Research and Development Opportunities for Technologies to Influence Water Consumption Behavior

Energy Systems Division

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EXECUTIVE SUMMARY

In April 2015, Argonne National Laboratory hosted a two-day workshop that convened water experts and stakeholders from across industry, government, and academia to undertake three primary tasks: 1) identify technology characteristics that are favorable for motivating behavioral change, 2) identify barriers that have prevented the development and market adoption of technologies with these characteristics in the water sector, and 3) identify concrete research and development pathways that could be undertaken to overcome these barriers, increase the penetration of technologies that influence water consumption behavior, and ultimately reduce domestic water consumption.

While efforts to reduce water consumption have gained momentum in recent years, there are a number of key barriers that have limited the effectiveness of such efforts. Chief among these is the fact that many consumers have limited awareness of their water consumption patterns because of poor data availability, and/or are unmotivated to reduce their consumption because of low costs and split incentives. Without improved data availability and stronger price signals, it will be difficult to effect true transformative behavioral change.

This report also reviews a number of technology characteristics that have successfully motivated behavioral change in other sectors, as well as several technologies that could be developed specifically for the water sector. Workshop participants discussed how technologies that provide active feedback and promote measurable goals and social accountability have successfully influenced changes in other types of behavior. A range of regulatory and policy actions that could be implemented to support such efforts are also presented. These include institutional aggregation, revenue decoupling, and price structure reforms. Finally, several R&D pathways were proposed, including efforts to identify optimal communication strategies and to better understand consumer perceptions and psychology as they relate to human behavior regarding water consumption.

The findings presented here can help to inform policy makers as they develop new policies and seek to support new research to help consumers use water more efficiently. It is our hope that these findings will also be utilized to prioritize topics for additional follow-up workshops to address individual issues and barriers more directly and in more detail. The goal of such future workshops will be to develop specific solutions, research plans, and technology development pathways that can be undertaken to increase the market penetration of technologies that effect behavioral change and reduce water consumption.

1 INTRODUCTION

1.1 BACKGROUND

The United States is experiencing a number of key trends that have increased the imperative to develop and implement comprehensive water conservation efforts (1). While total domestic withdrawals of both fresh groundwater and fresh surface water have been roughly constant since 1980 (2), populations are growing the fastest in arid regions that are more water-constrained. This rapid population growth in water-strained regions is illustrated in Figure 1, which shows high anticipated population growth rates over the next 15 years in states such as Nevada, Arizona, and Texas; all of which have greater than average per capita water consumption and are facing significant concerns over their long-term water availability and security. Furthermore, climate change is already contributing to increasing temperatures and shifting precipitation patterns in the United States, which may result in less certain freshwater availability (1). This is evidenced by the fact that

FIGURE 1 Projected population growth by 2030 (percentages), along with current domestic per capita water consumption levels (colors). Population growth is projected to be highest in the West and Southwest, where per capita water consumption is greater and supply is also more constrained. Source: (3)

one-third of the U.S. was affected by severe drought in 2012 (1). Additionally, new energy and water technologies are emerging that have the potential to augment and shift consumption patterns. For example, in the electric sector, many aging coal plants are retiring and being replaced with natural gas-fired generation. These natural gas plants generally use recirculating cooling technologies that reduce water withdrawals but increase total water consumption.¹

Practices designed to increase water use efficiency and thereby reduce water consumption can be divided into two broad categories: engineering practice and behavioral practice. Engineering practices involve technologies designed to passively reduce water consumption irrespective of the user's behavior. The U.S. Environmental Protection Agency (EPA) provides numerous examples of such technologies, including low-flush toilets, low-flow showerheads, faucet aerators, and pressure reductions. Behavioral practices refer to changing users' habits irrespective of the technology being used. Examples include running a dishwasher only when it is full, taking shorter showers, and turning off the faucet while brushing teeth or shaving. In addition to these binary approaches to water conservation, there also exists a conceptual area where technology and behavior influence each other. This is an area that has seen much less attention, and is ripe for development.

With this in mind, The U.S. Department of Energy Building Technologies Office (BTO) commissioned Argonne National Laboratory to conduct a scoping study of the market landscape for behavior-changing technologies in the water sector. To inform this scoping study, Argonne hosted a two-day workshop that convened water experts and stakeholders from across the country. Workshop participants were tasked with identifying 1) technology characteristics that are favorable for motivating behavioral change, 2) barriers that have prevented the development and market adoption of technologies with these characteristics in the water sector, and 3) concrete research and development pathways that could be undertaken to overcome these barriers, increase the penetration of technologies that influence water consumption behavior, and ultimately reduce domestic water consumption. Discussions during the workshop were primarily focused on water consumption in and around residential and commercial buildings. Technologies to improve water consumption efficiency in industrial and agricultural applications, as well as those for cooling at thermal power generation units, were not explicitly considered because of the vastly different problem scope in those sectors. The following report documents the findings developed through background research, stakeholder outreach, and stakeholder participation in a two-day workshop that was hosted at Argonne in April 2015. It is intended to serve as a resource for product developers, policy makers, product developers, and others who are seeking to effect behavioral change and increase the efficiency of water consumption in the United States and around the world.

¹ Withdrawals refer to any water that is removed from a natural source such as a lake, river, or reservoir, even if it is later returned to the same source. Consumption refers to water that is withdrawn and not returned to its original source.

1.2 BTO MISSIONS AND GOALS

The BTO has a critical stake in supporting research, development, and demonstration activities that lead to a reduction in energy use in U.S. buildings. BTO's mission is to develop, demonstrate, and accelerate the adoption of energy-efficient technologies, techniques, tools, and services that are affordable, as well as to enable high-performing, energy-efficient residential and commercial buildings in both the new and existing building markets. The BTO multi-pronged strategy includes technology research and development, market stimulation activities, and contributions to codes and standards, as depicted in Figure 2.

BTO's overarching goal is to reduce energy use intensity (energy use per square foot) of U.S. buildings to 50% of 2010 levels by the year 2030 (4). Water heating accounts for about 9% of all energy use in U.S. buildings, and thus reduction in domestic water consumption can result in substantial reductions in building energy use (5). Since nearly all domestic water consumption involves treated water, reductions in water use will also result in reduction in the energy required to treat and deliver the water, and thus reducing water use is of interest to DOE and BTO. It was estimated that 33 billion kWh of electricity would be used by public water agencies to provide fresh water in 2010 (6). A 5% reduction in both heated and unheated water consumption in United States commercial and residential buildings would result in more than 500 trillion Btu of annual primary energy savings associated with water heating and more than 1.6 billion kWh of annual electricity savings associated with water treatment and distribution.

FIGURE 2 The U.S. Department of Energy Building Technologies Office Ecosystem

1.3 STUDY OBJECTIVE AND APPROACH

The objective of this study is to identify concrete research pathways that can be implemented to increase the market penetration of technologies that influence water consumption behavior and ultimately reduce water consumption in buildings.

This work included background research and stakeholder outreach by the workshop organizers over a period of several months. The background information that was gathered during this period was then further augmented through stakeholder participation and discussion at the in-person workshop held in April 2015. This work evolved conceptually over four distinct stages, as shown in Figure 3.

1.3.1 Stage 1: Identify Types of Consumer Change

We first created a working definition of consumer change, and sought to understand how such change could be motivated and evaluated through consumer actions. This resulted in the categorization of three different types of consumer change, and the decision to focus further research specifically on behavioral change. These three types of consumer change are discussed in section 2.2.

1.3.2 Stage 2: Identify Technology Characteristics for Motivating Behavioral Change

Through early outreach and research, it was determined that the market for technologies that influence water consumption behavior is still relatively immature. Therefore, before discussing specific technological concepts for the water sector, it was important to first broadly identify desirable technology characteristics with the potential to motivate consumer behavioral

FIGURE 3 The four stages of this project

change, and understand how these could be applied to reducing water consumption. We therefore sought to draw upon lessons learned and best practices from technologies that have successfully transformed behavior in other sectors. The identified characteristics are identified in Table 1 and discussed in section 2.3.

1.3.3 Stage 3: Identify Barriers to Behavioral Change and Market Adoption

We next identified the barriers that have prevented these technology characteristics and the associated behavioral change from manifesting themselves in the water sector. These barriers span technological, institutional, and sociological dimensions and are identified in Table 2 and discussed in section 2.4.

1.3.4 Stage 4: Identify R&D Pathways to Overcome Barriers

Finally, we identified a number of research and development pathways that may be undertaken to overcome the barriers identified in stage 3, increase the penetration of behavior-influencing technologies in the water sector, and ultimately reduce water consumption in buildings. These research and development pathways are identified in Table 3 and discussed in Section 3.

2 MARKET OVERVIEW

2.1 STATE OF THE MARKET

2.1.1 Consumer Products

The market for consumer water products that are specifically designed to influence behavior is still relatively immature. While a number of such products do exist, their penetration is still very limited and there are no individual products that are currently in widespread use. To our knowledge, there are also no comprehensive data on the penetration or market size for such products. We briefly describe two of these products here to provide context for future discussion of the potential to develop related new technologies and increase their market penetration. However, this is not intended to be a comprehensive list.

Color-changing showerhead

The color-changing showerhead (Figure 4) is a simple, yet effective, device that encourages users to reduce the length of their showers. The showerhead features a light that gradually changes color from green to red over a preset period of time. The product inventors have shown that this cue alone can concretely influence consumer behavior and results in a 10%

FIGURE 4 The color-changing showerhead features a light that gradually changes color from green to red, reminding users to limit their time in the shower².

² www.ujishower.com

reduction in average shower time. While prototypes of the product exist, it is still in development and has not yet reached mass production or market penetration.

Thermostatic shut-off valve

Another new technology is a thermostatic shut-off valve (Figure 5) that can be attached to any standard shower arm. The valve utilizes the thermal properties of its materials to automatically restrict water flow once it has reached a target temperature (approximately 95 degrees Fahrenheit). A study conducted by a thermostatic valve product manufacturer found that 32% of those surveyed reported performing “other activities” while waiting for their showers to heat up, while 57% monitor the water temperature directly while it warms up (7). This results not only in the wasted cold water that is discarded while waiting for the desired temperature increase, but also wasted hot water that is discarded between the time the water reaches target temperature and the time the user notices and enters the shower. This valve seeks to eliminate the hot water that is lost during the latter period, allowing users to perform other activities while waiting for the water to heat up without constant monitoring, and signaling to them when the target temperature has been reached. In addition to reducing hot water wasted by the 32% who multitask while waiting for their shower to heat up, this technology enables behavioral change for the 57% who monitor temperature directly; allowing them to pursue other activities while their water heats up without worrying about hot-water waste.

FIGURE 5 A thermostatic valve that stops water flow once the flow temperature meets a preset temperature. Water flow is re-enabled by pulling on the valve release cable when the consumer is ready to begin the shower³.

³ <http://thinkevolve.com>

2.1.2 Smart Water Management

As water conservation efforts have begun to gain more mainstream appeal, there is a growing market for “smart” water meters. These meters are modeled after those that are being deployed in the electric sector and provide near-real-time water flow monitoring and, in some cases, networked connectivity to record and analyze water consumption data. Investments by U.S. utilities in smart water meters were estimated to reach \$395 million in 2010, and it has been predicted that such investments will total almost \$2 billion between 2013 and 2020 (8). A recent market analysis estimated that the total global market for smart water management services and technologies will grow from \$7.3 billion in 2015 to \$18.3 billion in 2020, with much of this growth occurring in North America (9).

2.2 TYPES OF BEHAVIORAL CHANGE

Through background research, stakeholder outreach, and workshop discussions and presentations, three primary categories of behavioral change were identified: forced change, voluntary change, and transformative change.

2.2.1 Forced Change

Forced change can be implemented through policies, regulations, and standards. For example, EPA maintains national water use efficiency standards for residential and commercial fixtures and appliances (10). This can be an effective means of achieving prescribed efficiency gains; successful examples in other sectors include energy efficiency standards for refrigerators that were first introduced in the 1970s and the Corporate Average Fuel Economy (CAFE) standards that have been implemented for vehicle manufacturers. Similarly, in the water sector, enhanced toilet efficiency standards that were implemented in the United States in 1994 are estimated to have save 18.2 trillion gallons of water; equal to the total water consumption of New York City, Chicago, and Los Angeles over a 20-year period (11). However, forced change can also lead to consumer resistance and low product persistence, as products will typically be designed only to meet these minimum standards. Therefore, standards must be updated regularly to encourage continual product advancement, but this process may not keep pace with the potential for innovation.

2.2.2 Voluntary Change

Voluntary change can be implemented through educational programs that encourage consumers to use water more efficiently. The goal is to have consumers consciously change their consumption habits; for example, taking shorter showers, shutting off the faucet while brushing their teeth, or reducing water use for landscaping. The hope is that with time these behavioral changes will become the norm. This approach has had recent success in California, where consumers have become much more aware of water scarcity in the region and have started to adapt their behavior to consume water more efficiently. However, voluntary change may still

encounter consumer resistance, as it requires conscious actions that are disruptive to a consumer's routine.

2.2.3 Transformative Change

Transformative change is achieved when consumers take actions that result in decreased water consumption, not through consciously trying to reduce consumption, but rather through a fundamental change in their daily routine without any conscious effort or loss of convenience. For example, many consumers currently turn on their shower and then engage in other activities (teeth brushing, etc.) while waiting for the shower to reach a desired temperature. As a result, consumers will naturally get distracted and may leave the shower running unoccupied well after the target temperature has been reached. A technology that can instantaneously heat water in the shower to a particular temperature would completely eliminate this behavior. Consumers will change their routines not out of a conscious desire to save water, but because they now save time by not having to wait for the shower to warm up.

Discussions at the workshop were focused primarily on voluntary and transformative change, although several potential enabling policy and regulatory changes were discussed as well. It was generally agreed upon that transformative change is the most desirable of these three options, but also the most difficult to achieve.

2.3 TECHNOLOGY CHARACTERISTICS FOR MOTIVATING BEHAVIORAL CHANGE

Workshop attendees were asked to broadly discuss technology characteristics (listed in Table 1) that are desirable for motivating behavioral change. Specifically, participants were tasked with identifying technologies that have successfully transformed behavior in other sectors and industries, enumerating the specific characteristics of these technologies that empowered behavioral change, and then discussing how these characteristics could be integrated into new technologies to achieve the same transformation in the water sector.

2.3.1 Access to Information on Demand

There was a general consensus among workshop participants that providing users with access to more frequent, high-resolution, and easily digestible information about their behavior is crucial for effecting behavioral change. In addition to being of primary direct importance, effective data collection and communication are critical enabling components for many of the other characteristics that were discussed. Improved data accessibility is specifically of importance in the water sector, where a lack of awareness is a major obstacle to influencing behavior, as discussed in section 2.4.5. As public awareness of the importance of water

TABLE 1 Five primary technology characteristics that have been shown to motivate behavioral change in other sectors. This is not intended to be a comprehensive list, but these characteristics are important considerations for the development of any new technologies that are intended to influence water consumption behavior.

Technology Characteristic
Access to information on demand
Active feedback
Social interactions and peer accountability
Measurable goals and gamification
Seamless integration

conservation grows, many people have a desire to reduce their water use but lack the tools to determine the impact of different measures that they may take. Improved data access will help consumers understand how and where they are using water so they can make informed decisions and then measure the impact of these decisions.

2.3.2 Active Feedback

Current water bills provide passive feedback that may reach a consumer once per month at most. Therefore, consumers may not be able to see the impact of any measures that they have taken until a significant amount of time has passed, and even then such impacts may be lost in the noise of other consumption.

The Fitbit was discussed as one example of a technology with active feedback, as it can be programmed to send user reminders to exercise when it detects periods of inactivity. In the water sector, active feedback could provide users with a daily summary of their water use or an instant email or phone notification when they exceed a predefined daily consumption budget. One study has found that consumers who receive bi-monthly home water reports reduce their water consumption by 4.6% to 6.6% more than those who do not (12).

2.3.3 Social Interactions and Peer Accountability

Social interactions have increasingly become an effective tool for influencing behavior. Consumers can use social media to hold themselves accountable for actions that they commit to take, and to provide positive feedback when they achieve specific goals. Workshop participants discussed diet and exercise apps that will automatically share workout results over social media,

or generate “shaming posts” when a user exceeds a daily calorie budget or fails to exercise for a given period of time.

Such an approach could similarly be effective when applied to water consumption. This approach would enable consumers to voluntarily share their water usage with friends and family, providing them encouragement to meet predefined usage goals.

2.3.4 Measurable Goals and Gamification

It is important for consumers to be able to define measurable goals for themselves and to be able to measure their progress towards reaching their goals. Gamification can be introduced to make achieving these goals more enjoyable, which is an important component of getting people to make sacrifices or change to their routine in a way that requires effort and causes inconvenience or discomfort. Workshop participants discussed how dieting and exercising are not in themselves necessarily enjoyable activities for many people. However, many do find enjoyment in achieving concrete weight loss or exercise goals and participating in friendly competitions with peers.

2.3.5 Seamless Integration

Finally, it is important that new technologies be seamlessly integrated into everyday life, so that they become standard components of modern appliances rather than luxury or novelty features. As an example, participants discussed the real-time “miles per gallon” indicators that are now a standard component of many modern vehicles. These meters are now seamlessly integrated into car displays so as not to be overly distracting, and do not disrupt routines or require conscious action. However, they do provide drivers with constant feedback on how their actions are affecting vehicle efficiency in real-time. Drivers can instantly see the relative impact of accelerating or increasing their average speed. This constant feedback helps drivers understand how their driving habits affect gasoline consumption, even if on a subconscious level. Saving gasoline is something that many people have a strong interest in doing; however, they have traditionally lacked the necessary information to understand how they could best accomplish that goal and quantify the impact of their actions to that end. Real-time digital water meters on faucets or other appliances can similarly provide constant, non-disruptive feedback to consumers, helping them understand how much water they use while brushing their teeth, washing dishes or performing other activities. Such devices could easily become every bit as integrated into daily life as gasoline efficiency meters are in modern cars.

It is also important that new technological features can be seamlessly integrated into existing infrastructure and consumer products. This is particularly true in the water sector, where infrastructure is deeply integrated into existing cities and buildings, generally in inaccessible locations (underground, within floors and walls), and is therefore often very costly to replace. Similarly, many water-consuming appliances (washing machines, dishwashers) are expensive and have long product lifetimes. Most consumers would not consider replacing a functioning washing machine or dishwasher with a more efficient version, even if the replacement

technology had the potential to dramatically curb water consumption. However, they may consider purchasing a cheaper add-on technology that can enhance the performance of or generate performance data from their existing appliances.

2.4 BARRIERS TO BEHAVIORAL CHANGE

We now identify several key barriers (Table 2) that have inhibited the increased penetration of water-saving technologies and pose unique challenges for influencing water consumption behavior. Potential pathways towards overcoming these issues will be discussed in later sections.

TABLE 2 Six primary barriers to behavioral change in the water sector.

Barrier
Low water prices limit economic incentives
Water price and consumption data are not readily available
Water utilities and regulators are highly fragmented
Water utilities' revenues are tied to sales volume
Consumer awareness and engagement are low
Water technologies and infrastructure are outdated

2.4.1 Low Water Prices Limit Economic Incentives

Participants at the workshop were in near-uniform agreement that low water prices limit the potential for economic incentives to reduce wasteful consumption. Consumers are rarely motivated to reduce their water consumption for purely financial reasons, and similarly, institutional water conservation programs are rarely justifiable on the basis of economics alone. For a variety of reasons, many consumers also do not fully internalize the amount that they pay for their water consumption, but rather consider water to essentially be a free public good. This is partially explained by the fact that state and local water collection, sanitation, and distribution systems are funded through taxes and other mechanisms that are relatively opaque to most consumers.

This issue is compounded by the fact that many consumers do not pay the water bill at their residence or place of business. Rather, the bill may be paid directly by a building owner or landlord. In such cases, consumers receive no price signals to motivate changes in their consumption behavior. This is known as the so-called “split-incentives problem,” where consumers must take measures to reduce their water consumption that have an associated cost, but do not receive any benefits as a result of their actions. Water rates have also traditionally been set according to a declining block structure, meaning that the unit cost of water decreases as consumption increases. This approach has been justified by the fact that economies of scale are

present for water treatment and delivery, since many infrastructure and customer service costs are fixed regardless of consumption levels. However, this framework also creates an incentive structure that strongly discourages conservation for the highest-consuming customers, as a large reduction in water consumption would lead to a disproportionately small reduction in costs.

2.4.2 Water Price and Consumption Data Are Not Readily Available

Typical residential or commercial water consumers receive data on their water consumption at most monthly, often less frequently, and in many cases never. Furthermore, water consumption may be reported in units that are obscure to a typical consumer, such as CCF (centum cubic feet—one hundred cubic feet—which is equal to 748 gallons). Even when a more standard unit like the gallon is used, monthly consumption data are often aggregated into thousand-gallon blocks, owing to the widespread use of analog meters, as discussed further in section 2.4.6. For example, a residential customer may receive a bill indicating a consumption level of three “one thousand gallon” blocks of water in the current month, compared to their consumption of four “one thousand gallon” blocks the month prior. This provides minimal insight into consumption habits and trends. While the reported data suggest that a large reduction in consumption occurred, the customer’s true consumption may have only decreased moderately from 3510 gallons to 3490 gallons. Similarly, if this consumer were to increase or reduce their water consumption by 10% the following month, the impact might not even be noticeable on the next bill. This lack of precision can make it difficult for consumers to evaluate the effectiveness of water conservation measures that they have implemented. Additionally, fees and charges on residential and commercial water bills are often split into several categories and it is not immediately clear to consumers how much money would be saved by reducing their consumption.

2.4.3 Water Utilities and Regulators Are Highly Fragmented

According to the EPA, there are more than 50,000 community water systems serving almost 300 million people in the United States. More than half (55%) of these are very small, serving 500 people or less, while only a small fraction (8%) serve more than 10,000 people (13). In contrast, there are roughly 3,300 electricity providers in the United States (14). These water utilities may also be overseen and regulated by local boards of elected officials, rather than through a single state public utility commission, as is more common in the power sector. This high level of fragmentation in the water sector results in a patchwork system of rules, regulations, and operational practices. It also makes it difficult to design and implement overarching policy that has the desired impact across all affected entities. The large fixed costs associated with developing and implementing water conservation programs may make such programs prohibitively expensive for smaller utilities with correspondingly small budgets.

At the federal level, there are a number of agencies that have some level of interest in water conservation efforts (e.g., EPA, Department of Energy, Department of Interior, Department of Agriculture, U.S. Geological Survey, and National Oceanic and Atmospheric

Administration); however, there is no single federal agency that is wholly tasked with addressing water-related issues and developing water policy on a national scale.

2.4.4 Water Utilities Revenues Are Tied to Sales Volume

In the water sector, utility revenues are generally tied to sales volume. As a result, conservation programs that reduce water consumption also reduce utility revenue streams. Therefore, these utilities have no incentive to encourage their customers to conserve water. As many utility costs are fixed regardless of the quantity of water delivered, these costs stay constant while revenue decreases with decreasing sales (15, 16). As a result, utilities that do implement conservation programs face a compounding problem; they are increasing expenditures while decreasing revenue, and therefore may need to increase water rates in their service territory. This outcome is counterintuitive and disagreeable for many consumers. Rather than being implemented directly by utilities, efficiency programs in the water sector are more typically funded by separate entities with a vested public interest in reducing water consumption, such as the California Department of Water Resources.

2.4.5 Consumer Awareness and Engagement Are Low

Many consumers simply are not aware of how much water they use when performing different activities or how much they pay for their water usage. This issue is directly related to many of those discussed previously. Water consumption data are obscure, irregular and unavailable, pricing structures are opaque, and in many cases consumers are entirely shielded from the cost of their water consumption because their water bill is paid directly by their landlord. This lack of public engagement on water conservation has begun to change to some extent as the water scarcity issues facing California and other parts of the U.S. are receiving more attention and becoming better understood by the public at large. However, on a national scale, awareness of clean water as a finite resource with associated costs is still relatively limited.

2.4.6 Water Technologies and Infrastructure Are Outdated

Most water infrastructure in the U.S. was originally developed nearly 100 years ago, with some pipes dating back as far as the Civil War era, and much of it has not been updated since. In 2012, the EPA identified a need for \$400 billion in infrastructure investments by 2030 to ensure that water systems can continue to provide safe drinking water to the public (17). In 2012, the American Water Works Association estimated that it will cost \$1 trillion over the next 25 years to restore aging water systems as they reach end-of-life and further expand infrastructure to meet the needs of a growing population (18). In addition to concerns over safety and hygiene, this aging infrastructure results in more water losses because of leaks and increases the challenge of water conservation efforts by making it difficult to assess the success of such programs. Water utilities still overwhelmingly measure and record consumption data by manually reading analog meters, and the data resolution of these meters is poor. There is little penetration of digital, high-resolution water meters with the ability to automatically record and transmit data electronically.

In multi-tenant buildings, consumption is typically aggregated at the building level rather than being sub-metered for individual units. On the consumer side, appliances tend to meet only the minimum mandated water efficiency standards, and there is little penetration of next-generation technologies that take advantage of modern user interfaces and data monitoring capabilities.

3 RESEARCH AND DEVELOPMENT OPPORTUNITIES

Several promising research pathways were identified to support the development of behavior-influencing technologies to reduce water consumption. These are segmented into three different categories, as summarized in Table 3.

1. Technology – Research pathways to identify specific technologies and technology characteristics that can directly influence consumer behavior and reduce water consumption in buildings.
2. Enabling Reforms – Research pathways to analyze how various institutional reforms may enable increased penetration of behavior-influencing, water-saving technologies.
3. Behavioral – Research pathways to analyze how to improve consumer awareness to optimally drive changes in consumer behavior towards water consumption.

TABLE 3 Research and development pathways that can be pursued to overcome the barriers to behavioral change that were identified in Table 2. Each pathway is linked to one or more specific barriers that it can help overcome.

	Research Pathway	Barrier(s) Addressed
Technology	Improved data collection and communication	Water price and consumption data are not readily available
	Next-generation appliances	Water technologies and infrastructure are outdated
	Leak and defect detection	Water technologies and infrastructure are outdated
Enabling Reforms	Water rate reform	Low water prices limit economic incentives; Water utilities' revenues are tied to sales volume
	Regulatory and institutional aggregation	Water utilities and regulators are highly fragmented
	Integrated water and energy efficiency programs	Water utilities and regulators are highly fragmented
Behavioral	Consumer education and communication	Consumer awareness is low
	Behavioral science	Consumer awareness is low

3.1 TECHNOLOGY SOLUTIONS

3.1.1 Improved Data Collection and Communication

There was broad consensus among workshop participants that an affordable, next-generation water meter will be essential for enabling large-scale behavioral change. Such a meter would facilitate improved access to consumption and cost data for both utility providers and consumers themselves. This access will enable utilities to more efficiently design conservation programs and evaluate their impacts, and empower consumers to better understand their own consumption habits.

Collecting high-resolution consumption and cost data is a vital first step towards facilitating behavioral change, but such data are only valuable if they can be analyzed and communicated to stakeholders in a timely, straightforward, and meaningful way. New software and data standards will be needed to facilitate this process. The Nest Learning Thermostat is an example of a technological platform that manages this whole process, from data acquisition and analysis to communication and visualization, for home energy consumption. Some workshop participants even discussed the possibility of integrating water consumption data directly into the Nest platform.

The following four key characteristics for this meter were also specifically identified. While a number of meters are currently available which have one or several of these characteristics, workshop participants were in agreement that there is no one single technology that adequately incorporates all of these attributes.

Plug-and-play

It is important that such meters can be cheaply and easily installed, as high installation costs would likely be prohibitive for many applications. Ideally, such sensors could be attached to the flex-nose pipe that attaches any appliance to copper water pipes. It is also possible to develop external meters that can be attached to the outside of a pipe and are able to measure water flow sonically. This would allow for low-cost, no-expertise retrofits of existing fixtures and appliances, enabling sub-metering wherever desired.

Real-time

Currently, most water consumption data are recorded and aggregated over periods of a month or more. Access to high-resolution, real-time data (e.g. temporal resolution of five minutes or less) would enable consumers to visualize the water usage of individual appliances as it occurs. In addition to providing greater insights into water consumption habits, real-time data would help both consumers and water providers detect leaks and other accidental water releases more quickly and efficiently.

Wireless communication

The meter would ideally be able to transmit any data it records wirelessly to a centralized data hub where they can be stored and integrated with software for filtering, analysis and communication to consumers. A primary hurdle for this attribute is the amount of power required to transmit such data on a regular basis, particularly as most meters would not have access to an outlet and would therefore need to be powered by batteries or self-powered by the water flow. There are also safety considerations when an external power source is located near water infrastructure.

Affordability

The meter should be cheap enough that it can be ubiquitously applied to a range of different appliances throughout a household: showers, faucets, toilets, washing machines, dishwashers, etc. In addition to appliance-level metering for consumers, this attribute also would facilitate easy and affordable utility-scale sub-metering in multi-family or multi-tenant buildings. A target of \$10 per meter was discussed as a price point that could enable widespread usage across a variety of applications, as opposed to limited penetration as a niche or novelty product.

3.1.2 Next-Generation Appliances

While water consumption data can be collected through external, third-party water meters, it will also be important to develop smart appliances that can engage in two-way communication with the data platform and therefore consume water more intelligently. In addition to the general technological characteristics outlined in section 2.3 that can motivate behavioral change, several specific ideas for smart water technologies were discussed.

Programmable showerheads and faucets

Programmable showerheads and faucets would be able to instantly provide water at a target temperature and flow rate that could be customized for each user. This would reduce water waste that occurs while users are fine-tuning temperature settings and could also reduce consumption by allowing consumers to regulate flow rates according to their preference. For example, some consumers may be willing to accept a lower flow rate in the shower but do not have the capability to consistently restrict the flow from their current showerheads. A similar system could be implemented for kitchen faucets, with varying temperature and pressure presets for different uses such as hand washing, dishwashing, and drinking.

Instantaneous water heaters

Instantaneous water heaters would also be an important component of the programmable showerheads described above. They would enable rapid delivery of water at a prescribed

temperature, reducing losses associated with waiting for showers to heat up. They also have the advantage of consuming less energy than traditional hot water heating systems. Unfortunately, this technology can also lead to negative behavioral changes. Instantaneous water heaters also provide unlimited amounts of hot water. The drop in water temperature that occurs with the depletion of hot water in the water tank of a traditional hot water heater is often a cue to a person in a shower to finish the shower. Such cues are non-existent with instantaneous water heaters.

Smart toilets

Toilets account for more water consumption in buildings than any other single source, including showers, washing machines, and faucets (19). While much of this use is justifiable, many toilet flushes consume more water than is strictly necessary for hygienic purposes. Some new toilets attempt to address this issue by offering two discrete flush levels. A potential extension along these lines would be a toilet that can detect exactly how much water is needed for each flush and dispense the proper amount accordingly.

Smart landscaping irrigation systems

Over 50% of residential water consumption is used for outdoor applications, primarily landscaping (19). Smart landscaping irrigation systems could be linked to weather forecast data that enable a more intelligent allocation of water based on anticipated shortages or surpluses due to precipitation. Sensors in the ground could detect moisture content in the soil and adjust the output of sprinklers and other irrigation accordingly.

Distributed water treatment

In-building water treatment systems could be developed to serve commercial buildings, thereby closing their water loop and eliminating the need for transportation back to centralized treatment facilities. This measure would save water that is typically lost to leaks during transport as well as the energy that is required for pumping.

Rainwater harvesting

Enhanced rainwater-harvesting technologies would provide an additional water source for residential and commercial consumers, reducing reliance on withdrawals from other water sources. These distributed sources of supply would also reduce the water losses and energy consumption that are associated with transport and distribution. Rainwater is limited in its end-use applications, as it is not generally fit for consumption or cooking without further treatment. Efforts to develop new technologies that increase rainwater harvesting in buildings should be accompanied by clear guidelines, standards, and regulations to establish appropriate end uses for rainwater.

Improved messaging

Water-efficient products will likely not become marketable solely on the basis of their potential water savings. Rather, such technologies should also seek to provide value to consumers through increased comfort, service quality, and convenience. This value will help to overcome the common perception that reducing water consumption necessarily requires personal sacrifice or inconvenience. It is therefore important for product developers to advertise the ways that “water efficiency can improve quality of life.” For example, the programmable showerheads and faucets discussed previously would reduce water consumption, but many potential consumers would be interested in them purely on the basis of their ability to provide an enhanced consumer experience. This is an example of the sought-after form of behavioral change that was outlined in section 1.4.3.

3.1.3 Leak and Defect Detection

Losses during water distribution may account for up to 15% of total water consumption in the United States, and leaks in homes alone waste over one trillion gallons of water each year (20). Leaks can go undetected for days or months, wasting tremendous amounts of water. Most seals within faucets are made of rubber washers, which naturally shrink and crack over time during wetting and drying cycles, eventually causing leaks. A faucet leaking a drop of water per second can waste over 3000 gallons per year; a showerhead leaking 10 drops of water per minute can waste over 500 gallons per year (20). Such leaks result in gradual consumption increases that typically go undetected or untreated by many consumers. More significant leaks also occur at all levels throughout a utility-scale water distribution infrastructure. Most water distribution systems are not capable of automatically sensing leaks, instead relying on manual identification of usage spikes that often are not apparent because of infrequent consumption data reporting. Leak and fault detection would be significantly aided by improved access to real-time data. Prolonged consumption increases could be correlated with leaks and metering on individual pipes will make it much easier to find the source of the leak. Improved technologies with the ability to detect leaks early could save a significant quantity of water that is currently wasted.

3.2 ENABLING REFORMS

While the workshop was focused on identifying novel technologies and technological characteristics with the potential to influence water consumption behavior, it also became clear that such technological progress does not exist in a vacuum. Participants also discussed a number of policy, institutional, and regulatory reforms that could be instituted to help create an environment that supports the development and deployment of advanced technologies in the water sector.

All of the reforms that were discussed will have associated financial and societal costs and benefits. Further research is needed to better understand the potential impacts of these and other institutional reforms so that policy makers can make informed decisions and prioritize their actions.

3.2.1 Water Rate Reform

Higher rates

Workshop attendees were generally in agreement that the water prices paid by consumers need to be increased in order for significant behavioral change to be realized. The low price of water compounds many of the issues created by the poor availability of water consumption data. For example, there are minimal incentives for consumers to invest time and energy in understanding and adopting conservation measures, as water consumption does not represent a significant expense in a typical household. Similarly, low prices make it difficult for consumers to justify personal investments in water efficiency measures on a purely economic basis. Low prices also result in limited revenue for water utilities, compounding their internal problems of maintaining and improving their infrastructure.

Increasing block pricing

It is politically challenging to raise water rates because of the complex competing interests involved. Chief among these is the general belief that water consumption up to a certain level should be considered a basic human right in modern societies, whereas consumption beyond that level can be classified as using a more standard consumer product. An analysis of data from the Los Angeles Department of Water and Power indicates that household income is one of the primary drivers of residential water consumption (21). It has also been shown that households with lower incomes reduce their water consumption more in response to price increases than households with higher incomes (22). Increasing block pricing would align economic incentives with the social objective of providing a basic level of water consumption at low cost, while also providing more appropriate price signals for heavy consumers to reduce their consumption. It was also suggested that customers could be charged different rates for indoor and outdoor water use, reflecting the concept that outdoor water consumption is typically more of a luxury good than indoor use. This could theoretically be achieved by separately metering indoor and outdoor connections, or permitting the use of lower-quality water for outdoor applications. However, the challenges inherent in implementing and enforcing such an approach make it highly unlikely to be implemented anytime in the near future. Other revenue-stabilizing mechanisms that appropriately value water on the basis of its short-term availability, such as drought or shortage surcharges, could also be considered. Research is needed to understand the impacts on potential water consumption levels, utility revenue, and consumer costs that may result from a transition to higher overall water rates, increasing block pricing, and other potential innovative pricing schemes.

Forward-thinking investments

Water rates in the United States are typically heavily regulated and set by boards of locally elected officials. Such elected officials are often hesitant to raise water rates because of the potential political backlash from their constituents. However, increasing water rates in order to fund conservation efforts can lead to significant long-term cost savings. One study conducted by the City of Westminster in Colorado found that conservation efforts since 1980 had saved “residents and businesses 80% in tap fees and 91% in rates compared to what they would have been without conservation (23).” Additional studies along these lines are needed to reinforce the financial justification for investments in conservation. Improved education can also help inform the electorate that low water prices lead to overconsumption, resource scarcity, and under-investments in existing and new infrastructure, all of which may have negative long-term impacts. Similarly, research and education on the true cost of water, including local and state funding that supplements end-use revenues could provide elected officials with the data and political support that they need to make necessary rate adjustments and allocate appropriate funding towards conservation efforts.

Revenue decoupling

Water utilities also have minimal incentives to promote more efficient water usage, as their revenues are tied to the consumption levels of the customers. A similar problem was identified in the electric sector and has been approached in many jurisdictions through revenue decoupling (24). Through this mechanism, a utility’s revenue is tied to its ability to serve the needs of its customers, as opposed to the amount of energy that it provides. This distinction empowers electric utilities to invest in efficiency and demand-side management programs that are often cheaper alternatives to further increasing supply through investments in new generation units and transmission and distribution infrastructure. These programs typically offer incentives to consumers who take well-defined measures to reduce their energy consumption. The resultant reduction in electricity demand negates the need for investments in new infrastructure. Revenue decoupling for water utilities began for some customers in California in 2008, but this is still not a widespread practice across the country. Further research is necessary to understand how revenue decoupling would influence water consumption, as well as its potential to provide greater incentives for long-term investments in conservation and efficiency programs.

Because revenues are generally still tied to sales volume in the water sector, decreased consumption can also cause revenue shortfalls for utilities that prevent them from making capital investments in new and existing infrastructure. Furthermore, water conservation can lead to unintended consequences. For example, sewage systems rely on wastewater to help push solid waste through pipes. In California, successful water conservation programs have reduced the amount of wastewater passing through the system, and as a result, solid waste has begun to collect, causing damage and pipe corrosion (25). It is important to account for these effects when designing pricing schemes to support forward-looking investments that can reduce costs over the long run.

3.2.2 Regulatory and Institutional Aggregation

Owing to the high level of disaggregation among service providers and regulators in the water sector, individual water conservation programs are typically limited in their scope and geographic reach. This results in high costs and barriers to entry for each new program.

The aggregation of small municipal water providers and utilities through regional consortia was also discussed. Under such an arrangement, each individual entity can still operate autonomously, but regional consortia would help to establish a consistent regulatory framework for the region and could also coordinate uniform conservation programs across multiple different stakeholders, reducing the associated implementation costs. One example of this approach is the Metropolitan Water District of Southern California, a regional water wholesaler serving almost 300 different retail water agencies. It currently oversees and operates a \$20 million-per-year regional water conservation program that provides commercial and residential rebates for prescribed measures that improve water efficiency and reduce consumption. This program is implemented and marketed consistently across numerous utility territories and has contributed to a roughly 15% reduction in per capita potable water consumption in the region between 2000 and 2014 (26). Workshop participants also discussed the possibility of expanding and formalizing increased cross-agency coordination on water issues at the federal level.

The disaggregated institutional landscape is also impacted by the dispersed nature of fresh water as a natural resource. Groundwater aquifers may span multiple different municipalities, regions, and regulatory landscapes. Therefore, the water withdrawals made by one municipality may influence water availability in the entire neighboring region. This “tragedy of the commons” provides an incentive for each municipality to increase its water consumption in the short term for fear of losing available supply to its neighbors over the long term.

3.2.3 Integrated Water and Energy Efficiency Programs

In 2012, nearly \$6 billion was invested in ratepayer-funded energy efficiency programs in the electric sector, which saved over 126 terawatt-hours of electricity (27). This level of support is simply not available for similar programs in the water sector. However, there exists an opportunity for water programs to “piggyback” on the maturity of their counterparts in the electric sector, drawing from the lessons learned and early growing pains of those programs; see, for example, Ref. (28). Furthermore, energy is required to treat water, deliver it to consumers, and collect wastewater after it has been consumed. Depending on the source, this full water life-cycle can require anywhere from 2 to 27 kWh of energy per thousand gallons of water consumed by end users (29). This requirement increases as much as 50-fold when the energy costs of heating water are also considered. Therefore, an integrated efficiency program framework could be implemented to recognize this relationship. Such programs could draw upon ratepayer funds from the energy sector—where a stronger efficiency program infrastructure already exists—to finance water efficiency programs that also save energy.

An example of this framework can be found in Southern California, where in 2012 the Los Angeles Department of Water and Power and Southern California Gas Company entered a

partnership that allows them to jointly offer efficiency programs to customers in their shared territories (30). However, these programs are primarily tied to the use of natural gas to heat water, and there are still no state energy efficiency programs that help fund cold-water conservation measures.

3.2.4 Greywater Recycling

In a residential and commercial context, greywater is generally defined as all wastewater that is generated by sources other than a toilet, e.g., sinks, showers, washing machines, and dishwashers. Such water is not suitable for human consumption, but may be suitable for certain forms of reuse, specifically in toilets, and for irrigation or landscaping. Although greywater itself is not fit for human consumption, it can be converted back into drinking water more efficiently than sewage and other forms of wastewater that have higher carbon and pollutant density. Combining these different types of wastewater increases the cost and energy requirements of extracting the carbon solids and applying further treatment.

While rules and regulations differ significantly from state to state, in most jurisdictions greywater is treated identically to sewage waste. These two water streams mix and are both sent directly to water treatment plants, eliminating any opportunity for productive reuse of greywater. Recently, some states have begun to implement new policies that potentially allow greywater to be used for irrigation and indoor reuse. Such policies have thus far been limited to water-starved states such as California, Arizona, New Mexico, Utah, and Texas, and permitting processes are still burdensome, inhibiting participation by many consumers.

The adoption of greywater reuse technologies could be facilitated by the creation of a standardized framework for the requirements of such systems. The costs of retrofits may limit initial participation, but these costs could also be subsidized through conservation programs. More importantly, with a consistent regulatory framework in place it would become much easier to incorporate these systems into new construction. Greywater recycling technologies could also be integrated into utility energy efficiency incentive programs, as discussed in section 3.2.3, because of the large energy savings that result from avoiding the need to comprehensively retreat the water at a centralized facility.

An average person in the U.S. consumes approximately 12.8 gallons of water per day for showers and baths and 18.5 gallons of water per day for toilet flushes (19). A clear regulatory framework combined with appropriate incentives could dramatically increase the penetration of shower-to-toilet greywater recycling systems, potentially making many residential toilets nearly “net zero” water consumers and saving billions of gallons of water per year.

3.3 BEHAVIORAL CHANGE

3.3.1 Consumer Education and Communication

Typical residential consumers have little to no concept of how much water they consume in a day or a month. Part of this lack of understanding is due to poor data availability, as has been discussed previously. However, it is also partially due to the fact that consumer awareness and interest in water conservation is low. Over the past century, clean water has come to be perceived as an infinite free resource by many in the industrialized world. This is a remarkable accomplishment in a world where more than 660 million people still lack access to reliable drinking water sources (31). Yet, it has also led to a high level of consumer complacency in parts of the developed world where water availability constraints should still be a serious concern. Consumers in the electric sector have also traditionally exhibited many of the same behavioral patterns; however, increased implementation of utility efficiency programs has led to new research on consumer behavior over the past decade. Research can draw upon such efforts in the energy sector to better understand the behavioral science behind water consumption.

In recent years, water conservation has begun to creep into the public consciousness because of the droughts and water scarcity concerns currently being experienced in California and the southwestern U.S. As an increasing number of consumers recognize the social imperative to reduce their water consumption, stakeholders now have an important window of opportunity to provide consumers with the tools they need to make informed decisions on how to reduce their consumption. For example, the “miles-per-gallon” (MPG) metric for vehicles has become a pervasive part of our culture. Car manufacturers advertise MPG ratings on their commercials, and many consumers factor MPG strongly into their choice of purchase. The gallon-per-minute (GPM) metric similarly exists for water products, but it has not reached the same level of public awareness. Manufacturers typically design their products to meet minimum standards, and offering a product with a lower GPM rating does not provide a competitive advantage as high MPG does in the vehicle market. This is partly because gasoline typically accounts for a larger household expense than water, but there is still likely a market of waste-conscious consumers who would be interested in reducing their water consumption by purchasing more efficient appliances.

Along similar lines, the concept of turning off the water while brushing teeth is somewhat well-known and discussed throughout households and popular culture. However, compared to other potential conservation measures, this action has relatively low water-saving potential. Many consumers would also likely be surprised to learn that toilets account for more water use in buildings than showers, faucets, or washing machines. Improving the dissemination of this form of information to consumers would help them make more rational choices when seeking to take measures to reduce their water consumption.

Research is needed to inform the design and implementation of any such education efforts. Such research would improve stakeholder understanding of which approaches to marketing and consumer education can effectively capture consumer attention and motivate behavioral change. For example, many consumers don’t respond well to simple messages telling

them to “reduce your water use.” Such a message is too broad, does not include actionable information, and implies that some sort of sacrifice is necessary. Research could focus on identifying forms of water conservation messaging that register more strongly with consumers.

3.3.2 Behavioral Science

Providing consumers with additional information tends to increase their knowledge and understanding of an issue but, with all else equal, does not generally lead to changes in behavior (32). It is human nature to resist change and maintain the status quo, and it is well known that there is a large gap between what consumers claim to care about and the actions they are actually willing to take. Additional research is needed to better understand how increased education, communication, and information availability interact with human psychology, behavioral economics, and behavioral science to influence actual changes in water consumption behavior. This will provide policy makers with the tools they need to motivate consumers to make intelligent and efficient water consumption their default action so that conscious behavioral change is no longer necessary.

Workshop participants discussed several specific potential behavioral research projects that are briefly outlined below. This is not intended to be an exhaustive list. Primarily, it is important that any such studies be conducted in a scientifically rigorous and reproducible fashion, with treatment and control groups as appropriate.

Consumer perception

New research might focus on identifying how products can be augmented so as to either improve the consumer experience while using the same amount of water, or reduce water usage while maintaining the same consumer experience.

Randomized controlled trials could be conducted to better understand consumer perception of novel approaches towards increasing water efficiency. For example, aerators are commonly applied to many faucets and showers to mix air into the water stream. These reduce water usage while intending to provide consumers with a comparable user experience. Further research could examine the extent to which consumers perceive a difference between various water flow profiles (i.e., larger or smaller droplets, different dispersion patterns) in a shower. Workshop participants also speculated on whether other sensory stimulation could alter the consumer experience. For example, the concept of emitting additional artificial water sounds in the shower was discussed as one approach that may cause users to perceive a greater water flow.

Gamification

Gamification can take advantage of natural competitive tendencies to motivate consumers to use water more efficiently. For example, utilities could pool neighboring homes with similar consumption profiles and offer a small financial incentive for the one that consumes the least

water each month. This might be coupled with a user-friendly data reporting interface where each household could monitor how its usage compares with its neighbors'. Similarly, contests could be introduced within a single home if each household member were provided a simple means of logging individual water use, i.e., swiping a personalized card before taking a shower or using the washing machine. Alternatively, a similar approach could be used to establish and enforce monthly water budgets for a single household. Homes might be offered lower rates for committing to stay below a certain consumption threshold, but would face a steep rate increase if they crossed it.

Limiting choices

Consumers can be overwhelmed when presented with too many choices, which often leads to inaction over the fear of making a sub-optimal decision. This problem may be exacerbated in the water sector, where initial consumer awareness is already low. Consumers presented with a number of different potential new water-saving showerheads may ultimately decline to purchase any of them, preferring instead to maintain the status quo. Alternatively, if a single option is presented with a simple actionable message, i.e., “install this to save water,” consumers may be more willing to act. Research could be conducted to analyze how presenting consumers with limited, clear and concise water conservation options impacts the adoption of these technologies and actions.

Emotional connections

Workshop participants also discussed the possibility of increasing the public's emotional connection to water conservation issues. Similar efforts with climate change and other environmental issues have had more success in making the potential impacts tangible and connecting with consumers. There is a sense that while water conservation has started to enter the public consciousness, it still lacks this emotional connection. For example, even during the drought conditions currently being experienced in California, most people have never directly suffered from a lack of water availability. This makes it difficult for an average consumer to internalize the long-term externalities associated with inefficient water usage. Research is needed to understand how to establish this connection with consumers, drive home the potential long-term impacts of water scarcity, and ultimately effect behavioral change.

4 CONCLUSIONS

This report summarizes the key findings of a workshop that convened experts from a wide range of water-related disciplines with the goal of identifying technologies that can be developed and deployed to change water consumption behavior. While efforts to reduce water consumption have gained momentum in recent years, there are a number of key barriers that have limited the effectiveness of such efforts. Chief among these is the fact that many consumers have limited awareness of their water consumption patterns because of poor data availability, and/or are unmotivated to reduce their consumption because of low costs and split incentives. Without improved data availability and stronger price signals, it will be difficult to effect true transformative behavioral change.

This report also reviews a number of technology characteristics that have successfully motivated behavioral change in other sectors, as well as several technologies that could be developed specifically for the water sector. Workshop participants discussed how technologies that provide active feedback and promote measurable goals and social accountability have successfully brought about changes in other types of behavior. A range of regulatory and policy actions that could be implemented to support such efforts are also presented. These include institutional aggregation, revenue decoupling, and price structure reforms. Finally, several R&D pathways were proposed, including efforts to identify optimal communication strategies and to better understand consumer perceptions and psychology as they relate to human behavior regarding water consumption.

The findings presented here can help to inform policy makers as they develop new policies and seek to support new research to help consumers use water more efficiently. It is our hope that these findings will also be utilized to prioritize topics for additional follow-up workshops to address individual issues and barriers more directly and in more detail. The goal of such future workshops will be to develop specific solutions, research plans, and technology development pathways that can be undertaken to increase the market penetration of technologies that effect behavioral change and reduce water consumption.

5 REFERENCES

1. USDOE, “The Water-Energy Nexus: Challenges and Opportunities” (U.S. Department of Energy, Washington, DC, 2014) (available at <http://www.energy.gov/downloads/water-energy-nexus-challenges-and-opportunities>).
2. M. A. Maupin *et al.*, “Estimated Use of Water in the United States 2010” (U.S. Geological Survey Circular 1405, U.S. Geological Survey, 2014) (available at <http://dx.doi.org/10.3133/cir1405>).
3. USEPA, “Domestic Water Use in Gallons per Day per Person and Projected Percent Population Change by 2030” (available at http://www3.epa.gov/watersense/our_water/tomorrow_beyond.html).
4. R. Risser, “Driving Innovation, Speeding Adoption, Scaling Savings: An Overview of the Building Technologies Office” (2015) (available at http://energy.gov/sites/prod/files/2015/04/f22/BTO_Overview_FY15_Peer_Review_RR.pdf).
5. USEIA, “Annual Energy Outlook 2014 with Projections to 2040” (DOE/EIA-0383(2014), U.S. Energy Information Administration, Washington, DC, 2014) (available at [http://www.eia.gov/forecasts/aeo/pdf/0383\(2014\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf)).
6. EPRI, “Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment — The Next Half Century” (1006787, Electric Power Research Institute, Palo Alto, California, 2002) (available at <http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001006787>).
7. T. Sherman, “Disaggregating Residential Shower Warm-Up Waste: An Understanding and Quantification of Behavioral Waste Based on Data from Berkeley National Labs” (Evolve Technologies LLC, Scottsdale, AZ, 2014) (available at <http://thinkevolve.com/wp-content/uploads/2014/09/Disaggregating-Residential-Shower-Warm-Up-Waste.pdf>).
8. J. Doom, “Water Utilities to Spend \$2 Billion on Smart Meters Through 2020” (*Bloomberg Business*, 2013) (available at <http://www.bloomberg.com/news/articles/2013-05-13/water-utilities-to-spend-2-billion-on-smart-meters-through-2020>).
9. PR Newswire, “Smart Water Management Market by Solutions, by Services , by Smart Meter Types, by Region - Global Forecast to 2020” (London, 2015) (available at <http://www.prnewswire.com/news-releases/smart-water-management-market-by-solutions--by-services--by-smart-meter-types-by-region---global-forecast-to-2020-300142695.html>).
10. USEPA, “National Efficiency Standards and Specifications for Residential and Commercial Water-Using Fixtures and Appliances” (Environmental Protection Agency, Washington, DC, 2008) (available at <http://www3.epa.gov/watersense/docs/matrix508.pdf>).

11. American Standard, “18 Trillion Gallons of Water Saved during 20 Years of Low-Flow Toilet Regulations” (2014) (available at <http://www.americanstandard-us.com/pressroom/18-trillion-gallons-of-water-saved-during-20-years-of-low-flow-toilet-regulations/>).
12. D. L. Mitchell, T. W. Chesnutt, “Evaluation of East Bay Municipal Utility District’s Pilot of WaterSmart Home Water Reports” (M.Cubed and A&N Technical Services, Inc., 2013) (available at [http://californiawaterfoundation.org/wp-content/uploads/PDF/1389391749-Watersmart_evaluation_report_FINAL_12-12-13\(00238356\)](http://californiawaterfoundation.org/wp-content/uploads/PDF/1389391749-Watersmart_evaluation_report_FINAL_12-12-13(00238356).)).
13. USEPA, “Fiscal Year 2011 Drinking Water and Ground Water Statistics” (EPA 816-R-13-003, U.S. Environmental Protection Agency, Washington, DC, 2013) (available at <http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf>).
14. APPA, “2015-2016 Annual Directory and Statistical Report: U.S. Electric Utility Industry Statistics” (America Public Power Association, Arlington, VA, 2015), (available at <http://www.publicpower.org/files/PDFs/USElectricUtilityIndustryStatistics.pdf>).
15. J. A. Beecher, “The Conservation Conundrum: How Declining Demand Affects Water Utilities.” *Journal - AWWA*. 102, 78–80 (2010).
16. D. S. Kenney, “Understanding Utility Disincentives to Water Conservation as a Means of Adapting to Climate Change Pressures.” *Journal - AWWA*. 106, 36–46 (2014).
17. USEPA, “Drinking Water Infrastructure Needs Survey and Assessment: Fifth Report to Congress” (EPA 816-R-13-006, Environmental Protection Agency, Washington, DC, 2013) (available at http://water.epa.gov/grants_funding/dwsrf/upload/epa816r13006.pdf).
18. AWWA, “Buried No Longer: Confronting America’s Water Infrastructure Challenge” (American Water Works Association, Denver, CO, 2011) (available at <http://www.awwa.org/Portals/0/files/legreg/documents/BuriedNoLonger.pdf>).
19. P. W. Mayer *et al.*, “Residential End Uses of Water Study (1999)” (American Water Works Association, Denver, CO, 1999) (available at http://www.waterrf.org/publicreportlibrary/rfr90781_1999_241a.pdf).
20. USEPA, “Fix a Leak Week Fact Sheet” (Environmental Protection Agency, Washington, DC, n.d.) (available at http://www3.epa.gov/watersense/docs/ws_fixaleakfactsheet508.pdf).
21. C. Kuklowsky, “Residential Water Consumption in Los Angeles: What Are the Drivers and Are Conservation Measures Working?” (available at <http://sustainablecommunities.environment.ucla.edu/wp-content/uploads/UCLA-Water-Consumption-Policy-Brief-FINAL.pdf>).
22. M. E. Renwick, S. O. Archibald, “Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden?” *Land Economics*. 74, 343–359 (1998).

23. S. Feinglas, C. Gray, P. Mayer, “Conservation Helps Limit Rate Increases for a Colorado Utility” (The Alliance for Water Efficiency, City of Westminster, and Water Demand Management, Westminster, CO, 2013) (available at <http://www.financingsustainablewater.org/resource-search/conservation-helps-limit-rate-increases-colorado-utility>).
24. RAP, “Revenue Regulation and Decoupling: A Guide to Theory and Application” (The Regulatory Assistance Project, Montpelier, VT, 2011) (available at <http://www.raponline.org/document/download/id/861>).
25. M. Stevens, “Unintended consequences of conserving water: leaky pipes, less revenue, bad odors” (Los Angeles Times, 2015) (available at <http://www.latimes.com/local/california/la-me-drought-consequences-20150901-story.html>).
26. MWD, “2015 Urban Water Management Plan” (Metropolitan Water District of Southern California, 2016) (available at http://www.mwdh2o.com/PDF_About_Your_Water/2.4.2_Regional_Urban_Water_Management_Plan.pdf).
27. A. Cooper, L. Wood, “Summary of Electric Utility Customer-Funded Energy Efficiency Savings, Expenditures, and Budgets” (The Edison Foundation Institute for Electric Innovation, Washington, DC, 2014) (available at http://www.edisonfoundation.net/iei/Documents/InstElectricInnovation_USEESummary_2014.pdf).
28. America’s Energy Future Energy Efficiency Technologies Subcommittee, National Academy of Sciences, National Academy of Engineering, National Research Council, “Real Prospects for Energy Efficiency in the United States” (The National Academies Press, 2010) (available at <https://www.nap.edu/catalog/12621/real-prospects-for-energy-efficiency-in-the-united-states>).
29. CEC, “2005 Integrated Energy Policy Report” (CEC-100-2005-007/CMF, California Energy Commission, Sacramento, CA, 2005) (available at <http://www.energy.ca.gov/2005publications/CEC-100-2005-007/CEC-100-2005-007-CMF.PDF>).
30. M. Drake, M. Lukito, G. Wright, D. Jacot, G. Hardinson, “Creating a One-Stop-Shop for Resource Efficiency: A Public-Private Partnership in the Delivery of Energy and Water Efficiency Programs” (Proceedings ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, 2014) (available at <http://aceee.org/files/proceedings/2014/data/papers/5-451.pdf>).
31. WHO/UNICEF, “Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment” (World Health Organization and UNICEF, Geneva, Switzerland, 2015) (available at http://www.who.int/water_sanitation_health/monitoring/jmp-2015-update/en/).
32. WaterSmart, “Tapping into the Power of Behavioral Science: Insights & Opportunities for Water-Use Efficiency” (WaterSmart Software, San Francisco, CA, 2014) (available at

http://www.watersmart.com/wp-content/uploads/2014/11/WSS_TappingintoBehaviorScience.pdf).

APPENDIX A: WORKSHOP SUMMARY

On April 29th and 30th, 2015, Argonne National Laboratory hosted a workshop, on behalf of the U.S. Department of Energy Building Technologies Office (DOE/BTO), that convened 34 water experts and stakeholders from across the country. Workshop participants spanned a range of different backgrounds, including private industry, government, and academia; and disciplines, including engineering, physical sciences, policy, product design, economics, and behavioral science. Participants were tasked with 1) identifying technology characteristics that are favorable for motivating behavioral change, 2) identifying barriers that have prevented the development and market adoption of technologies with these characteristics in the water sector, and 3) identifying concrete research and development pathways that could be undertaken to overcome these barriers, increase the penetration of technologies that influence water consumption behavior, and ultimately reduce domestic water consumption. The scope was generally limited to water use in and around residential and commercial buildings, owing to the wealth of different conservation issues facing water use for industrial and agricultural applications, as well as for thermoelectric cooling.

The workshop included five primary presentations by attendees that served to motivate open-ended discussion sessions in small groups. The thoughts, findings and suggestions identified during each of these small-group discussions were then presented to the larger group, where they were further refined, collected and organized by the workshop coordinators. This process was repeated for each of four broad topic areas:

- (1) Water Consumption and Behavior – Identifying the problem scope and definition.
- (2) Influencing Behavior through Technology – Identifying technological characteristics that can motivate behavioral change.
- (3) Water Programs – Identifying programmatic and institutional barriers that have inhibited market penetration of behavior-influencing technologies, as well as opportunities to encourage increased development and penetration.
- (4) Paths Forward – Identifying specific research pathways to overcome previously identified barriers and specific technologies that could be developed to motivate behavioral change.

Argonne and DOE/BTO would like to thank the following participants for all the knowledge that was shared during discussions leading up to the workshop and also for the invaluable contributions made during the workshop itself.

TABLE A1 List of workshop participants.

Participant Name	Organization
Antonio Bouza	U.S. Department of Energy
Oliver Browne	University of Chicago
Sriraam Chandrasekaran	Illinois Sustainable Technology Center
David DeBord	American Society of Plumbing Engineers
Shaun Dentice	CLEAResult Consulting
Mary Ann Dickinson	Alliance for Water Efficiency
Vicky Espinoza	Argonne National Laboratory
Kyle Gluesenkamp	Oak Ridge National Laboratory
Katie Hanson	Midwest Energy Efficiency Alliance
Chioke Harris	U.S. Department of Energy
Robert Horner	Argonne National Laboratory
Gary Klein	Gary Klein and Associates
David Lampert	Argonne National Laboratory
Cynthia Lane	American Water Works Association
Todd Levin	Argonne National Laboratory
Rich Lussier	TOTO USA
Peter Lynch	Argonne National Laboratory
Vinod Mahat	Argonne National Laboratory
Gabriel Martinez	Sandia National Laboratories
Brewster McCracken	Pecan Street Inc.
Bill McDonnell	Metropolitan Water District
Cary McElhinney	US EPA Region 5
Jessica Miller	Elevate Energy
Kenneth Molli	Veolia North America
Ralph Muehleisen	Argonne National Laboratory
Ken Rose	Michigan State University
Troy Sherman	Evolve Technologies
Benjamin Shorofsky	The Delta Institute
Joel Stauber	Argonne National Laboratory
Paul Thomas	Water Energy Innovations & Synergy (501c3)
Sharon Waller	Sustainable Systems LLC Consulting
Peter Yolles	WaterSmart Software
Qizhi Zhang	Argonne National Laboratory
Angie Ziech-Malek	CLEAResult

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