestration to reduce emissions from fossil-fuel power generation could double water demand. It is unclear whether it will be feasible to implement water-intensive carbon capture and sequestration (CCS) processes in water-stressed areas, such as in the southwest United States. Advanced decision-support tools can

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[9] Report to Congress on the Interdependency of Energy and Water. United States Department of Energy. Washington D.C., 2006, http://www.sandia.gov/energy-water/congress_report.htm.

[10] Monika Freyman, *Hydraulic Fracturing & Water Stress: Water Demand by the Numbers*, February 2014, http://www.ceres.org/resources/reports/hydraulic-fracturing-water-stress-water-demand-by-the-numbers.

provide the analysis needed to assist policymakers accelerate approaches to move to low-emission and low-water use power generation.

Applying robust data analysis to questions surrounding water and energy is crucial for good policymaking. Decision-support tools can assist policymakers in calculating the appropriate balance of agriculture, land, economic and energy development with available water resources and in setting priorities. Texas A&M's Water-Energy-Food (WEF) Research Group strives to quantify the trade-offs and interlinkages of the water-energy-food nexus. The group has developed a web-based tool[11] to analyze the balance of agricultural production, energy development, and other economic activity (such as imports) in light of available water and other natural resources. The WEF Nexus Tool allows the operator to develop multiple scenarios that reflect envisioned pathways to address a specific challenge at a defined scale. The emergence of a favorable scenario comes as a result of taking into account scientific information on the availability and interconnectedness of physical resources and policy inputs that reflect long-term goals.[12]

Given that the impacts of biomass and water use are regional, policymakers need to consider the effective use of agricultural land. A study by the National Renewable Energy Laboratory (NREL) estimated the distribution of biomass resources—such as agriculture and wood residues, municipal discards, and dedicated energy crops—by county in the US through time.[13] The trends indicate that the agricultural sector is moving away from irrigated agricultural practices in the western US because of the unreliability of water resources for irrigation in that region and toward the southeast. It is also important for policymakers to consider crop yield and water use as part of the biofuel calculation. Currently corn, soybeans, and safflower produce less than 100 gallons of fuel oil per acre per year. However, micro-algae have the potential to produce up to 7,000 gallons of oil per acre per year using brackish water or seawater. There are many interdependent issues and opportunities when considering competing demands of energy, water, and food.

The electric power sector provides another example of the use of decision-support tools. The sector has invested in modeling advanced cooling technology, since dry cooling is not efficient at temperatures above 100°C and thus would not be practical in regions like the southeastern and southwestern parts of the United States. These regions will need hybrid systems using water and air or other advanced cooling systems.[14]

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[11] The tool is available at wefnexustool.org.

[12] Rabi H. Mohtar and Bassel Daher, *A Platform for Trade-off Analysis and Resource Allocation: The Water-Energy-Food Nexus Tool and its Application to Qatar's Food Security*, London: Chatham House, 2014.

[13] "A Geographic Perspective on the Current Biomass Resource Availability in the United States," National Renewable Energy Laboratory, December 2005 NREL/TP=560-39181, http://www.nrel.gov/docs/fy06osti/39181.pdf.

[14] For example, hybrid cooling systems have the potential to achieve more than 50% water savings when compared to wet cooling systems when used with coal-fired power plants. See http://cornerstonemag.net/advanced-cooling-technologies-for-water-savings-at-coal-fired-power-plants/.

7. *Research is needed to develop energy production technologies that use less water and result in lower carbon emissions and to facilitate the use of alternative sources of water.*

A call was also made for more investment in developing methods to reduce water use in biofuel production and processing, advancing less freshwater-intensive technologies such as algal biodiesel, and assessing the hydrologic impacts of scaling-up production of cellulosic biofuels. It was also noted that in addition to concerns about water stress, biofuels compete with the food supply for crop production. Currently, over 28% of US corn production is used for biofuels and that percentage continues to grow.[15] This represents a complex intersection of sustainability, resiliency, and ethics that policymakers must consider in designing policies supportive of biofuels.

Investment is also needed to enhance the availability of alternative sources of water without stressing the energy-water nexus. For example, desalination and wastewater reuse have been growing at a significant rate each year.[16] But these processes each consume large volumes of energy, which, in turn, requires significant water use. Therefore, investment is needed to reduce the energy intensity of these processes.

While investment is needed, transitions take time. For example, the transition from wood to coal as the dominant source of energy took about 70 years and from coal to oil about 50-60 years; the move to renewables will also take time. Policies that will accelerate the transition must be carefully considered, but we also need to make some short- and long-term decisions now. For example, 35% of total US electricity generation is from coal and 74% of all coal-fired power plants are over 30 years old.[17] This is an important opportunity for policymakers to consider whether it is more appropriate to update or replace this aging infrastructure. Choices made today will have a long-term impact since new baseload power plants have expected lifetimes that approach 50 years.

There is a great need for research into alternative fuels, desalination, improved water resource forecasting and management, evaluation of the impact of climate variability, improved hydrological forecasting, and the development of common decision-support tools. It is also important to develop system analysis approaches for the co-location of energy and water facilities, improved national capabilities to support renewables, and the distribution of biofuel production. In addition, while it will take time to transition to new energy technologies and renewables, we need to start now.

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[15] Paul Wescott and James Hansen, *US Department of Agriculture Economic Research Service Agricultural Projections to 2024*, February 2015, http://www.ers.usda.gov/publications/oce-usda-agricultural-projections/oce151.aspx.

[16] Data published by the International Desalination Association and Global Water Intelligence indicate a 57% increase globally in the capacity of desalination plants on-line over the five-year period 2008-2013. See https://www.globalwaterintel.com/desalination-industry-enjoys-growth-spurt-scarcity-starts-bite/.

[17] US Energy Information Administration Short-Term Energy Outlook, March 2015.

The audience was encouraged to read the US DOE's water-energy nexus report.[18] This report identifies major research areas and suggested activities, such as thermoelectric cooling improvements, waste heat recovery in energy systems, process water use efficiency and quality, and desalination improvements. The framework was developed for the US, but the general tenets could also be applied internationally. The DOE is in the process of increasing funding to address some of these issues because the agency understands the impact of energy on long-term economic growth and stability in the US and globally.

8. *The oil and gas industry must continue to be part of the solution.*

The oil and gas industry has responded to the recommendations in the NPC prudent development study,[19] which indicates that the oil and gas industry should establish focused councils of excellence in effective environmental, health, and safety practices. These practices include sharing and comparing information relevant to the community through organizations such as the Energy Water Initiative (EWI), an industry-led organization wherein such a dialogue is taking place. Created five years ago, the group is composed of 17 oil and gas companies[20] working together to improve life-cycle water use and management in onshore oil and gas extraction. The group shares industry "best practices" and "lessons learned" as case studies to understand potential solutions to the diverse regional water resource challenges. It considers innovative strategies, educates stakeholders on unique water management challenges across producing regions, and shares the advances that industry is proactively achieving to address these challenges.

EWI case studies have yielded important findings on innovative technical trends in the industry and the associated benefits. For example, industry has worked to improve the chemistry used in hydraulic fracturing and increase the use of non-fresh water. It has implemented innovative treatment technologies that increase the reuse of produced water. It has increased the use of water conveyance systems to reduce traffic safety hazards and environmental, community, and infrastructure impacts associated with transporting water by truck. Many EWI members have hired dedicated staff to improve water management, provide technical support, enhance regional performance, and increase transparency while improving communication with local citizens, businesses and municipalities.

EWI members encourage and support increased research on advanced water treatment technology, improved analytical methodologies, and projects to enhance measurement and management of water, all of which will help in water sourcing and storage, delivery, and disposal. One example is a water delivery system improvement implemented by Anadarko in Colorado, in which the installation of a pipeline eliminated more than 2,000 truck trips

[18] U.S. Department of Energy, *The Water-Energy Nexus: Challenges and Opportunities*, June 2014, http://www.energy.gov/sites/prod/files/2014/06/f16/Water Energy Nexus Report June 2014.pdf.
[19] *Prudent Development*, 2011.
[20] EWI 2015 Case Studies participants: Anadarko Petroleum Corporation, Apache Corporation, BP, Chesapeake Energy, ConocoPhillips, Devon, Marathon Oil, Newfield, Pioneer Natural Resources, QEP Resources, Southwestern Energy, and Talisman. Other EWI participants: BG Group, Chevron Corporation, Hess Corporation, Shell, and XTO Corporation (an Exxon subsidiary).

per day. Projects like this are large, but the oil and gas sector has the infrastructure needed to be part of the solution. The industry can help avoid the projected water shortages that loom over the United States and other parts of the world. However, what is needed is support from well-designed public policies that will make it cost effective to manage water more efficiently and effectively.

9. *Water challenges are interdisciplinary and best addressed locally with a broad dialogue between stakeholders and policymakers.*

While water concerns are global, the impacts are borne locally. Therefore, solutions should be designed for local circumstances, as a single technology will not be the best practice in every region. Solutions will not come from the water community alone, but will require outreach to other sectors and must be interdisciplinary.

In the spring 2015 semester, Texas A&M University offered a course on sustainable resource management and the nexus as an example of an interdisciplinary and localized approach to water and energy. Students completed projects looking at various approaches to bridging the gap between water supply and demand in Texas using the nexus as a lens. The 2012 State Water Plan for Texas indicates that water demand will exceed supply by 2060. The plan describes strategies and projects developed by regional water planning groups to close the projected gaps. The challenge lies in implementing those strategies. Student projects for the course examined water use for hydraulic fracturing in the Eagle Ford shale; potential use of collected water from low-impact developments for irrigation; food security for the city of Lubbock, Texas; balancing water demand for energy, agriculture, and municipalities near San Antonio; and water reuse and aquifer storage and recovery in the Region J Water Planning Area.

The case of hydraulic fracturing in the Eagle Ford shale formation offers a prime example of a localized impact on water and other resources. Dramatic increases in energy development facilitated by advancements in hydraulic fracturing technologies have significantly increased water demand in the region. The increase in water use for shale production is a small fraction of the state's total water use, but the impact on water availability at the local level is much more significant: local water demand has increased by as much as 6%. Such developments highlight the importance of a holistic, multidisciplinary approach to problem solving in the nexus. The analytical platform developed by the WEF Group can be used to construct scenarios that consider the impact of different policies and resource allocations on economic and human elements, including water footprint, carbon emissions, employment indicators, infrastructure, and tourism. In order to obtain the full economic benefits associated with shale development while minimizing costs, complex analysis involving localized solutions is needed. In addition to sound science, community input must help guide policy priorities so that a multi-stakeholder approach to policymaking can be implemented.

10. Water reuse technologies continue to be developed that will improve our ability to use alternative water supplies to bridge the water gap.

An important piece of the puzzle to ensure water security is the availability of *alternative* water sources. Concerns were expressed multiple times over an emerging gap between water supply and demand; one speaker noted that more than one-third of US counties experience moderate to extreme water stress. It is important to consider alternative water supplies, including brackish groundwater, seawater, and industry/municipal wastewater. However, treating non-fresh water requires significant energy and chemical use and is costly in terms of the disposal of brine from desalination or waste from water treatment. Innovative technology is needed, especially to address challenges in remote locations.

Research at Rice University's National Science Foundation's Engineering Research Center for Nanotechnology-Enabled Water Treatment Systems (NEWT) is aimed at developing technologies that could help achieve these goals. NEWT is a large multi-stakeholder group that includes scientists, industrial participants, government entities, and international partners. The center applies nanotechnology to develop and commercialize low cost water treatment systems that are modular, use solar energy, and generate less waste. The technology would allow users to adjust the treatment level based on the intended use, treating water for drinking differently than water for industrial use. The center strives for solutions that avoid using electricity, including solutions that use photo-disinfection and advanced oxidation to kill bacteria and viruses, electro-absorption for scaling control, direct solar membrane distillation for desalination, and multifunctional nanosorbents to selectively remove targeted contaminants. All these technologies are intended for modular, solar-powered water treatment systems that would be ideal for remote locations.

11. A variety of creative new technologies and methods are needed.

The WEF Group at Texas A&M maintains a strong focus on soil science and "green water." Green water is precipitation on land that does not run off or recharge groundwater but remains in the soil or on vegetation until it evaporates or transpires through plants. Sixty percent or more of food we eat today comes from rain-fed agriculture, not irrigated agriculture. The WEF Group performs research on new agricultural models and techniques to improve efficiency in the green water space by maximizing water productivity rather than yield and increasing the proportion of food supported by rain rather than irrigation.

One option with the potential to improve agricultural water availability is biochar technology. Biochar is charcoal obtained from the pyrolysis (heating in the absence of oxygen) of organic material, such as wood, manure, or leaves, under conditions of limited oxygen and relatively low temperatures. Often mixed into soil, biochar has the potential to alter the water retention capabilities of soil, improve fertilizer retention thereby decreasing polluting runoff, improve crop productivity, and provide some level of carbon sequestration. However, despite the positive attention biochar has received in the popular press as a solution for reducing carbon in the atmosphere, it is not a complete solution for stabilizing or reducing carbon emissions. Biochar has the potential to sequester 10-15% of carbon emissions[21] and can be a part of the mix of new technologies that will be required to stabilize carbon emissions.[22]

Like solutions to water issues, the decision to use biochar as a soil additive must take into account local circumstances and soil properties. For example, biochar's ability to change the speed at which water drains from soil would be used differently in the sandy soils of west Texas versus the clay-rich soils of coastal east Texas. Biochar creates space between smaller clay soil particles to enable drainage, but prevents drainage in sandy soils by clogging the large spaces between sand particles. The ability of biochar to accelerate water drainage could alleviate flooding and improve drainage into subterranean aquifers. The material's potential to hold moisture and decrease drainage could also benefit crops in arid climates. Its ability to provide porous material to hold and slow the release of fertilizers could also improve crop productivity and reduce polluting fertilizer runoff.

There is community and entrepreneurial support for biochar. Small and large businesses are entering the sector and exploring the technology. Further, the production and use of biochar has not had the negative community response received by other carbon sequestration techniques, such as underground CO_2 injection. Biochar can be an environmentally prudent option if it is sustainably produced. The Biochar Group at Rice University focuses its work on questions related to optimizing production conditions, understanding ecosystem impacts (including to air, soil, and water) of biochar application, and the economics of biochar.

12. Public policy can make a difference.

All speakers echoed the importance of shaping and implementing policies that facilitate solutions. Many called for increased research and understanding. Public law and policy affect incentives and the ability of private actors to implement processes that benefit the greater society. Good policy can help facilitate the acquisition of data and the understanding of how water is used. One speaker stressed that "until we understand how water is used, we are at a disadvantage to use it more wisely," pointing to the lack of up-to-date, comprehensive data on water usage and produced water management in energy production and the need to improve this situation.

In some instances, policy may have the effect of reducing the ability to implement procedures and processes that reuse water to the benefit of the community. Incentives are needed to encourage the treatment and reuse of water, and regulatory impediments to such treatment must be lessened or removed. For example, in some US states, treated water belongs to the state rather than to the company that treated it. If the company cannot

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[21] D. Woolf, J.E. Amonette, F.A. Street-Perrott, J. Lehmann, and S. Joseph, "Sustainable biochar to mitigate global climate change," *Nature Communications* 1, no. 5 (2010): 1–9, http://doi.org/10.1038/ncomms1053.

[22] S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305, no. 5686 (August 13, 2004): 968-972.

reuse the treated water, it has no incentive to treat water and will thus use less costly fresh water to meet its needs. Remote well locations may prevent easy recycling and use of water, as may contractual obligations. A mineral owner who also owns water rights may require a company that leases her land to purchase and use water drawn from the owner's land for operations, rather than allowing the use of recycled water from nearby operations. Appropriate policy changes in cases such as these could incentivize companies to recycle and reuse water for operations. However, policymakers must be sure they are proceeding with a sufficient understanding of the local situation and the implications of any policy. Given the issues that may arise, public policies related to water reuse should be developed with caution and prudence.

The Texas Water Development Board's (TWDB) responsibilities and powers touch on many of the issues discussed in the workshop, including (1) increasing demand for water and energy as people move to Texas (around 1,000 per day), (2) the disparate and variable availability of water resources across the state, (3) institutional and regulatory hurdles for developing new water supplies, and (4) the need to facilitate the use of alternative sources.

Water conservation and reuse are key components of the solution, especially where and when there is little rainfall. Conservation is the least costly alternative, but strategies for capturing and storing rainwater and a more efficient use of available water are also important. Innovative technology is helping agriculture conserve water while preserving crop yields and positively impacting output and profitability. Individual producers in Texas can now achieve up to 98% irrigation efficiency by combining technology with best management practices. Through the State Water Plan, regional water planning groups have identified water conservation and reuse as viable strategies for investment to meet the state's future water needs. Of funds loaned by the TWDB from the $2 billion State Water Implementation Fund for Texas (SWIFT), the law requires that 20% be used for conservation or reuse projects and 10% be used by rural communities.

Texas should also be a place where alternative water supplies such as brackish water and seawater are part of the water supply equation. There is reason to be optimistic about the progress in desalination technologies in Texas. With the abundant supply of natural gas providing a reliable and relatively clean source of energy, desalination of brackish water and seawater has a greater chance to develop. Solutions are still needed for the challenges presented by high-energy requirements and issues related to the management of brine. Texas communities and businesses are focusing on opportunities that enhance reliability, capture synergies, and promote efficiencies. Within the manufacturing sector—where there is no need to treat seawater to potable water standards—desalination can become a more efficient and competitive process in providing alternative water supplies.

The solutions being implemented in Texas are consistent with the approaches highlighted by the speakers and are based on a bottom-up approach, allowing local communities and other stakeholders to participate through regional water planning groups. Consulting and engineering firms support the water-planning groups, and each is assigned a dedicated staff member to assist with the development of strategies best suited to local conditions and environment. The 16 regional water-planning groups develop well-vetted projects that address a 50-year outlook. Every five years, the local plans are incorporated into a statewide plan.

In addition to SWIFT, TWDB manages a variety of financial assistance programs to help communities with water projects from inception to completion. These projects focus on refurbishing aging infrastructure and ensuring that small and rural communities have adequate water supplies. To achieve this, the board provides technical, scientific, and engineering assistance to supplement its financial support. Trained personnel are available to communities in field offices across the state. The board is also a water data repository and provides information about the State Water Plan. Most importantly, the board sees itself as an important resource recognizing what industry and subject matter experts repeatedly underscored throughout the workshop; and recognizes that water is a local issue, and local community engagement is vital to developing successful solutions.

Summary

A number of common theses emerged from the workshop presentations and ensuing conversations:

1. Water is crucial to long-term energy stability.
2. Freshwater supplies are already strained globally.
3. Trends in demand and the limits on fresh surface and ground water availability are limiting shale development and putting energy in competition with agriculture for access to domestic freshwater supplies.
4. Treating and using produced water presents real challenges, and may result in water treatment becoming the largest electricity-consuming sector in the US and globally.
5. Policies to facilitate lower-emission power generation and transportation fuels must also consider water consumption.
6. Decision-support tools are needed to assist policymakers in choosing the appropriate balance of carbon emissions and land and water use impacts under specific regional energy and power-generation conditions.
7. Research is needed to develop energy production technologies that use less water and result in lower carbon emissions and to facilitate the use of alternative sources of water.
8. The oil and gas industry is and must continue to be part of the solution.
9. Water challenges are interdisciplinary and best addressed locally with a broad dialogue between stakeholders and policymakers.
10. Water reuse technologies continue to be developed that will improve our ability to use alternative water supplies to bridge the water gap.
11. A variety of creative new technologies and methods are needed.
12. Public policy can make a difference.

Fellows and scholars at the Baker Institute, Rice University, and the Texas A&M University Nexus Research Group will continue to examine the themes of this workshop and other important research topics to address the means and methods for tackling the pressing issue of sustainability in the water-energy nexus, taking into account the challenges presented by growing populations and improved living standards. To that end, an Oct. 14 CES conference on "Water and Energy: Challenges and Opportunities in the Nexus" focused on leading developments in water and energy in the legal, international, and industrial contexts. Future workshops and conferences will continue the discussion around the use of alternative, non-drinking water sources to meet agriculture, industry, power, municipal, and other demands. These projects will include work analyzing the regulatory regimes surrounding the use of water for hydraulic fracturing in various regions of the world, the economic modeling of Texas water, and research on brackish groundwater in Texas. The CES is also directing attention to policies and practices to improve lifecycle water use and conservation and management in US-based upstream unconventional oil and natural gas exploration and production.

Research by Rice University's NEWT Center and Biochar Group will continue advancing technologies for water treatment and soil amendment processes and helping society to understand and evaluate the costs and benefits of those technologies in the water-energy nexus. And, in November 2015, Texas A&M hosted the Texas A&M University System Resource Nexus: Water Forum in San Antonio, the goal of which is to engage stakeholders in meaningful discussions and produce outcomes to assist in the effective management of water resources.