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Water Security Grand Challenge Workshop Outcomes

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List of Acronyms

CAPEX	capital expenditures
CEC	California Energy Commission
CSP	concentrating solar power
DOE	U.S. Department of Energy
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
GAO	Government Accountability Office
NORM	naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OPEX	operational expenditures
OSTP	Office of Science and Technology Policy
SBA	U.S. Small Business Administration
SBIR	Small Business Innovation Research
SPE	Society of Petroleum Engineers
STTR	Small Business Technology Transfer
TENORM	technologically enhanced naturally occurring radioactive material
USGS	United States Geological Survey
WEF	Water Environment Federation
ZLD	zero liquid discharge

Executive Summary

Water is a critical resource for human health, economic growth, energy production, and agricultural productivity. The United States has historically benefitted from access to low-cost water supplies, but challenges for freshwater supplies could threaten U.S. economic competitiveness and water security. Water quality issues can also impact human health and the environment, yet municipal treatment systems face billions of dollars in unmet infrastructure investment needs. Lack of safe and secure water supplies is also a global problem, with several regions unable to afford traditional water treatment technologies. Globally, more than two billion people lack access to safe water at home, and water security is a national security issue.

To help address these challenges and opportunities, U.S. Department of Energy (DOE) Secretary Rick Perry on October 25, 2018 announced the Water Security Grand Challenge. The Water Security Grand Challenge is a White House-initiated, DOE-led framework to advance transformational technology and innovation to meet the global need for safe, secure, and affordable water. DOE hosted a stakeholder workshop on October 25, 2018 at the National Renewable Energy Laboratory (NREL) to gather input from external experts on prize competitions that could address water and associated energy-related challenges. The workshop included over 80 experts from 40 institutions, including water technology providers, trade organizations, energy producers, nonprofit organizations, academia, federal agencies, and DOE national laboratories. Participants contributed to breakout groups that developed prize ideas that align with the goals and topics of the Grand Challenge:

- Cost-competitive desalination technologies
- Transforming produced water to a resource
- Reducing water impacts in the power sector
- Increasing resource recovery from wastewater
- Developing small, modular energy-water systems
- Crosscutting, open topics

In the workshop, participants developed over 40 ideas suitable for prize competitions. Participants in each breakout group developed innovative prize ideas that could improve water security. Several common themes arose, suggesting solutions to these shared challenges could provide widespread benefits:

- Improving the collection, availability, and access to water data. Once data are available, transforming raw water data into useful information that can inform decision-making
- Addressing non-technological barriers, including creating innovative business models
- Utilizing small and modular technology systems for cost-competitively improving security
- Capitalizing on opportunities associated with replacing or maintaining aging infrastructure
- Recovering multiple types of resources from water resources across sectors
- Incorporating flexibility, phases, matchmaking, and other features into the prize competitions

The ideas developed at the workshop will be foundational to the success of the Water Security Grand Challenge. Moving forward, DOE will continue to develop prize ideas proposed during this workshop, internally and in collaboration with other federal partners. DOE will also explore other potential avenues for prizes and competitions that could advance the Grand Challenge goals.

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Introduction

Motivation

Water is a critical resource for human health, economic growth, energy production, and agricultural productivity. The United States has historically benefitted from access to generally low-cost water supplies, but new challenges are emerging that, if left unaddressed, could threaten water security. For example, traditional freshwater sources are coming under stress from competing uses in a growing number of U.S. regions. And, a range of water quality problems is impacting human health and the environment, while municipal water and wastewater treatment systems face billions of dollars in unmet infrastructure investment needs. These challenges are likely to be exacerbated as population grows, water demands increase, and water quality requirements become more stringent (Arzbaecher et al. 2013).

Lack of safe and secure water supplies is also a global problem. According to the World Health Organization (WHO 2017), more than two billion people globally lack access to safe, readily available water at home. Aside from humanitarian implications, this lack presents domestic risks and opportunities. The U.S. Department of State (State Department) views water security as an issue of national security, noting that water-related problems in other parts of the world could "prevent countries from advancing policies and programs important to the United States" (State Department 2017). At the same time, the State Department (2017) notes the global water and wastewater treatment market currently exceeds $700 billion, which highlights the economic opportunities available to U.S. companies. Addressing water security risks and vulnerabilities domestically and globally will require innovative approaches that recognize the interdependence of the energy and water sectors.

The Water Security Grand Challenge and Workshop

To help address these challenges and opportunities, U.S. Department of Energy (DOE) Secretary Rick Perry on October 25, 2018 announced the Water Security Grand Challenge. The Water Security Grand Challenge is a White House-initiated, DOE-led framework to advance transformational technology and innovation to meet the global need for safe, secure, and affordable water. Using a coordinated suite of prizes, competitions, early-stage research and development, and other programs, the Grand Challenge has set the following goals for the United States to reach by 2030:

- Launch desalination technologies that deliver cost-competitive clean water
- Transform the energy sector's produced water from a waste to a resource
- Achieve near-zero water impact for new thermoelectric power plants, and significantly lower freshwater use intensity within the existing fleet
- Double resource recovery from municipal wastewater
- Develop small modular energy-water systems for urban, rural, tribal, national security, and disaster response settings.

As part of the Water Security Grand Challenge, DOE hosted a stakeholder workshop on October 25, 2018 at the National Renewable Energy Laboratory (NREL) to gather input from external experts on prize competitions that could be administered by DOE or other partners to address water challenges. The workshop included over 80 experts from 40 institutions that either need or are creating innovative water solutions, including water technology providers, water industry trade organizations, electric utilities, energy producers, nonprofit organizations, academia, federal agencies, and DOE national laboratories. The views expressed in this report reflect the discussion of participants during the workshop and do not necessarily represent the views of the U.S. Department of Energy or the United States Government

Prize Competitions

In prize competitions, a given prize sponsor defines a problem and offers a reward for a solution (Hendrix 2014). A key characteristic of prize competitions is that they clearly define a problem without prescribing a particular solution path. Prize competitions are generally open to a wide range of participants, with financial or other rewards provided at the end of the competition, after a designated target or goal has been reached. Challenges and prizes are powerful tools because they can reach beyond traditional stakeholders to increase the number of solvers tackling a problem, identify novel approaches, bring out-of-discipline perspectives to bear, establish an ambitious goal without having to predict which team or approach is most likely to succeed, and maximize return on investment by paying only for success (OSTP 2017).

Prizes could be used to make progress in several different areas and issues. Workshop participants discussed a range of prize types, including the following:

- *Technology demonstration and hardware prizes* seek prototypes or fully developed solutions to catalyze and demonstrate breakthrough technical innovations.
- *Analytics, visualization and algorithm prizes* focus on finding better ways to interpret or communicate data.
- *Creative design and multimedia prizes* can help agencies capture, communicate and project a concept or aesthetic that would be difficult to achieve with a grant or contract.
- *Entrepreneurship or business plan prizes* are competitions to help train and equip entrepreneurs, as well as launch their ventures.
- *Ideation prizes* support new ways of understanding and framing problems, new processes to solve problems, and innovative implementations as solutions to problems.
- *Software and app development challenges* ask solvers to create a software application to solve an existing problem or draw attention to potential uses of available data sets.

Participants also considered special features to enhance the effectiveness of prizes, such as phased competitions, alternatives to cash prizes, access to unique federal assets, and mechanisms that elevate or involve the promising ideas of the non-winning teams.

Water Security Grand Challenge Workshop: Breakout Group Ideas

Participants were assigned to one of six breakout groups, five of which aligned with the goals of the Water Security Grand Challenge, plus one crosscutting, open session. Each breakout group included stakeholders from multiple disciplines and sectors. Groups were tasked with brainstorming prize ideas that could address high-impact water security issues. In the morning breakout session, participants worked together to identify and craft clear problem statements that could be addressed through prize competitions. In the afternoon breakout session, participants turned their attention to designing prizes addressing those problem statements.

Designated facilitators from DOE and other institutions led the sessions to generate an initial list of prize ideas that could be suitable for DOE or other agency-led prize competitions. In some cases, certain ideas were noted as important but not necessarily well suited for a prize competition. In other cases, certain ideas were noted as promising for a prize competition, but the group did not have sufficient time to explore specific details of a prize. Prize ideas are summarized below by the Water Security Grand Challenge goals or topics, with each individual prize idea including a description of an ideal state, barriers preventing that ideal state, and a competition that could help overcome those barriers.

Common Themes Across Breakout Groups

Several common themes arose organically across breakout groups throughout the workshop, indicating that prize competitions addressing these topics could potentially have benefits spanning all Water Security Grand Challenge goals. The themes identified include:

- *Data Availability:* A lack of water data is a crucial barrier to undertaking innovations that could improve water security. In some cases, data are unavailable because they are not collected or are unreliable. In other cases, data are collected but are not readily available for analysis or to inform decision-making because there is no central repository or other way to access it. However, systems-level data collection and storage for informing more water-efficient energy systems or energy-efficient water and wastewater systems and services delivery is now possible. Harnessing recent technology innovations, such as satellite imagery analysis, smart sensors and meters, and automated data processing could provide a mechanism to address the data availability gap that would be relevant for all Water Security Grand Challenge goals.

- *Data Management and Analytics*: In some cases, water data might be collected across an entire water system at high frequency (e.g., every 15 minutes), but the lack of an effective mechanism to process the data to inform real-time decision-making prevents the large amount of high-resolution data from being effectively used. Many operators are also not trained nor have the tools to perform big-data analytics that could identify innovative solutions to improve the efficiency of operations. Making use of these data through advanced analytics could enable the deployment and use of various new technologies that could rapidly respond to changing conditions. High-performance computing for energy-water system optimization as well as artificial intelligence and machine learning-based approaches to enable predictive analytics, if effectively applied, could facilitate improvements in water technology operations and decision-making.

- *Regulatory, Financing, and Other Non-Technological Barriers:* Across all topic areas, inconsistent regulation among energy and water sectors, lack of innovative financing mechanisms, and social acceptance challenges were identified as barriers preventing technology solutions alone from being sufficient to improve water security. Technology solutions could be complemented by non-technological prizes or by pairing regulatory, financing, and social science experts with a prize development team to ensure technology advancements adequately address these other crucial barriers. Multisector modeling approaches that can capture economic and policy considerations would also facilitate more effective prize development activities.

- *Business Model Innovation:* Closely tied to regulatory and financing barriers, all breakout groups recognized that traditional business models are not always effective at spurring technological innovations in the water sector, which is typically risk averse. Given that valuations of water resources in many areas does not adequately capture water's contribution to health and the economy, it can be challenging for innovative technological solutions and companies to be profitable. Developing alternative business models, such as those that focus on providing water services decoupled from specific quantities of water could be an effective mechanism to facilitate greater innovation and adoption of water treatment technologies.

- *Small and Modular System Designs*: Every breakout group highlighted the important role that modular systems could play in addressing a wide variety of water security challenges. Cost-effective and efficient modular systems manufactured and deployed at significant scale could have benefits for desalination, produced-water management, power sector water usage, and recovery of resources from waste streams, among other applications.

- *Aging Infrastructure*: Aging infrastructure can be both a challenge and an opportunity for water technology innovations. Aging infrastructure can be a challenge if existing infrastructure is incapable of incorporating new and innovative technologies, and it also could delay deployment of innovations if there are concerns about the infrastructure's remaining lifetime. However, the replacement of aging infrastructure also offers opportunities for new innovations to be deployed at scale.

- *Resource Recovery*: Beyond municipal wastewater, resource recovery techniques could play an important role in improving the cost-effectiveness and sustainability of water treatment in desalination, produced water, power sector, and small systems. Improving recovery technologies and approaches could have impacts across these multiple sectors.
- *Prize Structure*: Breakout groups suggested using phased approaches for prize competitions, whereby smaller but more numerous investments could be initially made to identify the most promising opportunities, and then larger and fewer investments could be made for select teams. In addition, many of these prize competitors would benefit from technical assistance in business plan development. This assistance could be facilitated using a matchmaking approach, where individual teams would have access to industry experts who could provide essential guidance to ensure prize proposals are relevant and financially feasible. Multiple breakout groups also discussed how intellectual property rights for the business models and technologies that are developed would need to be agreed on at the onset of the prize competition. There was interest expressed across most groups in having an advisory board and a judging panel to facilitate the prize competition. Finally, there was general recognition that creative solutions could be crowdsourced from utilities, industry partners, regional planners, data providers, startups, as well as disadvantaged populations in need of additional water security.

Topic Area 1: Cost-Competitive Desalination

Water Security Grand Challenge Goal: Launch desalination technologies that deliver cost-competitive clean water

Cost-competitive desalination technologies can address water security by expanding alternative water supplies without increasing costs to consumers. If achieved, the goal would have a significant impact in alleviating water stress, which is already a problem in several parts of the country and expected to grow. In a recent study, the U.S. Government Accountability Office (GAO) found that 40 of 50 state water managers expected water shortages in some portions of their states in the next 10 years (GAO 2014). Though seawater is an obvious potential source of new supply, especially for municipal water systems, desalination technologies could also be applied to brackish water from estuaries and underground aquifers, as well as other sources. Desalinated water from these sources could be used for a range of beneficial purposes, including but not limited to drinking water. The major barrier preventing greater adoption of desalination technologies in the United States is the higher cost of desalination systems, though environmental issues, such as brine disposal also pose a challenge. The energy intensity for desalination is the key driver of the high costs, where energy costs can be ten times higher for purifying seawater than treating freshwater to the same standards (CEC 2005). Figure 1 shows the energy intensity associated with providing drinking water for five source water options in California (adapted from Cooley, Gleick, and Wolff 2006).

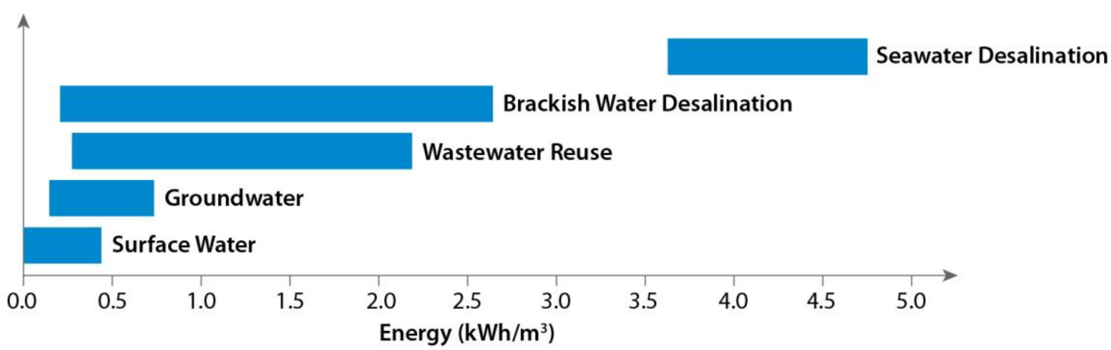

Figure 1. Energy intensity of source water options in California (adapted from Cooley, Gleick, and Wolff 2006)

The breakout group identified and assessed ideas and prize structures designed to decrease the cost of processed water, increase water supply and resilience, and increase the access to low-cost water. Two prize ideas addressed specific stages of treatment (pretreatment and brine management), and one prize idea addressed sensors and process controls, which could be used at all water treatment stages.

Prize Idea 1.1: Minimizing Pretreatment Costs and Impacts

- *Ideal End Goal:* The ideal for pretreatment would be to minimize the need for and costs of pretreatment through reduced capital expenditures (CAPEX), operational expenditures (OPEX), and a smaller facility footprint through adoption of improved technologies.
- *Key Problems and Barriers*: Current pretreatment technologies, especially those for coastal desalination, are expensive and energy intensive, partly due to variable intake water quality. Although pretreatment increases the feed water quality, it can often negatively impact the subsequent treatment stages. For example, adding chlorine in pretreatment stages reduces biological contaminants, but then the reverse osmosis membranes become more susceptible to fouling, scaling, and degradation, as many reverse osmosis membranes do not tolerate chlorine. This results in degradation of desalination system performance over time, leading to higher operational and replacement costs. Another challenge is overly engineered pretreatment systems (i.e., scale, number of process steps, and back-up systems) to deal with significant variations in the

input water (e.g., water quality, and algal and biological contaminants). Pretreatment adds significant cost (e.g., CAPEX to build overengineered systems), energy intensity, and system complexity for desalination technologies. These are suitable areas for a prize in pretreatment to address.

- *Proposed Prize:* The prize would design a low-cost pretreatment process where the desalination system performance degrades less than 5% over the lifetime of the desalination system, even with varying feed water quality. The less-than-5% lifetime degradation over 20 years is a bold goal—and the metric of success needs further refinement. The breakout group recommended a phased technology prize that would allow a large number of ideas to be refined and down-selected to the most competitive ideas in future phases. Resources for competitors in future phases could include using national laboratory test facilities and working with mentors either from relevant industries and national laboratories to foster the technology development and increase the learning associated with the idea. The Small Business Innovation Research (SBIR) or the Small Business Technology Transfer (STTR) programs could be possibilities to "onboard" the best ideas out of Phase 3 (post-prize) to get further federal funding (SBA 2018).
    - Phase 1—a white paper ideation phase to include initial proposals for pretreatment approaches: Phase 1 would have a low barrier to entry in order to level the playing field for small organizations or individuals to apply alongside large companies. After the white paper ideas are evaluated by a panel of experts, Phase 1 could provide a subset of those proposers with a modest cash prize to further refine, develop, and assess their pretreatment technology approaches during Phase 2.
    - Phase 2—a bench-scale prototype development phase (e.g., at a flow rate of approximately six gallons per minute): The prototypes would be evaluated under similar conditions and against a set of targeted performance metrics, and then down-selected to a subset for another cash prize to move into Phase 3.
    - Phase 3—a "build-and-prove" demonstration of a small pilot (e.g., skid-mounted) system performing under real salinized water slip stream conditions for a minimum number of continuous hours at a test site to be determined (e.g., at a site such as the Brackish Groundwater National Desalination Research Facility). The demonstrations would be evaluated under similar conditions against a set of targeted performance metrics and then down-selected to the top performers for another cash prize.

Prize Idea 1.2: Sensors and Process Controls for Optimized Operations

- *Ideal End Goal*: The ideal state for sensors and process controls would lead to desalination plant optimization approaches that enable the most efficient energy usage of and capital deployment for desalination technologies. Advanced sensors and process controls are fundamentally revolutionizing other industries, such as oil production. Through digitization, digital oilfields are increasing monitoring and production (Haliburton 2018; Schlumberger 2018). The current "internet of things" trend increases the amount, frequency, and functionality of interconnection devices (e.g., sensors and controls) to communicate with processing systems. This trend can provide insights and enable operators to change the operating parameters of a desalination system in real time and on a scale previously impossible (i-Scoop 2018). Software tools, system modeling and analysis, and web applications could represent a significant growth opportunity area for cost-competitive desalination technologies and could be part of process controls. Increased sensors and controls could also enable feed water blending strategies (to control desalination levels), use of onsite energy storage systems, and renewable energy onsite generation/grid integration to optimize desalination plant operations and improve overall system economics.

- *Key Problems and Barriers:* Reverse osmosis technologies that are used in desalination plants currently have limited module-specific monitoring and have replacement schedules that are typically not connected to the performance status or degradation of the module membranes. Modules are replaced on a schedule basis, even if useful life is still left in the membrane or modules. Currently, conducting high sampling rates and performing analysis in real time is very expensive and rarely used for desalination systems. As a result, current desalination technologies (particularly membrane technologies) suffer from two key issues that increases costs due to the lack of sensors and process controls. First, a lack of real-time data means operation and maintenance (O&M) decisions cannot be driven by or altered based on a specific module's performance status (e.g., replacing specific membranes that are fouled and not the whole set). Second, the inability to deal with changes in feed water source and quality typically means desalination and pretreatment systems are overengineered to handle the worst types of feed water. Additionally, few plants conduct in-line sensing for hardness, algal blooms, pathogens, and emerging contaminants. For these reasons, the water pretreatment or treatment stages are designed and operate at a high level of complexity, resulting in more energy-intensive and cost-intensive process steps than what may be needed. The increased data availability and processing power of today's computing allows for increased predictive maintenance and process control. Ultimately, this could result in decreased CAPEX for processing systems, as redundancy in systems designs can be reduced, if the process can be monitored more accurately in real time.

- *Proposed Prize:* The prize would improve sensors and process controls to increase the longevity of desalination plants, either through decreased capital or operating expenditures or increased service life due to less frequent equipment replacement, reduced redundancy in design, and optimized plant operations. This approach includes use of sensors and controls for early response to source water variations in order to enable the desalination operator to change system parameters to reduce the operating cost of the processed desalination water. The breakout group discussed some metrics of success that could be further refined. Some examples are new sensors and controls that can increase the life of a desalination plant by five years (e.g., 25% extra for a current 20-year plant) or can decrease the annual O&M replacement cost by a dollar amount per year or a percentage from the current levels. The breakout group recommended a phased technology prize, closely following the phased process of "Prize Idea 1.1." Phase 1 would be a white paper ideation phase to include initial proposals for sensors and controls approaches in desalination plants. Phase 2 would be a bench-scale prototype development phase to evaluate performance under similar conditions against a set of targeted performance metrics. Following down-selection, Phase 3 would be a build-and-prove demonstration in a larger desalination system under real conditions for a minimum number of continuous hours at a test site to be determined to show the longer-term potential of improved sensors and controls. As with "Prize Idea 1.1.," resources for competitors in future phases could include using national laboratory test facilities and working with mentors either from relevant industries.

Prize Idea 1.3: Cost-Effective Brine Management

- *Ideal End Goal:* Brine disposal is a significant and costly issue for water treatment facilities run by municipalities and industrial end users. An ideal state would be desalination or water processing technologies/systems where no brine is produced as a waste stream. The next generation of zero liquid discharge (ZLD) devices could reduce the brine to a solid output, where there is opportunity for selective mineral recovery from the solid wastes to improve overall plant economics by creating a value stream from a waste stream. Resource recovery and selective removal of minerals could help offset the costs of ZLD and brine management systems. Additionally, brine originally meant for disposal could instead be used in industrial processes; for example, using ion exchanger systems or high-concentration sodium chloride brine processes, a high-concentration brine can be fed directly to chlor-alkali and soda ash producers (Hyrec 2018a) to produce a revenue from the "waste" brine.

- *Key Problems and Barriers*: Expensive ZLD systems and a lack of good brine management processes prevent widespread adoption and deployment of inland desalination technologies. ZLD devices like crystallizers form a solid from the brine but are expensive and energy intensive. Crystallizers are currently the most suitable technology for ZLD, but they can have an energy intensity of 30–40 kilowatt-hours (kWh) per cubic meter (m^3) (Hyrec 2018b); decreasing that energy usage (e.g., to 5–10 kWh/m^3 [Hyrec 2018b]) through advanced technologies and processes would be a crucial step to reducing costs. Another key problem with brine management and disposal is that disposal fees for brine streams are often high, and many of the waste brine streams contain recoverable minerals (e.g., calcium, magnesium, and lithium) that could be valuable in many markets, if sufficient quantities could be effectively collected (Gagne et al. 2015).

- *Proposed Prize:* The prize would use a design and technology prize to develop a low-cost brine management process where near-ZLD (e.g., 98% recovery rate) is achieved in an inland desalination system. The breakout group identified the 98% recovery rate as an initial estimate, and this goal could be further refined. The breakout group determined that a phased prize would be most suitable, following the design of "Prize Idea 1.1" and "Prize Idea 1.2." Phase 1 would include a white paper ideation phase to include initial proposals for ZLD technologies. Phase 2 would include prototype development, and Phase 3 would be a build-and-prove small-scale demonstration. As with previous prize ideas, resources for competitors in future phases could include using national laboratory test facilities and working with mentors either from relevant industries.

Additional Potential Prize Ideas

The breakout group briefly discussed many other ideas that could be suitable for prizes, including: :

- *Selective Removal:* Selective removal can be seen as a subset of brine management. As highlighted in the brine streams discussion above, critical minerals (e.g., lithium), could be extracted if there was sufficient economic value in the recovered materials and low-cost removal processing steps. The use of brine streams as an input for commercial companies could be a way of decreasing the need to "dispose" the brine, if selective removal can enable the brine to become a feedstock or input into another industrial process.

- *Source Characterization of Inland Brackish Water:* Inland brackish sources can vary significantly in quality and availability, thus making it much more expensive to desalinate. Characterization of the source is important to enable movement of the brine to industrial sites that could use the brine and to understand the extent of treatment needed to enable water production of a certain quality.

- *Flexible Desalination Technologies to Integrate with Variable Renewable Energy Sources:* The current processes for desalination (e.g., thermal membrane distillation or reverse osmosis) have traditionally operated within an environment of stable energy inputs of heat or electricity. There are growing opportunities to use increasing levels of variable renewable energy to power desalination technologies, and for water treatment plants to provide demand response services to the grid. Technological advancements are needed, however, to allow desalination technologies to operate flexibly and accept variable energy inputs (e.g., solar PV, marine hydrokinetic, and wind) without impacting operations.

- *Process Intensification through Small-Scale Modular Units*: This approach could be used to decrease the number of process steps by combining multiple unit operations and, ultimately, decreasing the size, cost, and energy intensity of a desalination facility. Such small-scale modular units would significantly reduce the initial CAPEX for either pretreatment plants or entire desalination systems, which could be more easily deployed in remote locations to serve smaller populations, meet industrial needs for shale gas production in arid locations, or for emergency response and shorter-term purposes.

- *Gray Literature Access:* To date, significant R&D has been conducted by DOE; the U.S. Environmental Protection Agency (EPA); the U.S. Geological Survey (USGS); the U.S. Department of Interior, Bureau of Land Management; and other U.S. and global entities before the digitization of information and data. A prize could (1) bring the results of this research and data together in a data hub and (2) scrub the data for credibility and usability to enable easier access to researchers, analysts, and the public.

Topic Area 2: Transforming Produced Water into a Resource

Water Security Grand Challenge Goal: Transform the energy sector's produced water from a waste to a resource

Produced water most commonly refers to the water that is coproduced with the extraction of oil and natural gas (estimated in 2012 at 21.2 billion barrels per year across the United States), though it is also an issue with uranium mining and carbon capture, utilization, and storage (Veil, 2015). With some exceptions, current practice within the oil and gas (O&G) industry is to dispose of produced water in underground injection control (UIC) wells at a cost of about $40 billion annually (SPE, n.d.).

Cost-effectively treating produced water for non-oilfield and other beneficial uses presents a multitude of R&D opportunities and would bring several benefits. First, it could help address water scarcity in water-stressed regions by making more water resources available for agricultural use, mineral extraction and processing, and reuse in other industrial operations. Second, water sales for alternative uses could create a new revenue stream for the extraction industry. Cost-competitive desalination technologies developed under Topic Area 1 could also be applied to produced water. But additional challenges specific to produced water include complex treatment trains to remove specific constituents that often make it less expensive to dispose of produced water than to treat it for another beneficial use.

The breakout group focused its discussion on developing prize ideas that address opportunities for produced water reuse from different angles and disciplines. Their prize ideas included matching of water supply with potential water use, optimization of transportation networks, development of analytical testing methods for measuring produced water constituents, and improvements to resource recovery technologies. Prize ideas addressed in the breakout group specifically considered produced water from both O&G operations as well as uranium mining and processing.

Prize Idea 2.1: Optimized Transport of Produced Waters from Source to Demand

- *Ideal End Goal:* To facilitate reuse of produced waters for other beneficial purposes, a cost-effective and optimized method for physically transporting water from various sources to demand areas is needed. An ideal state would see the creation of a "midstream" water transport industry (similar to the midstream industry currently in the O&G industry) for safe, cost-effective, and efficient conveyance of water.

- *Key Problems and Barriers:* Currently, strategies for transporting water are highly dependent on oilfield conditions (e.g., size, produced water volumes, and proximity to other users) and individual extraction companies' operating procedures. If enough water were located in an area near its final destination, temporary or permanent piping infrastructure could be used to transport the water, but there are permitting challenges associated with this. Due to a lack of available options for reuse and disposal, produced waters are often trucked over long distances to disposal sites in certain areas (e.g., West Texas-produced waters are trucked to Oklahoma, and Marcellus shale-produced waters are trucked to Ohio), which leads to both high prices for disposal and potential spill points (Gilmore, Hupp, and Glathar 2013; API 2011; EPA 2013).

- *Proposed Prize:* The breakout group determined the prize could be effectively implemented by splitting it into two separate themes that could proceed either in parallel or in succession. Theme 1 would include ideation and a business development plan for creating a "midstream" water service to transport water from multiple locations to alternative users. Theme 2 would include a technology development prize focused on new designs, approaches, or materials that could enable more efficient and cost-effective water transport. The performance period for the ideation theme would be roughly one year, while the technology development theme would require a one- to three-year time frame, depending on the technologies proposed. This prize could be facilitated by partnerships with extraction process operators, which could provide water commitments or testbed locations, along with national laboratories, which could provide access to technology development and demonstration facilities.

Prize Idea 2.2: Rapid and Accurate Testing of Treated Produced Water for Alternative Uses

- *Ideal End Goal:* To enable reuse opportunities for O&G produced waters in a "fit-for-purpose" manner, a rapid and cost-effective analytical method or technology could demonstrate that the water treated is appropriate for its intended use. Effectively characterizing constituents in produced waters would help those selecting effective treatment methods to treat the appropriate constituents. Fit-for-purpose reuse opportunities can only be implemented after a technique for characterizing produced waters is identified (Boschee 2014; Shaffer et al. 2013; Theodori et al. 2014).

- *Key Problems and Barriers:* Currently, constituents in produced waters are not universally characterized for different treatment methods and reuse opportunities. There is no systemic screening method for testing constituents or even a list of constituents to be identified and removed, which means certain constituents might not be tested in all cases. Additionally, many different tests are often required, and the process can be time-consuming and require multiple parties.

- *Proposed Prize:* The prize would focus on developing analytical methods and technologies for rapidly analyzing treated produced water that could be used to characterize a standard set of constituents and indicate potential reuse opportunities. The analytical method should determine which constituents are to be analyzed and measured in order to demonstrate effective treatment along with associated testing methods. The end use of the produced water should also be considered as a part of technology and testing design. This prize would likely occur over a three- to five-year time frame and would require input from EPA and other public health organizations.

Prize Idea 2.3: Cost-Effective Resource Recovery from Produced Water

- *Ideal End Goal:* Produced water streams could become revenue-generating resources through the extraction of valuable raw materials and minerals that can be effectively collected and marketed. O&G produced waters contain raw materials that may have markets within the United States (Kim et al. 2018). Being able to reclaim these minerals could create new business opportunities, transform a waste product into a valuable resource, and allow the United States to domestically source certain materials that are currently imported, thereby increasing national security. Separation methods would be modular to take advantage of market prices of different coproducts to optimize production of coproducts at different times.

- *Key Problems and Barriers:* Some companies have developed methods to remove select materials from produced waters, but there are issues with the amount of materials contained in the water and the cost of treatment needed to remove these materials. The presence of other materials in the water may make separation at different scales more challenging or infeasible.

- *Proposed Prize:* The prize would develop and demonstrate technologies that separate desirable products in produced water while minimizing waste streams at costs that make resource recovery economically viable. This prize could be organized into three sequential phases. Phase 1 would be an ideation and business plan competition to identify recoverable materials and potential markets that would have a short (e.g., three-month) duration. Phase 2 would include a lab-scale demonstration to test recovery of co-products for at least one year. Phase 3 would include a commercial-scale pilot plant that could last two or more years. From Phase 2 onward, participants could collaborate with national laboratories to test the treatment methods as well as with industry partners to undertake demonstrations.

Prize Idea 2.4: Produced Water Resource Platform to Match Produced Water Sources with Potential Fit-for-Purpose Markets

- *Ideal End Goal:* The ideal end goal is a well-functioning market and supply curve platform to identify produced water availability and potential uses that would facilitate produced water to either be safely treated and used in other beneficial applications or used for resource recovery rather than be injected for disposal into saline aquifers (Guerra, Dahm, and Dundorf 2011). Reuse of O&G produced waters could preserve freshwater resources for other uses and turn an expensive waste product into a valuable resource. To facilitate reuse, O&G operators, potential users, and water markets would have access to a high-resolution dynamic resource map and supply curve that would provide information on the sources, volumes, and quality characteristics of produced water to match these sources with alternative use demands, whether for direct reuse or production of valuable coproducts found in the water (e.g., iodide and lithium).

- *Key Problems and Barriers:* Currently, there is no systematic way to geographically categorize sources, volumes, or qualities of produced waters that can be made available to other users or beneficial purposes. There is also a temporal component to produced water production, with production volumes and qualities changing over the life of the well and as new wells are developed. Without an accurate and systematic assessment of produced water availability, potential reuse opportunities are often overlooked.

- *Proposed Prize:* The prize would seek business model and software platform proposals to characterize produced water resource availability that could facilitate linking supplies with potential demands of alternative water sources. The proposed prize would elicit proposals to develop a method to connect the needs of alternative water demands with rapidly changing supplies of O&G operations. The prize could include the development of a market "clearinghouse" to connect produced water resources to other reuse opportunities. And, the final tool would be required to match the most cost-effective treatment technology with different water type and criteria constituents for the final use. Participants suggested the final prize winner could create a business model creating a software platform over a one- to three-year performance period.

Prize Idea 2.5: In Situ Recovery and Groundwater Remediation Strategies for Uranium Mining

- *Ideal End Goal:* Uranium in situ recovery (ISR) in the United States is performed mainly in fresh water aquifers (NRDC 2015), i.e., with less than 10,000 mg/l total dissolved solids, in which the mineralized portion of the aquifer contains naturally elevated levels of uranium and its decay products such as radium and radon (UPA 2015). Following the production phase, water continues to be pumped to the surface, treated, and then the purified water from the treatment process is reinjected to restore the aquifer water to regulatory standards that closely match pre-ISR aquifer conditions. The less water pumped to the surface and treated, the more groundwater remains in situ, and less groundwater will require disposal (NRC 2009). Conserving water during the groundwater restoration process would in turn conserve water in the formation where it is a valuable freshwater resource that can be used for other purposes. Moreover, minimizing surface treatment to achieve restoration goals can reduce the full-cycle cost of uranium ISR. The ideal end goal would be to keep water in the reservoir throughout the entire process; doing so could help conserve water, develop domestic uranium production competitiveness, and decrease dependence on foreign uranium supplies.

- *Key Problems and Barriers:* Surface treatment of produced water is technically effective in removing dissolved contaminants but generates wastewater and is time consuming and expensive. Commercially viable technologies using reductants or bio-stimulators need to be developed for use during the restoration phase to return the ore zone to pre-ISR geochemical conditions—in situ—to reduce the amount of necessary surface treatment.

- *Proposed Prize:* This prize would be a technology demonstration prize to develop new methods for in situ recovery and remediation technologies to preserve formation water following uranium production. The prize would be delivered into two phases: (1) a lab and demonstration and pilot phase followed by (2) field testing for down-selected technologies. Industry partners could offer physical rock and ore material and groundwater samples for lab testing in the first phase. In the second phase, industry partners could offer current field locations for pilot and field demonstrations. The performance period would be one or two years for Phase 1 and three to five years after for field demonstrations in Phase 2. Intellectual property rights of the new technologies would be negotiated from the beginning.

Additional Potential Prize Ideas

The breakout group discussed other ideas that could be suitable for prizes:

- *Treatment Concentrate Management and Disposal:* Participants discussed issues with brine/concentrate left over after water treatment for both O&G operations and uranium mining. Currently, this concentrate is injected into disposal wells that can be very costly, and depending on the constituents, expensive pretreatment may be needed before injection. Development of a cost-effective method to dispose of or repurpose concentrate for a beneficial purpose could be suitable as a prize.

- *Technoeconomic Tools to Identify Opportunities for Produced Water Reuse:* Participants mentioned that any reuse activities would likely need to be much more cost competitive than current disposal methods to allow for market changes. Industry is unlikely to react to modest changes in disposal cost due to regulatory and liability concerns. Developing tools to identify and optimize the cost of different treatment methods and produced waters reuse opportunities could support other prizes.

- *Innovative Methods to Determine Impact of Injected Chemicals on Water Chemistry:* Participants identified lack of knowledge regarding the impact of chemical injection on formation water. Identifying the impact of injected fluids on geologic formations and in situ water sources can facilitate optimization of chemicals injected, and it can potentially reduce surface treatment of produced water for other reuse opportunities. A potential prize could develop a unique approach to determine the impact of chemical injection on in situ water resources for several large O&G fields.

- *Induced Seismicity-Monitoring Programs and Technology:* Induced seismicity is a large driver of allowable injection volumes into underground injection control wells in certain regions (e.g., Appalachia and Oklahoma) (Weingarten et al. 2015; Holland 2013). Induced seismicity has also been a large area of public concern with respect to hydraulic fracturing operations increasing produced water volumes (Ellsworth 2013; Ellsworth et al. 2015). A prize competition could help find solutions to develop early indicators of induced seismicity or to develop analytical methods for calculating optimal water injection volumes to reduce seismicity concerns.

- *Public Education on Beneficial Reuse of Produced Waters for Non-Oilfield Applications:* Participants discussed the potential for an ideation prize that would call for multifaceted and multidiscipline proposals to demonstrate opportunities (e.g., case studies, data creation, and communications) to increase education around the reuse of produced waters.

- *Effective Management of Naturally Occurring Radioactive Material (NORM) from O&G-Produced Waters*: NORM is a collection of natural constituents that can be found in produced water. Currently, NORM is removed during normal treatment operations (e.g., reverse osmosis and desalination), but this removal causes concentration within the brine concentrate and in filter media (Perma-Fix 2015). Once this NORM is concentrated, it can become costly to dispose of, and it can eliminate the feasibility of mineral recovery from produced waters. Participants discussed a prize that would seek technology innovations to minimize or limit the impact of NORM concentration in conventional water treatment processes.

Topic Area 3: Reduction of Water Impacts in the Power Sector

Water Security Grand Challenge Goal: Achieve near-zero water impact for new thermoelectric power plants, and significantly lower freshwater use intensity within the existing fleet

The thermoelectric power sector is critically dependent on water resources for its operations. Most importantly, thermoelectric power production requires large volumes of water at sufficiently cool temperatures for optimal cooling operations. The majority of the water that is withdrawn for cooling operations is returned to its source, while water that is not returned to its source is considered consumed, typically through evaporation. In the United States, the water withdrawn for thermoelectric cooling accounts for about 40% of all water withdrawals and 3% of consumptive use across the country (Dieter et al. 2018). Effluent water from the power plant's operations, including water released from the cooling systems, can affect aquatic ecosystems by altering natural water temperatures and flows. The power sector's reliance on water resources for operations poses risks to ideal power production, especially in the context of anticipated warming ambient temperatures, increased water stress, and more frequent extreme events such as droughts (USGCRP 2018; Miara et al. 2017). Water-related curtailments of power plants have already occurred in many parts of the United States (McCall, Macknick, and Hillman 2016). Similarly, water impacts on power supply are also a global concern. For example, several nuclear plants in France recently curtailed production after a heat wave raised the temperatures of rivers that the plants depend on for cooling (Nucleonics Week 2018). The thermoelectric power sector's water demand can also limit the availability of water supplies for other uses, potentially limiting the economic growth of surrounding communities. New technologies are being developed that significantly reduce freshwater impacts in the thermoelectric power sector. These solutions include dry cooling technologies that require negligible amounts of water, improved operational practices that minimize water losses within a plant, and the use of alternative non-freshwater sources for cooling in plant operations. Traditionally these solutions have faced challenges to deployment due to economic, technological, and regulatory barriers. Figure 2 shows an overview of the power sector's potential impacts on water resources.

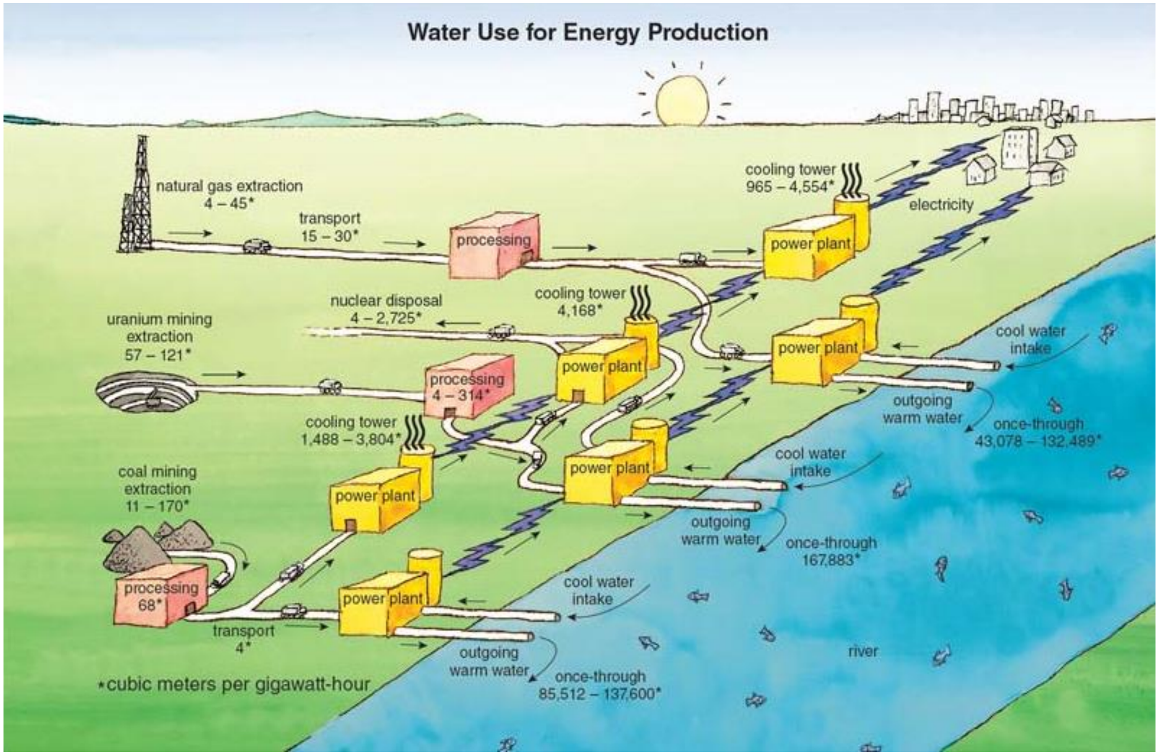

Figure 2. Water use for energy production (Averyt 2016).

The overarching focus of the breakout group discussions was on identifying prizes that could lead to near-zero water impacts for newly built thermoelectric power plants along with significantly lower freshwater use intensity for existing thermoelectric power plants. Prizes focused on improving sensors and data analytics, increasing resilience of cooling technologies, developing new materials to increase efficiencies, fostering unique industry partnerships to beneficially use wastes, creating zero-liquid discharge technologies, and identifying risk.

Prize Idea 3.1: Sensors and data analytics for optimized power operations

- *Ideal End Goal*: Power plant operators would have access to real-time water flows throughout a power plant and apply data analytics to achieve optimal water use and improved thermal efficiencies. A technology that tracks water quantities and quality (e.g., enthalpy and chemical compositions) in real time could help improve the understanding of water balances at power plants. Importantly, this technology should be linked with a data analytics and optimization package that would help show capabilities in lowering water use, improving operating efficiencies, and lowering parasitic loads. Successful implementation of the technology might include state-of-the-art sensors and must be (1) low-cost, (2) scalable across any power plant technology, (3) noninvasive with minimal human intervention or interruption to operations, and (4) automated with readings uploaded to a central device and connected to the analytics system.

- *Key Problems and Barriers:* The movement of water and steam through the thermal cycle of a power plant, including water withdrawal and consumption rates for cooling, depends on the prime mover, cooling technology type, location and operator of the plant (Meldrum et al. 2013). Each power plant has unique water use characteristics, and the complexities involved in quantifying these have been articulated in several studies (Averyt et al. 2013; Luo, Krishnaswami, and Li 2018; Macknick et al. 2012). Operators lack understanding of the water balance and water characteristics across a power plant, and conducting one-time, plant-specific studies that aim to understand and lower water use and leaks can be costly. This lack of understanding limits both thermal efficiencies and efficient water use.

- *Proposed Prize:* The prize would be a multiphase prize with multiple components focusing on developing a technology that would facilitate real-time sensing, analysis, and response to water flows in order to achieve optimal water use and thermal efficiencies. In Phase 1, a monetary prize could be offered to help fund laboratory tests over two years, with a technology demonstration at the end. In Phase 2, there could be a matchmaking prize with industry to deploy and test the technology at a pilot power plant. The technology would be used to simulate base-case water use and demonstrate, but not implement, potential improvements in water use and thermal efficiencies. This stage would be conducted over two years. In Phase 3, the technology could be implemented as an optimal water use strategy with industry partners over a one-year test period.

Prize Idea 3.2: Reducing the Dependence of Power Plants on Water and Temperature Conditions

- *Ideal End Goal:* Power plants that can operate at full capacities and efficiencies while requiring less water and being unaffected by local environmental conditions. Ideal technologies should lower lifetime costs and parasitic loads or provide efficiency benefits that offset differential costs, relative to existing recirculating systems. Technologies that achieve this result could maintain condenser inlet temperatures as close to the wet-bulb temperature as possible with minimal variability throughout the year. Technologies could have net-zero or near-net-zero cooling water makeup needs to reduce vulnerabilities related to freshwater supply. Net-zero water usage innovations may leverage wastewater treatment capabilities to recover water from combustion turbine and flue gases for cooling purposes. Using recycled water in the cooling process to achieve net-zero freshwater use could reduce vulnerabilities associated with water resource variability and extreme weather events.

- *Key Problems and Barriers:* Cooling-water temperatures and the variability of water resources can reduce thermal efficiencies and power output (McCall, Macknick, and Hillman 2016). Currently, dry cooling technologies may be used to help alleviate any potential water constraints as they require no water for cooling. However, dry cooling has a higher capital cost than recirculating and once-through technologies, and it includes an inherent efficiency penalty associated with its cooling process (EPA 2001). Recirculating cooling technologies are more efficient than dry cooling technologies, but they depend on low humidity levels, cool air temperatures, and consistent freshwater supplies, while consuming most of the water they use.

- *Proposed Prize:* Two specific technology prizes were identified to address this key issue. Under the first prize, approaches for near net-zero freshwater for cooling maintain or improve thermal efficiencies. With the second prize, climate-water independent cooling systems are unaffected by local environmental conditions, including air temperatures, water temperatures, humidity or minor variations in water availability. Each prize could follow a similar multiphase process. In Phase 1, a monetary design prize could be awarded to top-three contestants that would help fund development of the technology. In Phase 2, the prize could serve as a matchmaking prize with industry or national laboratories to collaborate on development and deployment of the technology/process. This stage would be implemented over three years. In Phase 3, the technology could be deployed at a pilot site with monitoring of cooling system technology and power plant performance; this stage would be implemented over two years.

Prize Idea 3.3: Smart Materials for Improved Heat Transfers

- *Ideal End Goal:* Heat degradation occurs throughout a power plant, which affects the plant's overall thermal efficiency. In an ideal state, power plants could improve heat transfer at various stages of the thermal cycle to simultaneously produce a higher overall thermal efficiency and lower water intensity. Solutions could be applied to all heat transfer surfaces throughout the power plant, including all pipes and cooling systems.

- *Key Problems and Barriers:* In certain phases throughout the heat cycle, heat transfers or thermal losses are suboptimal, and these are not always known or detected by plant operators. These losses might occur in piping systems before the heat transfer in the condenser, the condenser itself, and piping between the condenser as water flows back to the boiler. The thermal losses lead to lower efficiencies and higher water use rates.

- *Proposed Prize*: The prize would seek improvements in heat transfer processes through the use of smart materials to boost the overall thermal efficiency of a power plant, thereby reducing water requirements. The breakout group discussed several applications of these innovations, including (1) long-lasting multipurpose pipe coatings that minimize biofouling and scaling on the water side or promote hydrophobicity to promote drop-wise condensation on the steam side of condensers and heat exchangers, (2) advanced cooling systems that might include use of hydrophobic and super-hydrophobic materials and coatings on steam side of condenser tubes, and (3) different types of cooling tower fills, additives, and coatings to enable higher cycles of concentration while preventing scale and maintaining heat transfer. The prize could operate in two phases. Phase 1 would be a monetary design prize that would be proportional to the proposed efficiency gains to develop the technology and design the process of application to a test-plant. Phase 2 would involve joint industry participation to test, monitor, and deploy the technology.

Prize Idea 3.4: Unique Industry Partnerships to Beneficially Use Waste Heat and Wastewater in Other Sectors

- *Ideal End Goal:* The ideal end goal is that power plants proactively partner with other industrial or agricultural entities to provide a mutually beneficial use for waste heat and wastewater outputs. Ideally, waste heat and wastewaters are eliminated as they serve as beneficial inputs into other industrial processes. This concept is in line with current industrial ecology theories and practices but seeks novel and advanced systems designs and technologies in the context of utilizing resources at power plants for enhanced productivity in other sectors.

- *Key Problems and Barriers:* Cooling-water effluents and their heat content are typically released to local environments, without beneficial or economic use. District heating is an example of waste heat utilization for beneficial use, but plants in the United States are typically too far from sufficiently dense population centers to economically employ this approach. Similarly, wastewater effluents from flue gases and the cooling process are treated at costly rates and are sometimes discharged back to natural water bodies, potentially harming the environment. The beneficial use of recycled wastewater, brines, and solids faces technological challenges related to material durability, treatment efficiencies, and transport costs; and it also faces non-technological changes such as identifying suitable markets and public acceptance of beneficial uses.

- *Proposed Prize:* The prize would seek technology and design solutions to maximize the use of waste heat and wastewater from power plants for a secondary revenue-generating industrial process. The secondary processes and systems are unspecified, but may include water treatment and recovery for irrigation purposes, heat for biogas systems, greenhouse operations, and modular desalination. The technology solution would need to demonstrate its cost effectiveness through techno-economic assessments and be applicable in multiple locations. Successful concepts could also include approaches that might help improve the social acceptance of wastewater reuse for both irrigation and potable purposes. The prize could proceed in multiple phases. Phase 1 would include a design competition that showcases ideas including system designs and performance modeling, but potentially a demonstrable system. In Phase 2, the ideas from Phase 1 could be developed at a pilot site.

Prize Idea 3.5: Low-Cost Zero Liquid Discharge

- *Ideal End Goal:* The ideal end goal is a "universal silver bullet" technology or method that could treat water used in a power plant for on-site reuse to allow for cost-effective zero liquid discharge (ZLD). Ideal technologies could adapt to changing input water quality conditions, including high total dissolved solids concentrations. Through reuse, power plants become less vulnerable to changes in water availability and minimize their ecological impacts through ZLD or near-ZLD operations. Technologies have sufficiently low costs to incentivize voluntary adoption at new and existing power plants.

- *Key Problems and Barriers:* Wastewater treatment and disposal can represent a significant cost for power plants. ZLD technologies could help alleviate these costs, but power plants attempting to achieve ZLD face both technological and cost challenges. To date, no technologies have been developed that can cost-effectively achieve ZLD for power plant waste streams. Through the encapsulation process, certain constituents can be isolated and removed to improve the quality and disposal options of waste streams, but costs still remain the primary barrier.

- *Proposed Prize:* The prize would seek technology advancements that achieve ZLD or near-ZLD for power plant wastewater streams. The breakout group discussed lowering wastewater concentrations of total dissolved solids to 300,000 or less—a value that could be refined. The technology process may aim to recover as much water as possible from waste streams for potential reuse within the plant or for industrial, irrigation, or even potable purposes. For example, a possible process might be low-cost wastewater treatment that meets effluent limitation guidelines for wastewater with no impact on the local environment. The breakout group discussed how a tiered monetary technology prize could be implemented, whereby applicants receive different levels of funding support depending on how well their proposals ranked.

Prize Idea 3.6: Readily Accessible Water Risk Data for Power Plant Operators and Planners

- *Ideal End Goal:* Power plant operators, energy planners, and decision-makers have access to data via a tool that can accurately and reliably inform them of potential water-related vulnerabilities to cooling systems and operations, at both existing and potential sites. This information would provide crucial insights on the potential water-related vulnerability of power system assets, and it could improve operational dispatch as well as decision-making for siting new power plants. Data could be made available through a user-friendly risk assessment tool or software platform that could identify and estimate water-related power production risks under various conditions.

- *Key Problems and Barriers:* Water shortages and warm air temperatures affect the cooling process and operations of thermoelectric plants, resulting in lower thermal efficiencies and power output. Water resource availability and quality characteristics are local, and many estimates of changes and variability of water resources are not tailored to power system planning and operations decisions. Moreover, site-specific near-term and long-term water availability and quality projections are not always well understood, leading to large uncertainties in future conditions and how they might affect power plants. Available data or modeling tools that would be useful for power plant operations and planning decisions are often not formatted or presented in a way that they can be directly used by the power sector in its decision-making.

- *Proposed Prize:* The prize would seek innovations that would make relevant water risk data available to the power sector to help with operations and planning decisions. This could include building a water risk assessment tool that identifies water-associated vulnerabilities at existing and future sites. Ideally, the prize would include a range of modeling estimates combined with robust statistical assessments of water availability and quality to provide a more-comprehensive risk profile. The water risk information would include hydrology, climate, land-use and land cover, and power plant and system operations models. If possible, the information would also include competing water users, upstream reservoir operations, regulatory requirements as well as both near-term and long-term risks associated with power plant operations. The prize could also include a design and implementation element along with industry partnership for validation.

Topic Area 4: Resource Recovery from Wastewater

Water Security Grand Challenge Goal: Double resource recovery from municipal wastewater

Wastewater treatment plants face more than $200 billion in future capital investment needs to meet water quality objectives (EPA 2016). At the same time, wastewater treatment plants purchase about $2 billion worth of electricity each year (Arzbaecher et al. 2013). These energy costs can significantly impact municipal budgets; when coupled with drinking water systems, water services can account for a third or more of a city's energy bill (EPA 2018). Energy costs are expected to increase over time, impacting the affordability of water for businesses and consumers, which have seen steady rate increases over the last decade (Arzbaecher et al. 2013; DOE 2017). Disposal of residual biosolids that come out of the treatment process represent another significant cost for municipalities.

Wastewater treatment plants can address these challenges by recovering critical resources and turning them into marketable products. This includes energy that can be used on-site or sold to others, nutrients, such as phosphorous and nitrogen, which can be used as fertilizer, and clean water that can be reused for agricultural, industrial, and potable purposes. By recovering and marketing these resources, wastewater treatment plants create new revenue streams, prevent nutrient pollution, and provide new sources of alternative water supplies. Energy efficiency and resource recovery may be especially beneficial for wastewater treatment systems that serve small rural communities. Treatment plants in these communities often need significant infrastructure upgrades to maintain reliable services. However, such systems serve smaller populations of often price-sensitive customers that struggle to absorb the rate increases needed to finance the investments. Resource recovery measures could raise revenue for these upgrades, easing some of the financing burden for ratepayers. Figure 3 shows resource recovery opportunities for wastewater treatment facilities.

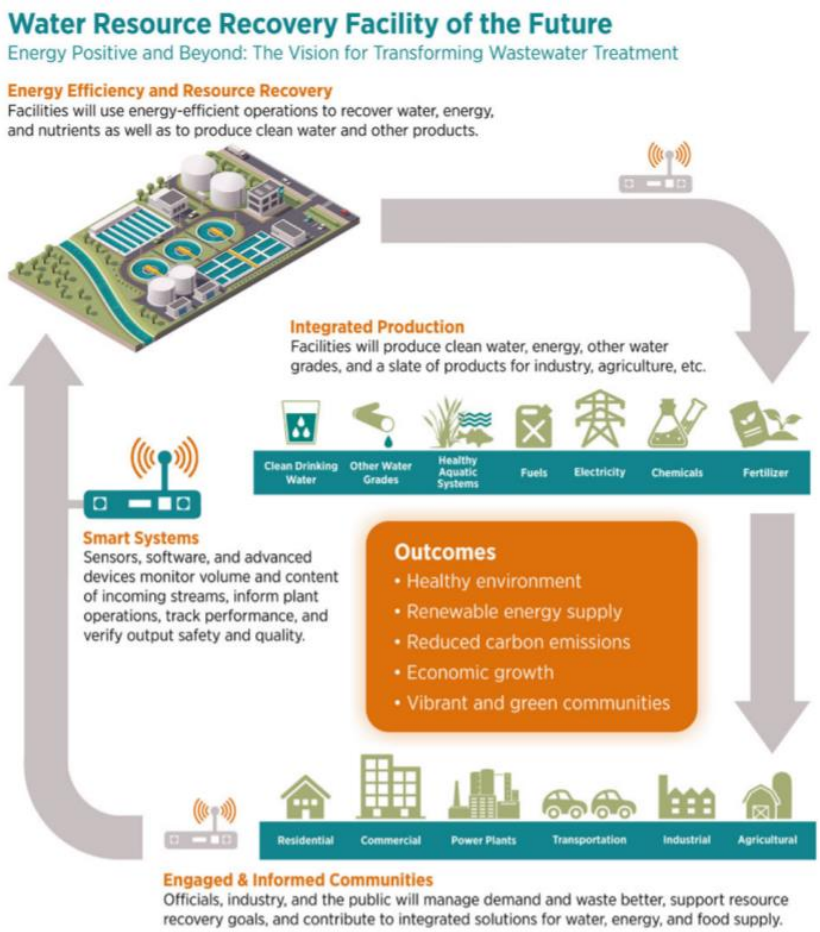

Figure 3. Water Resource Recovery Facility of the Future (DOE 2016)

The breakout group noted the large potential resource base in wastewater and the current lack of recovery of these valuable resources, and it focused on identifying and exploring opportunities to increase resource recovery from wastewater by developing prize strategies that would address multidisciplinary components of barriers. Specific prize ideas included a baseline assessment approach for characterizing and valuing resources, increasing resource recovery at small facilities, making beneficial use of low-grade heat, and aligning energy and water policies to be consistent such that they could foster increases in resource recovery.

Prize Idea 4.1: Characterization and Valuation of Resources in the Wastewater Stream

- *Ideal End Goal:* The ideal end goal is that resources in the wastewater stream—valuable elements, water, energy, and nutrients—are adequately characterized, valued, and recovered. The value captured includes not only the monetary value but also the value of associated ecosystem services. Wastewater utilities become an important provider of not only clean water but also nutrients, minerals, energy, and ecosystem services (WEF 2013). Each wastewater utility would have both reliable data on the constituents of its resource stream and access to data on the potential value in various markets of those constituents, allowing it to make informed decisions on resource recovery.

- *Key Problems and Barriers:* Currently, wastewater treatment operations are focused on treating a waste stream and meeting regulations; efforts to characterize, value, and market products are often seen as outside their scope of activities. Moreover, no standardized approach is used to characterize and value resources in wastewater streams, and often resource assessments will target only certain types of resources, when each wastewater stream is likely to contain elements, water, energy, and nutrients that are of value. Even if values of some resources are known, the wastewater treatment facility might not have knowledge of, or access to, an appropriate market.

- *Proposed Prize:* The breakout group developed two prize ideas that could facilitate greater resource recovery from wastewater streams related to characterizing and valuing resources. The first prize would be a technology and business model prize for which a standard approach to characterizing various resources in wastewater streams would be developed. Such a solution could empower wastewater treatment plant operators to accurately assess and value the resources present in their individual waste streams, or it could foster the development of new companies to perform such an assessment. The second prize would be a software application, or app, challenge using publicly available data to highlight locations where resource recovery would likely be most valuable. Data from wastewater operations, including flow, temperature, nitrogen, phosphorus, and other variables is collected and made publicly available by the EPA. This information could be combined with resource demand data, water scarcity, commodity prices, as well as ecological data to provide unique visualizations and analyses that could support more resource recovery activities.

Prize Idea 4.2: Increasing Resource Recovery at Small Wastewater Treatment Facilities

- *Ideal End Goal*: All wastewater utilities, regardless of size or treatment processes, can capture valuable resources from their systems for beneficial and revenue-generating purposes. Resource recovery would include energy, water, nutrients, and other elements that are often only deemed to be economic at larger wastewater facilities. Small-scale plants (e.g., those processing about 100,000 gallons per day or less) could operate as energy-neutral on only the flow of the wastewater coming in and from their on-site generation. Unique partnerships could form (1) among small, independent wastewater treatment facilities or (2) for a network of small wastewater treatment facilities in a given region to achieve economies of scale.

- *Key Problems and Barriers*: Currently, resource recovery is done almost exclusively on large treatment facilities, albeit not as effectively or efficiently as possible. Larger wastewater facilities can provide more resources per site, and resource recovery at smaller facilities has not been economically viable. The vast majority of wastewater plants in the United States treat less than one million gallons per day (MGD), which indicates a large potential opportunity for resource recovery innovations that target smaller facilities (Arzbaecher et al. 2013).

- *Proposed prize:* The prize would seek innovative technology and design solutions that would enable cost-effective resource recovery from small wastewater treatment facilities. This prize competition could take a phased approach. Phase 1 would entail a design competition in which proposals would include flow diagrams and concept papers. Phase 2 would include partnership matchmaking and business plan development to ensure the technology designs meet requirements of smaller facilities. Phase 3 would include development and testing of technologies at lab-scale.

Prize Idea 4.3: Recovering Low-Temperature Waste Heat from Wastewater Influent Sewer Pipes

- *Ideal End Goal:* The ideal end goal is that wastewater treatment plants consistently recover the low-temperature waste heat from incoming wastewater streams and use the waste heat to improve efficiencies and reduce costs. Ideally, wastewater utilities could use the low-temperature heat to reduce building energy usage and increase treatment efficiencies for various processes. Capturing this low-temperature heat would provide immediate operating cost savings that could offset any capital expenditures required.

- *Key Problems and Barriers:* Waste heat recovery from incoming influent pipes is rarely done in the United States; however, the potential for waste heat recovery from distribution and collection systems is very large. Although some existing technologies could allow for heat recovery on a municipal scale (e.g., heat pumps), they are seldom deployed. One factor is that energy costs are still relatively inexpensive, which can disincentivize energy efficiency and recovery. Also, wastewater utilities are often financially constrained, and installing heat recovery systems requires capital. Furthermore, many wastewater utilities are unaware of the potential benefits of economically viable heat recovery, and those that are aware are likely overwhelmed by the potential O&M and potential costs on the recovery system. Very little is known about O&M on waste heat recovery systems at scale. Another important technical consideration is the impact of withdrawing heat upstream on wastewater treatment plants, many of which use anaerobic digestion techniques. There is a risk that too much heat could be extracted upstream from the inflow, which could make waste stream temperatures drop below desirable levels for anaerobic digestion (Informed Infrastructure 2012). Participants noted that this could be designed around specific metrics, and they suggested it could be framed around recovery of a specified quantity of British thermal units per gallon, with a different goal for small treatment plants.

- *Proposed Prize:* This prize competition would seek innovative technology solutions in which a competitor would pair with a city or a treatment plant to identify a wastewater heat recovery solution. The contest would challenge the competitor to identify where in a system waste heat recovery is economically viable and would then include the development of a new technology or an improved system design to capture the waste heat for beneficial use within or outside of the plant. Given current limitations of this technology's deployment at large scale, and given the unknowns of O&M of the recovery systems at such a scale, the prize competition should explicitly require that these two limitations be considered and pathways to overcoming them be proposed.

Prize Idea 4.4: Aligning Energy, Water, and Other Regulations to Foster Resource Recovery

- *Ideal End Goal*: The ideal end goal is that energy, water, and other applicable regulations are consistent and aligned to foster resource recovery. Ideally, regulations that impede state of the art resource recovery are updated to encourage resource recovery while maintaining public health, environmental health, and safety.

- *Key Problems and Barriers*: Innovation in wastewater operations and resource recovery can be stymied by regulations that unintentionally restrict recovery activities. For example, wastewater utilities might be prevented from selling energy resources they have captured from their waste streams, depending on the form of energy and the target energy market. Energy, water, and environmental regulations are often created by different entities and might not capture all unintended consequences that affect other sectors.

- *Proposed Prize:* This prize competition would be designed to bring together relevant stakeholders to discuss how wastewater and associated regulations could be aligned to support broader resource recovery. The competition would be held at the municipal or state level, and competitors would be multi-institutional and would include regulators, municipal utilities, economic development organizations, and other stakeholders. Communities could identify specific regulations that are inhibiting resource recovery and contribute to solutions; regulators would partner with businesses and community entities while also developing educational opportunities with business schools and public policy programs at the collegiate level. The anticipated outcome would be the development and broad dissemination of innovative policy frameworks for wastewater treatment that could encourage innovation, resiliency, and resource recovery.

Topic Area 5: Development of Small, Modular Energy-Water Systems

Water Security Grand Challenge Goal: Develop small modular energy-water systems for urban, rural, tribal, national security, and disaster response settings

Small, modular energy and water systems have the potential to cost-effectively serve areas where energy or clean water is expensive and/or challenging to produce. Such areas include urban settings, where population growth is occurring but central energy or water systems are nearing maximum capacity; rural communities, including tribal regions, where population levels cannot accommodate the economies of scale needed to make large, central systems viable; military sites in remote areas without access to central electricity and water systems; and disaster response areas when storms and other events have knocked existing energy and water systems offline. Small, decentralized energy-water systems can play an especially important role in serving the more than one billion people worldwide that currently lack access to reliable sources of electricity and water (WHO 2017). In addition, small-scale energy systems that take advantage of existing water conveyance infrastructure have been shown to provide several benefits, including economic benefits, water conservation, and energy for rural agricultural communities (Samora et al., 2016). Lower-cost distributed energy resources have opened opportunities to power decentralized water systems that lack access to a centralized grid. Innovation is needed to improve the cost-effectiveness of linked energy-water systems and test their performance in a range of applications. Advancements in this area would also support several of the other Water Security Grand Challenge goals, including launching cost-effective desalination technologies (Topic 1), reducing treatment costs for produced waters (Topic 2), and lowering energy costs in wastewater treatment plants (Topic 4).

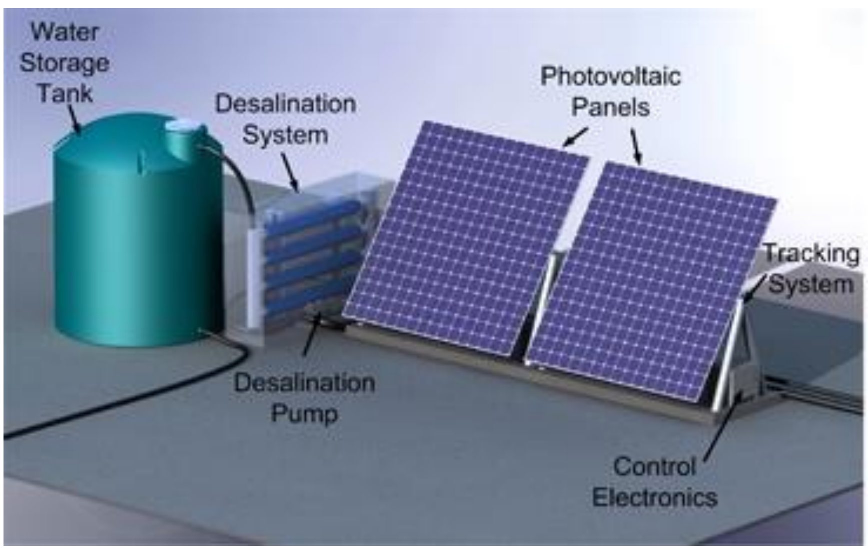

Figure 4. Disaster recovery energy and water system (Dubowsky 2010)

The breakout group largely focused on modular prize ideas that would be applicable at different scales. These ideas included designing the house of the future, a modular community of the future, and a deployable energy-water in a box concept that could be used for disaster recovery or in isolated communities, as well as furthering data analytics and controls for multiple energy-water objectives and developing an agricultural energy-water optimization platform. The first three ideas were developed most completely for the Water Security Grand Challenge, and the last two ideas were recognized as highly desirable, but the group did not have time to fully develop them.

Prize Idea 5.1: House of the Future

- *Ideal End Goal:* As ideal end goal, an energy-water efficient house of the future could be rapidly deployed. Reducing modular energy-water systems to the smallest single unit, this prize involves designing a residential-scale system that could operate behind the meter, free from grid constraints.

Ideally, the house of the future would strive for net-zero energy and water, and it would integrate and co-optimize residential-scale energy and water systems. The house should aim for high energy efficiency and flexibility and incorporate energy generation and storage to meet consumption needs. In terms of water, emphasis should be placed on conservation, recycling, and fit-for-purpose water, such as increased potable water efficiency, matching water treatment level to purpose, and proper treatment of gray and black water generated from the household water use or reuse.

- *Key Problems and Barriers*: Though progress has been made toward achieving net-zero energy homes in recent years, optimizing of water systems at the household level has been limited. Certain cultural challenges need to be overcome before the distributed energy model could be applied to the water system. For example, greater acceptance of non-potable reuse must be achieved, and technologies that enable gray water reuse in premise-scale applications must be expanded. Policies and regulations around gray water reuse may need to be reexamined in certain locations. Greater understanding of the scarcity problem and conservation needs—through education and outreach—may be needed to raise social awareness about water issues and to promote new designs.

- *Proposed Prize:* This prize would be best formulated as a design challenge and would lead to seed funding for a proof of concept for top ideas. The broad goal is to optimize energy consumption and production as well as water use at a household level, and to structure the prize to avoid limiting participants to specific metrics based on predefined technology pathways. Refinement of metrics would be needed, and the group emphasized that affordability (e.g., cost per square foot) should be a main metric of comparison. While the house of the future may have systems that operate independently, it should be able to integrate into existing communities with legacy energy and water infrastructure.

Prize Idea 5.2: Modular Community of the Future

- *Ideal End Goal:* The ideal end goal would be to develop and standardize small modular energy-water systems that could be quickly and reliably deployed to support greenfield development in urban and suburban spaces as well as in remote isolated communities. The goal would capitalize on the modular nature of small efficient energy-water systems to quickly build up new communities, from housing developments to campuses and other networks of buildings. The modular and self-contained nature of such systems can drive down permitting time and costs and simplify installation processes, ideally overcoming the high land development costs found in many locations. Components should be co-optimized and highly efficient. Furthermore, modular systems can be easily added to quickly expand communities and accommodate rapid population growth rates.

- *Key Problems and Barriers*: A key barrier to the advancement of small, modular energy-water systems is that developers often have limited access to funding and they lack the staff and resources to innovate. And, the maintenance and operation of existing systems have been emphasized more than the optimization and coordination needed to streamline growth and development. This prize could help remove some barriers to greater resource efficiency by developing networks of small systems with standardized products and procedures. Resources, staff, and best practices could be shared across many networks to further improve the economic viability of small, modular energy-water systems.

- *Proposed Prize:* Like Prize 5.1, this prize would be ideally suited as a design challenge. Metrics could be established around system performance, affordability, and time to market. Key criteria for selecting the winner include the level of resources required to build the system and the ease of deployment. To involve current market players in this space, multiple rounds of funding could be made available at regular intervals, depending on performance and achievement toward goals.

Developers of small energy-water systems often lack resources and cannot devote large amounts of time to other efforts if funding streams are unclear or insufficiently attractive.

Prize Idea 5.3: Energy-Water in a Box

- *Ideal End Goal:* The goal of the prize is to produce a well-designed, adaptive plug-and-play energy-water system that can meet the needs of most small modular applications while being flexible enough to address unique application requirements, including rapid deployment to aid disaster response efforts or serve long-term needs in remote isolated communities where centralized systems may be unreliable or unavailable and too costly to construct. The product developed should be easily transported, highly flexible, and able to adapt to a variety of environmental and load conditions across different geographical areas and use cases. The system should be reliable, resilient, and able to withstand harsh operating conditions. It must be completely self-sufficient and require no external fuel inputs. To ensure the processed water is safe for use and to build confidence in the infrastructure, monitoring systems should alert users whenever quality is compromised.

- *Key Problems and Barriers:* A challenge to the energy-water in a box concept is in defining the scope of functionality. No one-size-fits-all solution addresses all small, modular energy-water system needs. Variations in input can drastically impact the types of technology required and the levels of output quality are achievable (e.g., processing waste water versus seawater). Furthermore, there is also a large variation in the source of energy and water, depending on many factors (e.g., geography, season, and time of day). Climate also will have an influence on system designs, as technologies suitable for the Tropics might have different requirements than those in the Arctic. It is difficult to define the most relevant input and output metrics for a one-size-fits-most solution to small, modular energy-water system applications, and further breakdowns may be required to target groups of applications.

- *Proposed Prize:* This prize is ideally suited to be a design challenge. Metrics could be established around system performance, affordability, and time to market. Key criteria in selecting the winner include level of resources required to build the system and ease of deployment. Size requirements and performance criteria could be established to judge winning designs. Water and energy output quality metrics may be specified and designs could compete based on which system can produce the most output quantity while meeting the desired quality constraints.

Additional Potential Prize Ideas

The breakout group discussed two other promising ideas for prizes but did not have as much time to fully develop the ideas:

- *Data Analytics and Controls for Multiple Energy-Water Objectives:* This idea calls for an improved monitoring and optimization platform for small, modular systems that could operate autonomously to support integration of multiple objectives related to energy production, grid services, water supply and treatment, and environmental conservation. Ideally, a large number of sensors would be leveraged or deployed to collect real-time data across all domains of interest. Big data and machine learning methods could then be used to improve system integration across multiple sectors. Data analytics from system components should be standardized to ease modular integration within small-scale isolated systems and between modular systems and legacy systems. Current challenges in this prize area include a lack of high-resolution, real-time data measurements for many data streams of interest; "siloing" of existing data streams; bandwidth challenges in communication and control; and a lack of standardized protocols and data formats for the ease of data exchange between systems. These barriers decrease operational efficiency and hinder high-fidelity optimization of multiple interconnected systems. The prize could be structured as a design or software challenge leading to additional funding for a proof-of-concept and technology demonstration.

- *Agricultural Energy-Water Optimization System:* This prize idea focuses on small, modular energy-water systems for agricultural applications. The goal is to develop a tool that incorporates sensors and monitoring technology, advanced control strategies, and detailed hydraulic modeling to more effectively optimize irrigation schedules and water delivery to crops, meet stream conservation needs, and deliver power system benefits (e.g., serve as a demand response or ancillary services resource). Greater integration of agricultural systems with environmental management and power system signals could lead to efficiency opportunities that individual systems cannot separately address. Currently, hydraulic modeling is expensive, time-consuming, and highly labor intensive. Lowering the cost of acquisition and automating the processing of high-resolution LIDAR data are cited as a key barrier to improving current modeling processes. Improved hydraulic models will be needed to modernize agricultural systems and to identify energy, water, and environmental opportunities that arise from large-scale systems integration. Unaddressed water management challenges is seen as an underlying barrier to achieving greater energy system improvements. This prize could be presented as a design or software challenge, where winners would receive seed funding for a proof-of-concept demonstration. Reducing time and cost should be emphasized over existing solutions.

Topic Area 6: Crosscutting, Open Topics

The first five topic areas of the Water Security Grand Challenge represent DOE's initial priorities for addressing critical energy and water security issues for the nation. While some of these five topic areas have unique challenges to address, several crosscutting issues are common across all topic areas. Certain challenges are common among all aspects of the water sector, including data availability and quality, regional differences in water management, and inconsistent water pricing and market development, among others. The intent of the sixth breakout group was not only to capture the crosscutting themes but also to allow for discussion of topics that fell outside the five goal areas, understanding that other important water issues are worth discussing and considering for prize ideas.

The breakout group focused on exploring key crosscutting and open topic prize strategies that could enable potential synergies of the water, energy, and other sectors through new data, sensors, automation, technology integration and other options to help achieve increasingly energy efficient, affordable, clean, safe, and secure water resources and related services. The breakout group highlighted crosscutting challenges that would be well-suited for a prize competition, including improving data, metrics, and visualization of water use; creating markets that could foster innovation; addressing aging infrastructure; improving finance models for water innovations; and training the next generation of water managers. The results of these prizes would have benefits across all other topic areas.

Prize Idea 6.1: Integrating Water Data Across Sectors for Urban Regions

- *Ideal End Goal:* With urban areas rapidly expanding globally, this prize idea highlights the foundational role and challenge of data management within the urban context. The goal of this prize is to create a common data collection, aggregation, and analysis platform for water and energy resources that would contain data across multiple sectors, allowing energy, water, and other sector managers to make better-informed decisions. Energy and water managers would have access to water accounting data at the appropriate resolution to improve their own operations and planning, and this information would also be shared with other sectors to facilitate coordinated planning. Such data sharing on a common platform would allow for a more comprehensive view into water usage, security, and sustainability in the urban context. Software applications, novel data collection streams, and "smart city" analytics could inform utilities and their end users on choices and decisions that further advance and develop more energy efficient, affordable, and secure water resources and related services. In addition, responses to chronic issues such as aging infrastructure or water scarcity, as well as acute issues from extreme events (e.g., weather or cyber-related) could all be addressed.

- *Key Problems and Barriers:* Today, most water and energy managers and end users do not collect, analyze, or make decisions using water data at a granular spatiotemporal resolution for their own systems. Collecting data can be a challenge because of the need for installation of sensors; analyzing data can be a challenge because of the computational and analytic requirements of evaluating large amounts of data; and managers may not have capabilities to adapt to changing water resource information in real time. Moreover, plans and potential impacts on water resources are often not shared across sectors, which can negatively affect planning decisions. There is a critical need to build an integrated data platform for smart city and community uses, where enhanced data capabilities are an essential component to linking infrastructure across sectors.

- *Proposed Prize:* This prize would be best formed as a software and data integration challenge that would demonstrate the value of combining high-resolution water data across multiple sectors to improve water security in urban regions. Models and novel analytical approaches could be used to quantify various aspects of water use data, and data could be collected through increased deployment of sensors, advanced metering technologies, and nonintrusive monitoring (e.g., through apps or other mechanisms) of all water uses in a targeted pilot neighborhood of an urban area. The prize could take a phased approach. Phase 1 would include a design challenge. Phase 2 would include a data collection and analysis strategy. Phase 3 would offer a pilot demonstration of the data collection, integration, visualization, and mapping platform.

Prize Idea 6.2: Integrated Water and Wastewater Utilities Providing Multiple Water and Energy Services

- *Ideal End Goal*: Water and wastewater utilities provide many beneficial services to communities by being able to provide water services, energy, valuable resources recovered from waste streams, and ecological services. Each of these services is appropriately priced in an efficient market and utilities maintain financial solvency. Integrated approaches could facilitate self-sufficiency of certain regions, allowing them to meet current needs while generating surplus value that could benefit surrounding areas.

- *Key Problems and Barriers:* Water markets are not well-defined or efficient, and many water and wastewater utilities face economic challenges due to rising compliance costs and decreasing per capita water usage. Business models and structures for water and wastewater utilities are not designed for multiple revenue streams, and in many cases, markets are not established to support integrated services that utilities could provide. Many utilities do not have the capacity to support innovations in business models or resource recovery that would enable the provision of multiple services to communities.

- *Proposed Prize:* The prize would seek innovative business model ideas to transform current water and wastewater utilities into multi-resource providers. Other resources that utilities could provide include electricity, thermal energy, valuable minerals and nutrients, and ecosystem services. The business models would use market-based solutions to facilitate the creation of integrated utility hubs that provide multiple services, facilitating resource production that can enhance community sufficiency and revenue generation. Proposals would complement business model ideas with integrated and crosscutting performance metrics that demonstrate the value of systems integration on smaller scale than business-as-usual siloed investments. This prize could build on, or serve as the foundation for, other prizes in other topic areas, including Prizes 4.1 and 4.2.

Prize Idea 6.3: New Financing, Business, and Governance Models for Small, Modular Systems

- *Ideal End Goal:* Small, modular energy-water systems can be rapidly deployed not only because of technology advancements but also because business models are appropriately configured, financing mechanisms are in place, and there is a policy and regulatory framework to support deployment. At a state level, finance, business, and governance frameworks all consistently evaluate, finance, and enable the deployment of technologies that could effectively improve water security. These highly adaptable, nimble systems would be more capable and effective in responding to local shocks or stresses.

- *Key Problems and Barriers:* Current water markets, policies, regulations, business models, and financing approaches limit the impact that disruptive technological innovations in modular water systems can have on water security by inhibiting adoption and deployment of technologies. For example, requirements of regulations and finance might be opposed to one another, leading to inefficiencies and less cost-effective designs.

- *Proposed Prize:* The prize would seek combined innovations in the design of finance models, business models, and governance approaches that would help facilitate deployment of small, modular water treatment systems and other innovative technologies. Consistency among finance, business and governance models is increasingly viewed as key for facilitating hybrid decentralized-centralized systems, especially when considering linking existing infrastructure with new technologies.

Prize Idea 6.4: Workforce Development for the Next Generation of Water Managers

- *Ideal End Goal*: Under the ideal end goal, many workers would be entering the water, wastewater, and energy utility fields with the skills to operate and plan for integrated water utilities of the future. Their skillsets would include not only water treatment expertise but also data analysis, resource recovery, economics, and energy capabilities. Ideally, as the water and wastewater industries evolve, the workforce would be readily equipped to ensure the nation has secure water supplies.

- *Key Problems and Barriers*: The workforce in the water treatment industry is aging, and insufficient numbers of younger staff are being adequately trained as replacements. Moreover, as water systems become more interconnected, dynamic, and "smarter," the types of skills and expertise of water managers is also changing. And, there is no concerted effort or program to train the next generation of water managers that can develop and lead integrated water and energy systems.

- *Proposed Prize:* The prize would seek innovative workforce development and training programs that would equip the next generation of water, wastewater, and energy utility workers with the requisite skills. The breakout group discussed some ideas that could be a part of a workforce development proposal, including localized employment and training programs, new businesses, and new curricula and educational software or tools.

Conclusions and Next Steps

Water is a critical resource for human health, economic growth, energy production, and agricultural productivity. Emerging challenges for freshwater supplies could threaten U.S. economic competitiveness and have global implications. To help address these challenges and opportunities, DOE has created the Water Security Grand Challenge to advance transformational technology and innovation to meet the global need for safe, secure, and affordable water. Using a coordinated suite of prizes, competitions, early-stage research and development, and other programs, the Grand Challenge has set goals for the United States to reach by 2030. This workshop brought together experts from multiple sectors to identify promising ideas for prize competitions that could improve water security. Workshop participants identified more than 40 prize competition ideas across six different topic areas that correspond to Grand Challenge goals. Prize competition ideas included technology innovations, data collection and analytics improvements, creative business model designs, decision and market support tools, and other prizes that address social and regulatory barriers. Successful outcomes from these prize competition ideas could lead to improvements across multiple industries in the United States and abroad, simultaneously improving energy and water security.

DOE benefitted from the range of experts who participated in this workshop. The ideas developed at the workshop will be foundational to the success of the Water Security Grand Challenge. Moving forward, DOE will continue to develop prize ideas proposed during this workshop, internally and in collaboration with other federal partners. DOE will also explore other potential avenues for prizes and competitions that could advance the Grand Challenge goals.

Finally, DOE will seek out opportunities for collaboration with other organizations moving forward. Complementary activities already announced include DOE's cooperation agreement with Chevron Technology Ventures on the Chevron Tech Challenge for produced water—a contest seeking cost-effective solutions for managing produced water from O&G exploration. DOE has also entered into an agreement with The Water Council, a Milwaukee-based nonprofit organization, to support its efforts to develop prize competitions to drive innovation on critical water issues. And, workshop participants emphasized that the Water Security Grand Challenge could leverage and build on several other ongoing initiatives, including efforts by the National Science Foundation, the U.S. Bureau of Reclamation, the Electric Power Research Institute, the Energy-Water Initiative, as well as individual state efforts, and activities supported by international foundations. Finally, participants felt it was important to identify water security areas not currently being addressed and to not duplicate efforts.

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Appendix I. Workshop Participants

Participant	Organization
Madhav Acharya	ARPA-E
John Albert	Water Research Foundation
Doug Arent	National Renewable Energy Laboratory
Jennifer Beardsley	US Bureau of Reclamation
Dean Bell	American Electric Power
John Bigham	Marathon Petroluem
Levi Brekke	Bureau of Reclamation
Scott Bryan	Imagine H2O
Carrie Capuco	Water Reuse Association
Jon Carmack	US Department of Energy, Office of Nuclear Energy
Tzahi Cath	Colorado School of Mines
Young Chul Choi	Southern Research
Anthony Contento	Genesis Systems
Aldis Darzins	Nano Gas Technologies
Jim Davis	Electric Power Research Institute
Andre Defontaine	US Department of Energy
Elise DeGeorge	National Renewable Energy Laboratory
Ashwin Dhanasekar	The Water Research Foundation
Jill Engel-Cox	National Renewable Energy Laboratory
Paul Faeth	Cadmus Group
Peter Fiske	Lawrence Berkeley National Laboratory
Alex Fitzsimmons	US Department of Energy, Office of Energy Efficiency and Renewable Energy
Lisa Friedersdorf	White House Office of Science & Technology Policy
Michael Gaither	Ur-Energy USA
Simon Geerlofs	Pacific Northwest National Laboratory, on Assignment to DOE

Johney Green	National Renewable Energy Laboratory
Peter Green	National Renewable Energy Laboratory
Maureen Hodgins	The Water Research Foundation
Kerry Howe	University of New Mexico
Andrew Howell	Electric Power Research Institute
Scott Jenne	National Renewable Energy Laboratory
Jered Jorgensen	Energy Trust of Oregon
Martin Keller	National Renewable Energy Laboratory
Neil Kern	Duke Energy
Ben King	US Department of Energy
Melissa Klembara	US Department of Energy, Advanced Manufacturing Office
Chad Laurent	Cadmus Group
Alexsandra Lemke	US Department of Energy, Wind Energy Technologies Office
Barry Liner	Water Environment Federation
Matt Lira	White House Office of American Innovation
Albert LiVecchi	National Renewable Energy Laboratory
Jordan Macknick	National Renewable Energy Laboratory
Barbara Martinez	Conservation X Labs
Jan Matuszko	U.S. EPA
Carol Maxwell	MICROrganic Technologies
Travis McLing	Idaho National Laboratory
Elena Melchert	US Department of Energy
Tom Miller	US Department of Energy, Office of Nuclear Energy
Jeff Moeller	The Water Research Foundation
Alejandro Moreno	US Department of Energy
Thomas Mosier	Idaho National Laboratory
Rebecca Osteen	Southern Company

Greg Pearce	Environmental Treatment LLC
Mark Pelizza	M.S. Pelizza & Ass. LLC
Gautam Phanse	Chevron Technology Ventures
Kevin Price	Middle East Desalination Research Center; Bureau of Reclamation, retired
David Raff	Bureau of Reclamation
Nalini Rao	Electric Power Research Institute
Tanja Rauch-Williams	Carollo
Matthew RInger	National Renewable Energy Laboratory
Janice Rooney	National Renewable Energy Laboratory
James Rosenblum	Colorado School of Mines
Carleigh Samson	American Water Works Association
Denice Shaw	US EPA
Eric Shuster	National Energy Technology Laboratory
Seth Siegel	Let There Be Water LLC
Daniel Simmons	US Department of Energy
Aaron Simon	Lawrence Livermore National Laboratory
Chinmayee Subban	Lawrence Berkeley National Laboratory
Vincent Tidwell	Sandia National Laboratories
Andrew Tiffenbach	Bureau of Reclamation
Jason Trembly	Ohio University
Bill Tumas	National Renewable Energy Laboratory
Jason Turgeon	US EPA Region 1
Mitchell Walrod	Genesis Systems
Tracy West	Southern Company Services
Paul Westerhoff	Arizona State University
Aaron Wilson	Idaho National Laboratory

Appendix II. Workshop Agenda

U.S. DEPARTMENT OF ENERGY

Water Security Grand Challenge Workshop

OCTOBER 25, 2018 | NATIONAL RENEWABLE ENERGY LABORATORY, GOLDEN, CO

Agenda	
8:00 a.m. – 8:45 a.m.	**Registration and Networking Breakfast**
8:45 a.m. – 9:00 a.m.	**Welcome and Introduction** Speaker: U.S. Department of Energy (DOE) | TBD
9:00 a.m. – 9:30 a.m.	**Overcoming Water Security Challenges Through Innovation** Speaker: Seth M. Siegel | Author, "Let There Be Water: Israel's Solution for a Water-Starved World"
9:30 a.m. – 10:15 a.m.	**Designing and Using Prize Competitions to Drive Innovation** *Topic introduced by:* • Matt Lira | Special Assistant to the President for Innovation Policy and Initiatives, White House Office of American Innovation *Panelists:* • David Raff | Science Advisor | U.S. Bureau of Reclamation • Gautam Phanse | Technology Manager | Chevron Technology Ventures
10:15 a.m. – 10:30 a.m.	**Break**
10:30 a.m. – 12:00 p.m.	**Breakout Session I: Identifying and Crafting Problem Statements that can be Addressed Through Prizes** Through discussion facilitated by two experts (listed below), participants will work together to identify and craft clear problem statements that could be addressed through prize competitions. **Cost-Competitive Desalination Technologies** • Melissa Klembara | DOE, Energy-Water Desalination Hub • Lisa Friedersdorf | White House Office of Science & Technology Policy **Transforming Produced Water from a Waste to a Resource** • Elena Melchert | DOE, Office of Oil and Gas • Gautam Phanse | Chevron Technology Ventures **Reducing Water Impacts in the Power Sector** • Madhav Acharya | DOE, ARPA-E • Rebecca Osteen | Southern Company **Increasing Resource Recovery from Wastewater** • Andre de Fontaine | DOE, Office of Energy Efficiency & Renewable Energy • Jason Turgeon | EPA, Water Technology & Innovations Unit **Developing Small, Modular Energy-Water Systems** • Jon Carmack | DOE, Office of Nuclear Energy • Simon Geerlofs | DOE, Water Power Technologies Office **Cross-Cutting, Open Topics** • Diana Bauer | DOE, Energy-Water Co-Lead • Denice Shaw | EPA, Office of Research & Development

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12:00 p.m. – 12:30 p.m.	**Report Outs and Discussion**
12:30 p.m. – 1:30 p.m.	**Lunch** Speaker: Martin Keller | Director | National Renewable Energy Laboratory
1:30 p.m. – 3:00 p.m.	**Breakout Session II: Structuring the Prizes** Groups will focus on designing prizes that address the problem statements they identified in the morning session. This can include thoughts on prize types, structure, performance targets, incentives, desired participants and partners.
3:00 p.m. – 3:15 p.m.	**Break**
3:15 p.m. – 3:45 p.m.	**Report Outs and Open Discussion**
3:45 p.m. – 4:00 p.m.	**Adjourn and Next Steps**
4:30 p.m. – 6:00 p.m.	**No-host Happy Hour** Abrusci's Fire and Wine | 2200 Youngfield St., Lakewood, CO

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit:
energy.gov/water-security-grand-challenge

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