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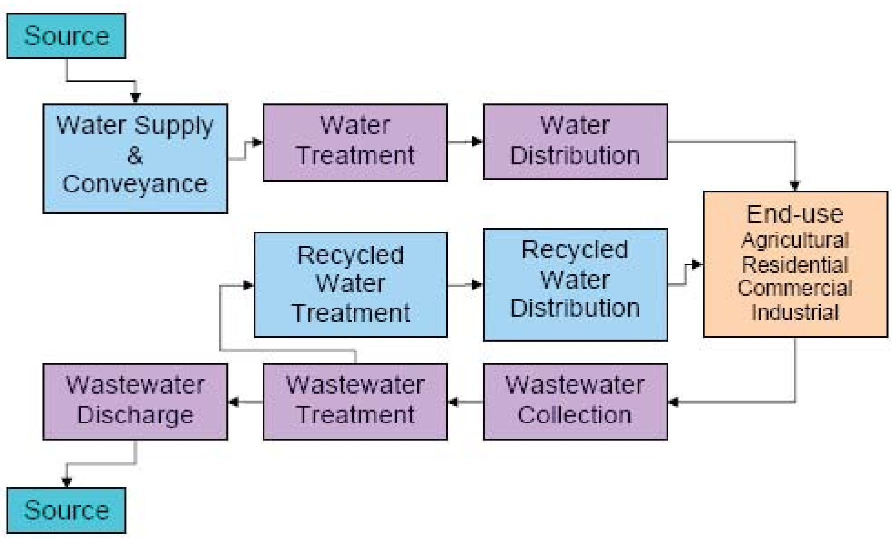
Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use



Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use

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Final Report, March 2008

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PRODUCT DESCRIPTION

This report provides background information on the use of freshwater in the United States and the basic technologies employed to treat and utilize water. The connections between water use and energy consumption are also highlighted. Opportunities are discussed for improving water use efficiency through on-site water reuse, water reclamation, and water use reductions. Lastly, recommendations are provided for future action to advance specific technologies and market opportunities.

Results and Findings

This report identifies opportunities that promise to significantly improve water use efficiency, with results directed to the power generation, water and wastewater, utility, agricultural, industrial, commercial, and residential markets. Emphasis is placed upon opportunities that have heretofore been overlooked or under-funded.

Challenges and Objectives

The power generation sector is a very large user of water and is also a large supplier of electricity to the water and wastewater sector. As such, electric utilities have a vested interest in the advancement of water use efficiency. On the supply side, future electricity generation will be challenged by the availability of water for power plant cooling. On the demand side, large electric customers will be demanding new electrotechnology solutions to help deal with current and future water shortages. The objective of this study was to define technology research opportunities for efficient water treatment and use.

Applications, Values, and Use

Water use is important in all market segments and to all end users. Synergies exist for advanced technology applications across many sectors, but none so much as between water and energy. Original and powerful partnerships will likely develop between leading players from within the water and energy industries.

EPRI Perspective

This report offers specific recommendations for future work that complement the interests and capabilities of the electric utility market segment. The report outlines water related needs and concerns and provides a comprehensive list of tangible opportunities for water use efficiency improvements. In addition, the report considers opportunities within all areas of water use efficiency—reuse, reclamation, and use reduction—to enable the reader to appreciate the big picture and to better identify the most practical next steps. Research opportunities specifically directed to power generation are discussed in EPRI report 1015371, *Program on Technology Innovation: An Energy/Water Sustainability Program for the Electric Power Industry* and EPRI technical update 1015444, *Program on Technology Innovation: Power Generation and Water*

Sustainability. Technologies and approaches to increasing water use efficiency for electric power generation are evaluated in EPRI report 1014026, *Water Use for Electric Power Generation*.

Approach

The report is structured to:

- Provide background information through the first three chapters
- Include a workshop summary in Chapter 4
- Outline market needs and opportunities in Chapter 5
- Review specific water treatment technology opportunities in Chapter 6
- Review specific water use technology opportunities in Chapter 7
- Outline final recommendations in Chapter 8

Keywords

Water Use Efficiency
Water Reuse
Water Conservation
Water Treatment
Water Quality
Energy and Water

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

The availability and use of water is emerging as a major concern in the electric power sector. Water shortages across the United States are preventing many new power plants from being permitted, and burdening existing ones with new environmental compliance problems. Furthermore, the treatment and use of water is consuming a growing share of the country's energy resources – in some regions, up to 20% of the total power generated is being used to supply, treat, distribute and otherwise process water and wastewater.

There is a growing need in the U.S. for new sources of freshwater. Fortunately, there are also many opportunities across virtually all industries to improve the efficient treatment and use of water. This could involve using less water via new conservation measures, reusing water for multiple purposes prior to disposal, or implementing innovative ways to reclaim usable water from nontraditional sources. Market segments highlighted in this report that hold potential for improvements are Power Generation, Water & Wastewater Utilities, Agriculture, Industrial, and Commercial & Residential.

This report focuses on technical opportunities for improving water use efficiency, and identifying specific areas where additional research is required to make those opportunities possible. Water use efficiency is a broad topic that often has different meanings to different professionals. For the purpose of this report water use efficiency refers to three specific areas: water reuse, water reclamation, and water use reduction.

Water reuse refers to the retention of water within a given facility that has already served a useful purpose, and then putting the same water to use again for a beneficial purpose within the same facility. This could be as simple as a commercial linens washing operation treating and reusing laundry rise water for subsequent wash cycles. It can also refer to practices by water utilities that treat municipal wastewater or contaminated storm water, and provide for beneficial reuse of the final effluent. Sometimes the used water can be utilized without any treatment; for landscape irrigation as an example. Other times the used water is treated to very high standards and recycled as clean makeup water within the original process. The water could be reused once, twice, or almost indefinitely within a closed loop system.

Water reclamation is the utilization of alternative or degraded sources of water. Examples include sea water, brackish water, and "produced" water from oil production. Such sources, depending upon location, may be thought to have no value, or worse yet, be a liability. Fully utilizing the potential of these sources to augment, or even replace, freshwater draws is the promise of new technology.

Water use reduction refers to the use of less water for the same desired process or output, or a reduction in the volume of water to achieve a given purpose. Well known technology examples would include high efficiency commercial and residential appliances like clothes washers, dishwashers, and toilets. Larger commercial and industrial opportunities for water use reduction abound, often related to the use of less water for process cooling, and the reduction of blowdown water on boilers, cooling towers, and rinse tanks. Use of soil moisture sensors employing various platforms and models can lead to better water management efficiency and irrigation scheduling for agricultural and large landscape applications.

Potential for Water Use Efficiency

One of the best opportunities for improved water use efficiency is water reuse. The EPA estimates that publicly owned treatment works (POTWs) in the U.S. treated about 34 billion gallons of wastewater per day in 2004.[1] This does not include the effluent from the 21% of homes not served by a public sewer system, nor wastewater treated on-site by industrial users. The potential for reuse exists both upstream and downstream of the wastewater treatment facility. Water can be reused on-site before it is discharged to the sewer. For example, partially impaired water (often referred to as greywater) can be used for secondary, less sensitive uses such as irrigation or toilet flushing. Downstream of the wastewater utility the treated effluent can be supplied for non-potable uses like those above, as well as for commercial washing processes, dust control for construction applications, and fire protection via reclaimed water fire hydrants. In 2004 approximately 1.7 billion gallons per day of wastewater was being reused and that amount was growing at a rate of 15% per year.[2] This reflects a very small percentage of the total reuse potential.

Water reclamation also presents many opportunities for improved water use efficiency. One technical area receiving much attention is the desalination of ocean or brackish inland water. Current technologies require very high levels of energy to adequately treat the water. Efforts are focused on developing materials and processes that will make desalination of alternative sources of water much more cost effective. Figure 1-1 illustrates the large energy savings potential that theoretically exists for improved technology. The theoretical minimum energy required to remove salt from solution is about 10 times less than current commercialized technologies.

Improved desalination technologies would also create an opportunity to reclaim vast quantities of impaired ground water. Figure 1-2 depicts the location of major saline aquifers within the U.S., which have the potential to double the available groundwater in the country. This water has very high salt levels, and contains additional minerals that produce unique challenges for purification systems.

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[1] U.S. Environmental Protection Agency, *Clean Watersheds Needs Survey 2004: Report to Congress* (January 2008).

[2] U.S. Environmental Protection Agency, *Guideline for Water Reuse*, EPA/625/R-04/108 (Washington, DC, September 2004).

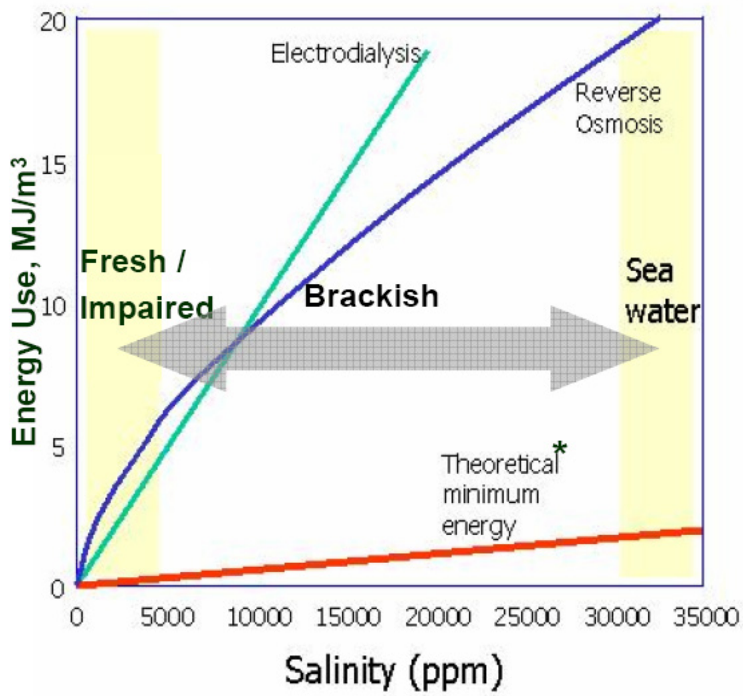

Figure 1-1
Actual vs. Theoretical Energy Intensity for Treating Saline Water

Source: Lawrence Livermore National Laboratory

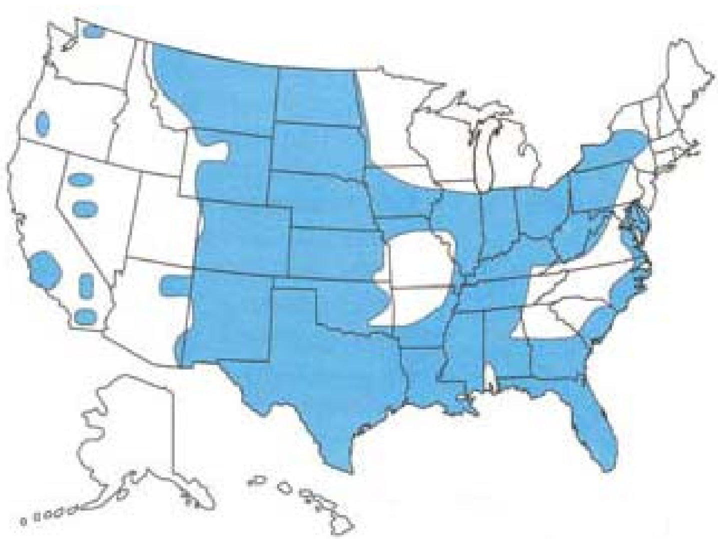

Figure 1-2
Location of U.S. Saline Aquifers

Source: Sandia National Laboratories and U.S. Bureau of Reclamation, 2003

There is potential for the reclamation of "produced" water generated through the extraction of oil and natural gas. Produced water can range from being nearly fresh to being a salty brine, with the vast majority being at least as saline as seawater. In 1995, the American Petroleum Institute (API) estimated that oil and gas operations generated 18 billion barrels of produced water (49 million gallons per day). It was also noted that approximately 71 percent of produced water is recycled and re-injected into the field for extracted oil replacement.[3] The remaining water has to be treated to minimal environmental quality standards and then discharged. Finding suitable locations to discharge the effluent and obtaining the required environmental permits is a growing problem. If the excess produced water could be treated as a resource instead of a waste, then perhaps multiple problems could be addressed simultaneously.

In addition to finding new sources of water, there are many opportunities for reducing the volume of water required by end use processes. Advanced cooling technologies and improved power plant design could dramatically decrease the water consumption associated with power generation. Dry cooling technologies are already making inroads as well as power generation cycles that require less cooling. In the water utility market, infrastructure improvements hold the potential to decrease water losses substantially. Water loss for a well operated municipal water utility is about 10%. Many utilities however operate with losses in excess of 20%. By making monitoring and controls a priority, dramatic water savings can be achieved upstream of the consumer. Lastly, there are many opportunities for virtually all end-users to reduce their water consumption through the implementation of better technologies and practices. The Pacific Institute claimed in a 2003 study that urban consumption could be reduced by over 30% if consumers simply implemented currently available water use technologies.[4] This would include the adoption of fixtures and appliances that meet current standards by all end users, and the utilization of best management practices by larger commercial and industrial users.

[3] American Petroleum Institute, *Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States*. Prepared by ICF Consulting (Washington, DC, May 2000).

[4] Peter H. Gleick et al., *Waste Not, Want Not: The Potential for Urban Water Conservation in California* (Oakland, CA: Pacific Institute, November 2003).

2
PROJECT APPROACH

This project explored the water use needs of the major market segments within the United States – Power Generation, Water and Wastewater Utilities, Agriculture, Industrial, and Commercial & Residential. The purpose was to identify market needs and opportunities related to on-site water reuse, water reclamation, and water use reduction that could benefit from the application of advanced technologies. Opportunities were considered that could either significantly increase the supply of freshwater, or could significantly decrease the demand. This tended to place technologies within one of two categories – advanced water treatment technologies, or advanced water use technologies.

The large demand for water within the power generation segment connects electric utilities to the water supply market. The large demand for power by the water and wastewater segment links electric utilities to the water treatment technologies market. Lastly, the large demand for energy by agricultural, industrial, commercial, and residential customers to pump, heat, chill, or otherwise process water on-site, links electric utilities to the water end-use technologies market. Each of these perspectives was considered when evaluating new water use efficiency opportunities.

Three Project Stages

The project included the following three stages.

- Review of market needs and applicable technologies
- Workshop to present and discuss opportunities
- Final technology evaluation and recommendations

Review of Market Needs and Applicable Technologies

A review was performed of water related needs and opportunities within various market segments, including: Power Generation, Water & Wastewater Utilities, Agriculture, Industrial, and Commercial & Residential. All water use in the U.S. can be categorized within one of these market segments. Residential and commercial use is closely linked to the Water & Wastewater segment as over 90% of water consumed by these users is supplied through a public utility. The review included current as well as perceived future needs, and sought to compare demand forecasts with supply options.

Technologies were identified that are currently employed in each market segment related to on-site water reuse, water reclamation, and water use reduction. These were differentiated between mature technology, and emerging technology. A search was made for opportunities for new technologies and research activities aimed at addressing water use efficiency.

Technology areas were identified that still require research and development and hold the greatest potential for effectively and efficiently satisfying market needs. These technologies were presented for further review and discussion amongst leading industry researchers and technology experts. The initial list of screened technologies is presented in Table 2-1. These represent both new laboratory research, such as nano-filtration membranes, as well as older research that has yet to find a niche for commercialization, such as super critical oxidation.

These technologies also address multiple solutions for water use efficiency. For example, many technologies focus on the treatment of water, which can enable more cost effective means of delivering freshwater and can enable the use of untapped marginal supply sources. This would include disinfection technologies like UV irradiation and photocatalytic oxidation, as well as ion removal technologies like electrodeionization and selective ion exchange.

Some technologies do not treat the water at all, but rather enable more efficient use of the water that is consumed. For example, advanced heat transfer materials can reduce the cooling water requirements in thermoelectric power plants, and advanced soil moisture sensors can enable more efficiency agriculture irrigation management.

An initial list of technologies and practices was outlined in an October 2007 discussion paper titled *Advanced Technologies for Water Use Efficiency*, prepared for the participants at the EPRI *Workshop to Assess Research Opportunities for Water Use Efficiency Technologies*.

Workshop

To review the initial list of technologies, and to discuss other needs and opportunities, a workshop was held November 14th and 15th, 2007 at EPRI's headquarters in Palo Alto, CA. Attendees included research professionals from government, university, and private laboratories, technology experts from within EPRI and its member electric utilities, and industry consultants. A list of attendees, along with additional details on the workshop can be found in Chapter 4.

The workshop was a day and a half long, and consisted of three main sessions focused on water reuse, water reclamation, and water use reduction respectively. Each session consisted of multiple presentations given by technology subject matter experts, followed by moderated group discussion. The conclusion of the workshop included an interactive idea generation and prioritization exercise. Some of the recurring themes discussed at the workshop included:

- Means for reducing water use for power generation
- Better utilization of inland brackish water sources
- The need for water and wastewater infrastructure improvements
- Distributed water treatment
- Improved use of sensors and controls
- Emerging water contaminants

- Lack of a genuine water "market" that values water resources uniformly across all market segments

Table 2-1
Advanced Water Treatment and Use Technologies

Advanced Technology Area	Reuse	Reclamation	Reduction
Nano-filtration Membranes	●	●	
Reverse Osmosis Membranes	●	●	
Membrane Biofouling Abatement	●	●	
Membrane Bioreactors	●		
Activated Fiber Adsorption	●	●	
Selective Adsorption	●	●	
Electrodeionization	●	●	
Capacitive Deionization	●	●	
Selective Ion Exchange	●	●	
Pulsed UV Irradiation	●	●	●
Microwave Disinfection	●	●	●
Bactericidal Fibers	●	●	
Supercritical Oxidation	●	●	
Photocatalytic Oxidation	●	●	
Catalytic Reduction of Inorganics	●	●	
Electron Beam Irradiation	●	●	●
Gamma Ray Irradiation	●	●	●
Soft X-ray Irradiation	●	●	●
Mechanical Vapor Compression			●
Freeze-Thaw Distillation	●		
Microwave Separation	●		
Ultra-sonic Separation	●		
Radio Frequency Separation	●		
Electro-chemical Coagulation	●	●	
Electro Filtration	●	●	
Advanced Heat Transfer Materials			●
Evaporative Cooling Condensate Recovery			●
Flue Gas Condensate Recovery			●
Evapotranspiration Monitoring			●
Trace Constituent Monitoring	●	●	●

Final Technology Evaluation and Recommendations

The initial list of market needs and applicable technologies was refined in light of the insights and suggestions received during the workshop. Subsequent discussions with industry professionals, and the review of additional literature provided further clarity on which opportunities held the greatest potential. The final list of recommendations presented in Chapter 8 address seven unique market opportunities for advance water treatment and water use technologies.

- Advanced Cooling
- Brackish Water Reclamation
- Advanced Tertiary Filtration
- Distributed Power Generation
- Distributed Water & Wastewater Treatment
- Waste Heat Utilization
- Irrigation Management

Final Report Structure

The report proceeds by providing additional background information in Chapter 3 on the interconnections between water and energy, and how water shortages are threatening both industries. Following a summary of the EPRI water workshop in Chapter 4, a detailed review of market needs and opportunities is presented in Chapter 5. This includes focused sections on each market segment. Chapters 6 and 7 respectively outline advance water treatment technologies and advanced water use technologies that are considered to have significant market potential. Lastly, recommendations for action are included in Chapter 8.

3
GROWING WATER AND ENERGY DEMANDS

Water and energy use are critically interdependent – without energy it is not possible to supply freshwater, and without water it is not possible to produce energy. A change in the supply or demand of one has an impact on the other. Consider a large thermoelectric power plant that draws water from a river for steam condenser cooling. If the river level becomes too low environmental restrictions will limit how much cooling water can be withdrawn, which could in turn limit generation from the facility. Assuming that the low river level corresponds with high ambient temperatures the power plant may also be restricted by environmental limits on the maximum water discharge temperature. Alternatively, consider a large water utility seeking to build a new water desalination facility to help augment supply. This single facility could increase local electric demand by 10 to 100 MW, depending upon size and process requirements. This in turn could create unintended strain on local generation or grid capacity. From both a water supply and demand perspective it is therefore important for electric utilities to be familiar with major end uses of water and with basic water use technologies.

Figure 3-1 shows the major end uses of water for the U.S. in the year 2000. The numbers reflect total water withdrawals, and are dominated by agricultural irrigation (40%) and cooling water requirements for thermoelectric power generation facilities (39%). The vast majority of water withdrawn for power generation is passed through a once-through heat exchanger and then returned to the original source. In this case the water is "used" for the cooling process but it is not "consumed".

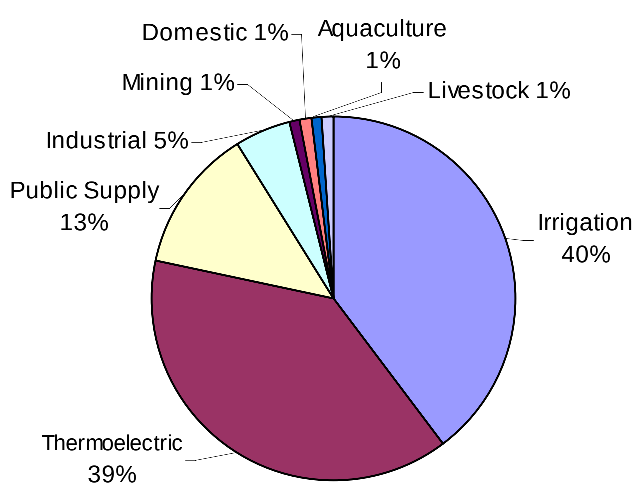

Figure 3-1
U.S. Freshwater Withdrawals in 2000

Source: USGS Circular 1268, *Estimated Use of Water in the United States in 2000*

Figure 3-2 reflects the best available data for net consumption of water by end use, which was gathered for year 1995. In this case agricultural irrigation represents over 80% of total water consumption. At only 3.3%, water "consumed" for thermoelectric power generation may seem small. However, this is the fastest growing consumptive end use, being driven by growing electric demand and a gradual shift within the power generation industry away from once-though cooling to evaporative closed-loop cooling systems. A review of U.S. power generation water use for the year 2005 by the DOE and NETL revealed that consumption had already increased from about 3.3 billion gallons per day in 1995 to about 6.2 billion gallons per day in 2005.[5]

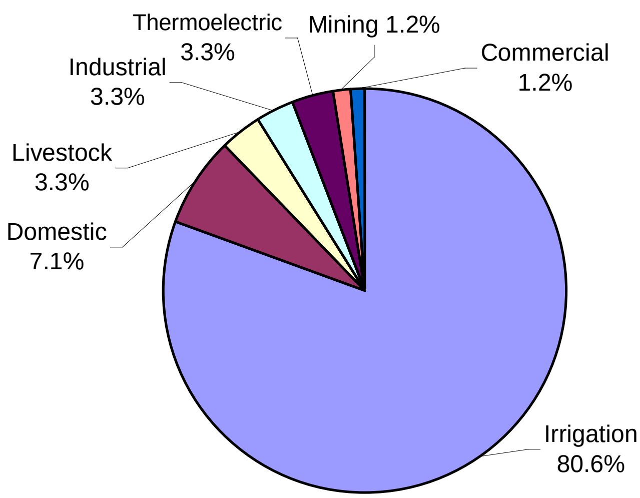

Figure 3-2
U.S. Freshwater Consumption in 1995

Source: U.S. DOE, *Energy Demands on Water Resources: Report to Congress* (2006)

Significant energy is expended to supply water

According to the U.S. Department of Energy, approximately 4% of electric power consumed in the U.S. is used for water supply and treatment.[6] This includes energy to:

- Pump water from surface and ground sources
- Treat the water to potable standards
- Pump the water through distribution systems
- Collect, treat, and discharge the subsequent wastewater

[5] U.S. Department of Energy, National Energy Technology Laboratory, *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*, DOE/NETL-2006/1235 (August 2006).

[6] U.S. Department of Energy, *Energy Demands On Water Resources: Report to Congress On the Interdependency of Energy and Water*, (December 2006).

In EPRI's 2002 *Water & Sustainability: V4* report it was estimated that 123 million megawatt-hours were consumed in 2000 for water supply and wastewater treatment, and that this number would grow to 143 million megawatt-hours by 2010.

Figure 3-3 depicts the various stages included in the water use cycle. Each stage represents a point where energy is used to pump, treat, heat, chill, or otherwise enhance the value of the water.

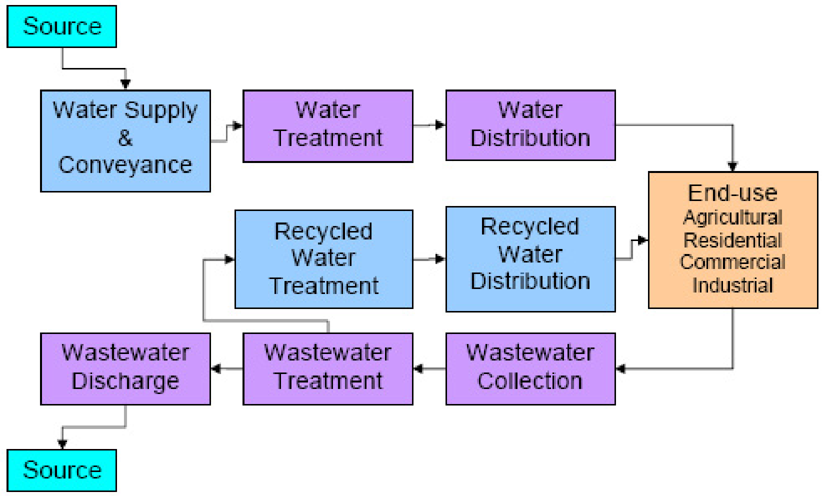

Figure 3-3
Water Use Cycle

Source: CEC, *Water-Energy Relationship Report*, 2005.

The energy intensity of a given unit of water factors in the total energy consumed through the use cycle divided by the total volume of water. The common units of measure are kilowatt-hours (kWh) per million gallons (MG), or kWh per acre-foot (AF). The energy intensity of water can vary dramatically depending upon the source, the distance the water must be conveyed, water quality, and local topography. Surface water fed by gravity and used for irrigation will have very low energy intensity. This water will require minimal pumping, does not have to be treated to potable standards, and will not contribute to municipal wastewater flows. Conversely, groundwater pumped to a treatment facility serving the domestic needs of a community with significant elevation change will have a high energy intensity.

The same EPRI report estimated that the average energy intensity associated with delivering water to consumers varies from about 300 – 800 kWh/MG. Water that subsequently must go through wastewater processing will see an additional energy intensity of 955 – 2,500 kWh/MG. Work performed by the California Energy Commission (CEC) concluded that average urban water energy intensity in Northern California for the entire water use cycle was about 5,000 kWh/MG, with 3,000 kWh/MG attributed to the supply side and 2,000 kWh/MG on the wastewater side. The numbers would be very similar for Southern California were it not for the massive State Water Project and the Central Valley Project that convey surface water hundreds of miles from Northern to Southern California. Due to the distance and the mountains surrounding the Los Angeles basin, the energy intensity required just to convey the water into the region is about 8,000 kWh/MG.[7] This unique conveyance requirement aside, the CEC numbers are a reasonable proxy for most of the US.[8]

The above energy intensity estimates represent actual values for historical water use. A greater concern is what future energy intensities will be. With the best freshwater sources already tapped, new supplies will logically be expected to be more costly in monetary as well as energy terms. Marginal water sources being pursued across the country include brackish water and ocean water desalination. In a 2003 report, the California Department of Water Resources concluded that brackish water desalination requires between 4,000 kWh/MG and 10,000 kWh/MG based upon a review of operating facilities. The energy intensity is significantly impacted by the actual levels of salinity and other impurities that vary greatly by source. A review of ocean desalination facilities revealed energy intensities between 10,000 kWh/MG and 15,000 kWh/MG. Actual salinity levels, water temperature, and specific technologies employed all factor into the variability.[9] A similar nationwide review performed by the Pacific Institute in 2006 concluded that even the most efficient ocean desalination plants require 12,000 kWh/MG to produce municipal quality water.[10]

An evaluation performed by San Diego County in 2004 illustrates the severe energy penalty associated with marginal water supply sources. As depicted in Figure 3-4, the baseline energy intensity for the supply of local surface water was 246 kWh/MG. Supplying local recycled wastewater required 1,228 kWh/MG; brackish water desalination required 3,220 kWh/MG; inter-regional water transfers (towed water bags) was estimated to require 3,621 kWh/MG; and ocean desalination required 12,890 kWh/MG.[11]

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[7] California Energy Commission, *Refining Estimates of Water-Related Energy Use in California*, CEC-500-2006-118 (December 2006).

[8] Gary Klein, "The Water-Energy-Greenhouse Gas Connection" (presentation at the Water Conservation Showcase, San Francisco, CA, March 22, 2007).

[9] California Department of Water Resources, *Water Desalination: Findings and Recommendations*, (October 2003).

[10] Heather Cooley, Peter Gleick, and Gary Wolff, *Desalination, With a Grain of Salt: A California Perspective* (Oakland, CA: Pacific Institute, June 2006).

[11] Ronnie Cohen, Barry Nelson, and Gary Wolff, *Energy Down the Drain: The Hidden Costs of California's Water Supply* (Oakland, CA: Natural Resources Defense Council and Pacific Institute, August 2004).

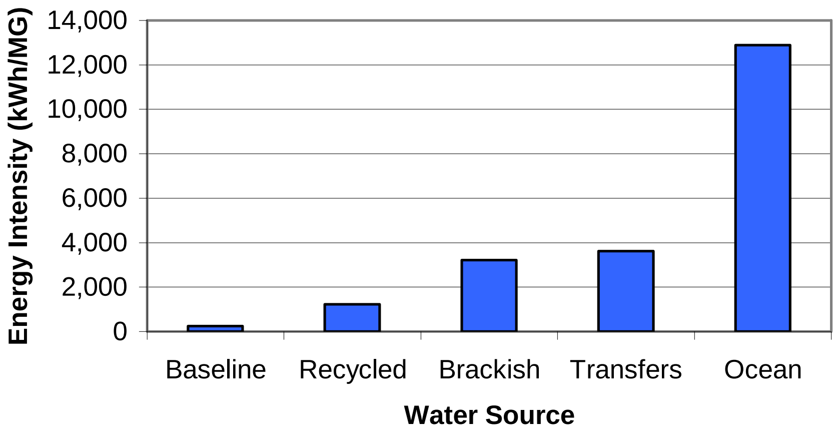

Figure 3-4
Energy Intensity Associated with Various Water Sources for San Diego County

Source: *Energy Down the Drain: The Hidden Costs of California's Water Supply*, NRDC and Pacific Institute, 2004.

Significant Water is Used to Supply Energy

Over 80% of U.S. electricity is generated by thermoelectric power plants. This includes fossil fuel and biomass fired boilers, nuclear generators, as well as geothermal plants. These facilities require vast amounts of water for cooling the discharge steam from the turbine generators. Thermoelectric power plant cooling withdraws 39% of the U.S. total of 345 billion gallons of freshwater per day. Due to a large amount of once-through cooling, most of this water is returned to its source, such as a lake or river, but often with impaired quality. Actual water consumption associated with thermoelectric power plant cooling is about 6 to 7 billion gallons per day.[12] This would include water consumed through evaporation and blowdown as part of evaporative cooling tower systems. Lack of water for thermoelectric power plant cooling and for hydropower can constrain generation and has the potential to increase demand for technologies that reduce the water intensity of the energy sector.

Between 1950 and 2000, the volume of water consumed per generated megawatt-hour decreased by about two-thirds. However, total power generation increased by a factor of 15, resulting in a net increase in water consumption by a factor of 5.[13] This increasing trend in water consumption is expected to continue.

An analysis performed by the National Energy Technology Laboratory (NETL) considered the average water withdrawals associated with power generation on a per person basis within the U.S. Utilizing data from 2000, it was estimated that the average kWh of power requires 25

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[12] DOE/NETL-2006/1235 (August 2006).

[13] Brent Barker, "Running Dry at the Power Plant," *EPRI Journal* (Summer 2007).

gallons of water. Based upon average residential electricity consumption, this was translated to about 300 gallons per person per day for power generation. As a point of comparison (see Figure 3-5), the average water withdrawals for residential consumption was only about 100 gallons per person, or three times less than the requirements for the home's energy consumption.[14]

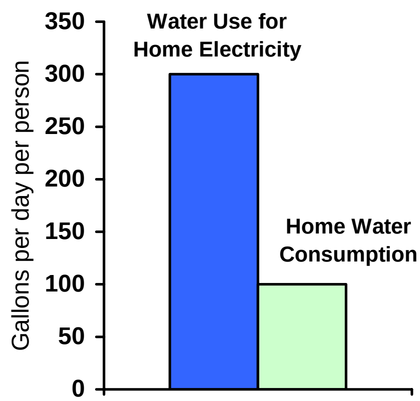

Figure 3-5
U.S. Residential Freshwater Use – Gallons per day per person

Source: U.S. DOE/NETL

The production of fuels also contributes significantly to total U.S. freshwater use. The DOE estimates that petroleum refining consumes 1-2 billion gallons per day, natural gas processing and pipeline operations consume about 400 million gallons per day, and coal mining consumes between 70-260 million gallons per day. Water may be even a greater concern for the emerging biofuels industry. Current ethanol production technology requires about 4 gallons of water per gallon of ethanol, compared to 1-2.5 gallons of water per gallon of gasoline.[15] Furthermore, this does not consider the water required for biofuel crop irrigation, which can increase total water consumption per unit fuel output for ethanol by a thousand fold.[16]

The potential for a new hydrogen based fuel economy may also be hampered by water availability. One kilogram of hydrogen contains approximately the same amount of energy as one gallon of gasoline. Using current steam reforming technology to extract hydrogen from natural gas requires about 4.9 gallons of water per kilogram of hydrogen, or 2-3 times that required to produce a gallon of gasoline. If the hydrogen were to be produced through electrolysis approximately 2.4 gallons of water per kilogram of hydrogen would be required as a feedstock. However, an additional 10-20 gallons of water per kilogram would be needed for the corresponding cooling required to generate the electricity used to drive the electrolysis process.[17]

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[14] U.S. DOE, NETL, *Water-Energy RD&D Scoping Study*, Final Report (Sept. 2003).

[15] Dennis Keeney and Mark Muller, *Water Use by Ethanol Plants: Potential Challenges* (Minneapolis, MN: Institute for Agriculture and Trade Policy, October 2006).

[16] U.S. DOE, *Energy Demands On Water Resources: Report to Congress...*

[17] Ibid.

Forecast for Shortages

The demand for water, and the goods and services produced with water, are closely correlated with the growth of U.S. population. In 2000 the U.S. census was 285.3 million people; in 2010 the population is forecasted to be 336.7 million, or an increase of 18%.[18] Figure 3-6 depicts the forecasted trend for water consumption, excluding agricultural use. Domestic and industrial use are expected to see modest growth thanks to efficiency improvements, but energy related use is forecasted to see a dramatic increase, largely due to the forecasted increase in thermoelectric power generation and the water intensity associated with the production of fuels.

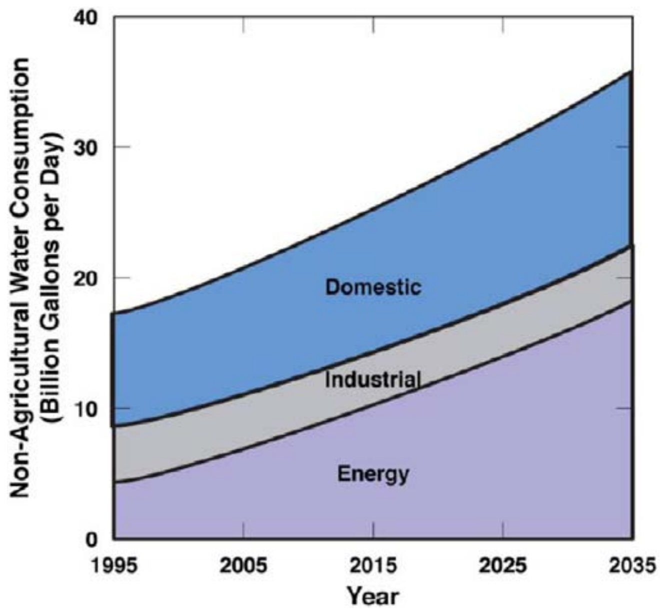

Figure 3-6
U.S. Nonagricultural Water Consumption

Source: Sandia National Laboratories, (Hightower 2007) available online:
http://www.swhydro.arizona.edu/07symposium/presentationpdf/HightowerM_pro.pdf

The forecasted growth in U.S. electricity demand is presented in Figure 3-7. In 2006 total U.S. electricity generation was about 4,000 billion kWh. By 2030 this is expected to be about 5,500 billion kWh. The Energy Information Administration estimates annual demand to grow by 1.5% under its baseline "reference case". This increase in generation will be dominated by thermoelectric coal plants. Between 2005 and 2030 coal fired generation is expected to increase by 156 gigawatts, and increase from 50% to 57% of the total generation mix.[19]

[18] U.S. Census Bureau

[19] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2007: With Projections to 2030*, DOE/EIA-0383 (Washington, DC, February 2007).

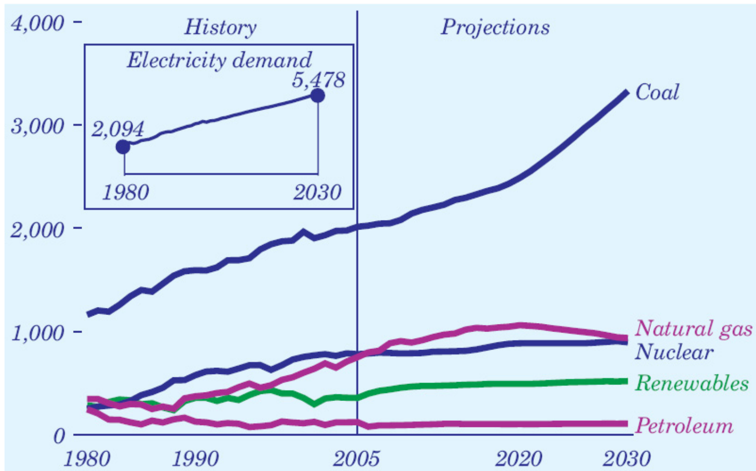

Figure 3-7
U.S. Electricity Generation by Fuel, billion kWh

Source: EIA Annual Energy Outlook 2007, DOE/EIA-0383(2007), Feb. 2007

To provide the water needed for electricity generation new sources must be developed. Figure 3-8 highlights the fact that current freshwater sources are not expected to increase substantially in the future. New water must come from other sources such as wastewater reuse and desalination. Projections from Sandia Laboratory for 2035 would have these alternative sources contributing to greater than 50% of total water supply.

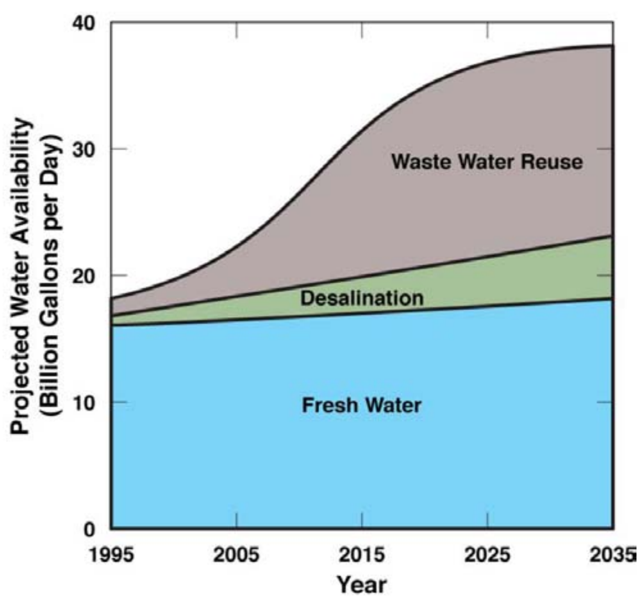

Figure 3-8
U.S. Projected Nonagricultural Water Availability

Source: Sandia National Laboratories, (Hightower 2007) available online:
http://www.swhydro.arizona.edu/07symposium/presentationpdf/HightowerM_pro.pdf

Additionally, it should be noted that water shortages are no longer a concern for just the Desert Southwest. The USDA tracks water supply levels across the nation through its "Drought Monitor" system. As seen in Figure 3-9, critical drought conditions exist within many regions across the U.S. According to the U.S. EPA, nationwide there are at least 36 states projecting water shortages between now and 2013.[20]

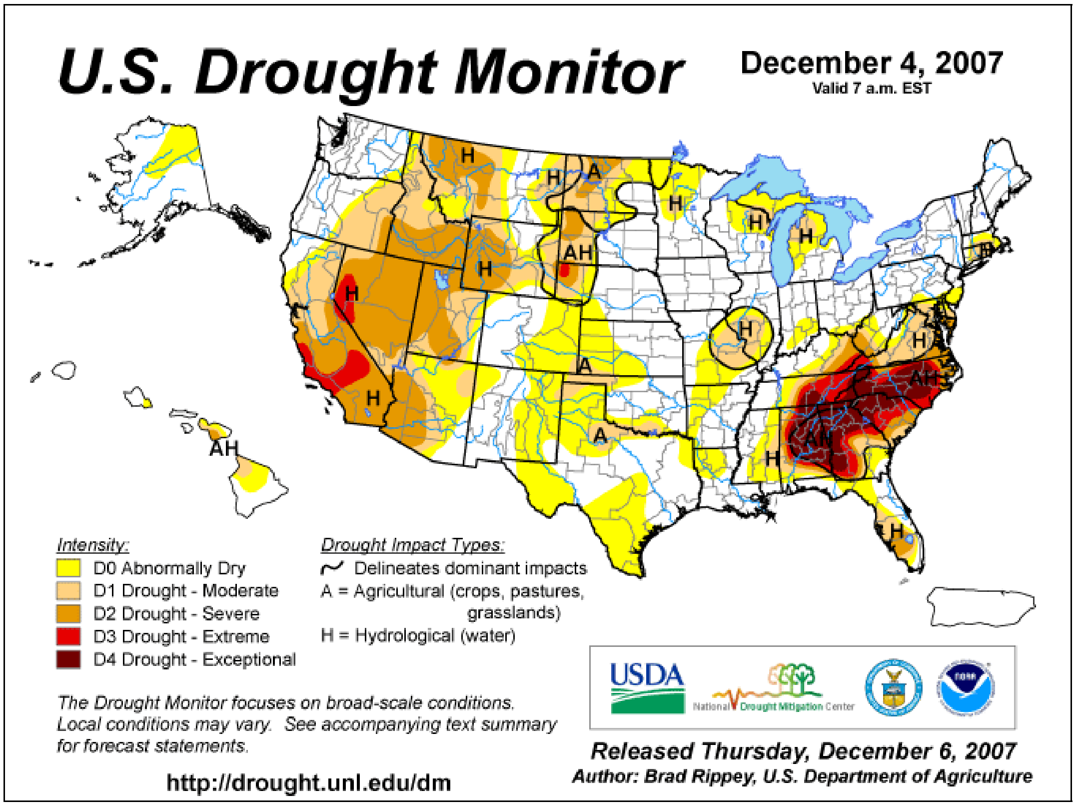

Figure 3-9
U.S. Drought Monitor Map for December 4, 2007

Source: U.S. Department of Agriculture

Environmental Concerns

Major river systems within the U.S. are strained from excessive water demand resulting in elevated salinity levels and the degradation of wetlands. Not only do native fish, migratory birds, and other animals suffer, but so do humans. High salt and mineral levels require additional water treatment for urban use, and may preempt the use all together for agricultural irrigation, which in turn necessitates the use of more expensive and more energy intensive sources. When more surface water is consumed there is less water available to percolate down into ground aquifers. This prevents the aquifers from adequately recharging. To compound the problem, with dwindling surface water sources available, agriculture and urban users must rely

[20] James A. Goodrich, "EPA Initiatives To Reduce the Volume of Water and Wastewater That Must be Treated" (presentation, EPRI water workshop, Palo Alto, CA, Nov. 15, 2007).

more on ground water. This draws down the level of aquifers even further. Eventually, major problems with land subsidence and/or saltwater intrusion can occur. In many parts of the country ground-water level is a major concern, including the Atlantic Coastal Plain, West-central Florida, the Gulf Coastal Plain, the High Plains, the Chicago-Milwaukee area, the Pacific Northwest, and the Desert Southwest.[21]

The U.S. Clean Water Act supports "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." This legislation provides funding and regulation to safeguard the nation's surface waters. This has a direct impact upon end users who withdraw from, and/or discharge to surface sources. As water sources become strained, it is more challenging to comply with federal and state regulations enabled through the Act. Power generation facilities in particular face multiple hurdles. The water withdrawn for cooling and other uses must minimize the impingement, mortality, and entrainment (IM&E) of living organisms. All water discharges must meet minimal standards for impurities, and must also remain below levels set for maximum allowable discharge temperatures. Decreased availability of surface water complicates the compliance with all these requirements.

Water utilities and businesses face increasing environmental pressure as well with regard to wastewater effluent. Permitted levels of impurities in discharged waters are decreasing, and new limits are being placed in sensitive watersheds. For example, higher treatment requirements for nutrient removal are being implemented in many areas of the country that have environmentally sensitive lakes and estuaries or in areas where surface waters are already impaired. The imposition of storm water regulations by the EPA is forcing many large cities to look for innovative solutions for separating and treating urban runoff, or providing source control.

At a macro level, greenhouse gas emissions associated with water and wastewater are also a major factor. The CO_2 emissions related to the electricity used to pump and treat water is a large number by itself. However, much additional energy is consumed by end users associated with additional on-site pumping, cooling, and heating to satisfy process needs. For example, the CEC concluded that residential, commercial, and industrial customers consume 11% of all electricity in California through water related on-site processes. Additionally, it was concluded that 31% of all natural gas consumed in the state was attributed to water use by these same users.[22] Combined electricity and natural gas consumption associated with the entire water use cycle is very high. Significant advances related to greenhouse gas emissions and climate change can not be achieved without addressing the water use component.

Missing from these projections are the contributions that aggressive energy efficiency policy or new measures taken to curb greenhouse gas emissions would have on energy consumption. Similarly, the projections do not factor in the impact of water shortages on energy costs and consumption, nor the potential impact of significant improvements in water use efficiency. This suggests that new technologies aimed at improving water use efficiency and/or energy efficiency would have a positive and even multiplicative impact on reducing the preceding forecasts for water and energy consumption.

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[21] U.S. Dept. of the Interior, *Ground-Water Depletion Across the Nation*, USGS Fact Sheet-103-03 (Nov. 2003).

[22] California Energy Commission, *California's Water-Energy Relationship*, CEC-700-2005-011-SF (Sacramento, Nov. 2005).

4
WORKSHOP SUMMARY

The EPRI *Advanced Technologies for Water Use Efficiency* workshop was held November 14th and 15th, 2007 in EPRI's Starr Auditorium in Palo Alto, CA. The purpose of the workshop was to review the initial list of technologies and opportunities outlined in the October 2007 discussion paper, *Advanced Technologies for Water Use Efficiency*, and to discuss additional ideas for the application of advanced water treatment and water use technologies. Approximately 40 attendees participated (see Table 4-1) representing various organizations including:

- Government research laboratories
- Universities
- State and Federal energy agencies
- Private research laboratories
- Industry consultants
- EPRI member electric utilities
- EPRI technology teams

The workshop consisted of three main topic sessions. The first day covered Water Reuse, and Water Reclamation. The second day covered Water Use Reduction, and also provided time for an interactive idea generation and prioritization exercise for the attendees. The workshop agenda is included for reference at the end of this chapter.

Each session consisted of a moderated panel with three or four technical presentations provided by a subject matter expert. Moderated group discussion followed each panel session.

Table 4-1
EPRI Water Use Efficiency Workshop Attendees, November 14-15, 2007

First Name	Last Name	Title	Company
William	Bourcier	Chemist	Lawrence Livermore Nat. Lab.
Keith	Carns	Vice President	Global Energy Partners, LLC
Shahid	Chaudhry	Contract Manager	California Energy Commission
John	Crittenden	Dr.	Arizona State University
Gil	Crozes	Partner	Carollo Engineers
Franck	David		EDF Electricite de France
Ray	Ehrhard	Research Associate	Washington Univ. in St. Louis
Alex	Ekster	principal	Ekster and associates
Lynne	Galal	Senior Project Manager	Pacific Gas & Electric Co.
Clark	Gellings	V.P., Innovation	Electric Power Research Institute
Jerome	Gilbert	President	J.Gilbert, Inc.
Laura	Goldie	Meeting Planning Administrator	Electric Power Research Institute
Robert	Goldstein	Sr. Tech. Exec. Water & Ecosystem	Electric Power Research Institute
James	Goodrich	Env. Scientist	U.S. EPA
Gerry	Hamilton	Senior Associate	Global Energy Partners, LLC
Greg	Heck	Principal Research Engineer	Southern Company Services, Inc.
Yongheng	Huang	Assistant Professor	Texas A&M University
Patricia	Hurtado	Vice President	Global Energy Partners
Amor Valeriano	Ines	Asst. Research Scientist	Texas A&M University
Myron	Jones	director	M/J Industrial Solutions
Pramod	Kulkarni	Mgr., Pub Interest Energy Research	California Energy Commission
Lory	Larson	Consulting Engineer	Southern California Edison Co.
Ronald	Lewis	Scientist	Duke Energy Corp.
Nancy	Long	Account Manager	Pasadena Water & Power Dept.
Bruce	Macler	Dr.	USEPA Region 9
Benito	Marinas	Professor	University of Illinois
Chuck	McGowin	Senior Project Manager	Electric Power Research Institute
Paul	Meagher	International Account Executive	EPRI International, Inc.
Charles	Noss	National Program Director for Water Qual	U.S. EPA
Babu	Nott	Area Manager, Land & Groundwater	Electric Power Research Institute
Robert	Rutledge	EHS Integration & Governance	Duke Energy Corp.
Mark	Shannon	Director, Water CAMPWS Center	University of Illinois
Mike	Song	Account Executive	EPRI International, Inc.
Jeff	Stallings	Mgr., NOx Emission Control	Electric Power Research Institute
Richard	Sustich	Government & Industrial Dev. Mgr.	University of Illinois
David	White	Project Manager	U.S. Bureau of Reclamation
Camilla	Whitehead		Lawrence Berkeley Laboratory
Thomas	Yeager	Project Manager	Kennedy/Jenks Consultants

Topics discussed on Day 1 related to Reuse and Reclamation included:

- Separation Technologies
- Filtration Technologies
- Deionization
- Biological Treatment
- Oxidation
- Disinfection
- Monitoring and Controls
- Combination Technologies
- New Practices
- Managing Reclamation Residuals
- Policy
- Information Availability

Topics discussed on Day 2 related to Use Reduction included:

- Advanced Cooling Technologies
- Monitoring and Controls
- Moisture Capture
- Institutional Changes

Many suggestions complemented others, such as the need for advanced monitoring and controls, which was brought up in the context of multiple market segments. Table 4-2 lists the suggestions made by the workshop attendees related to Water Reuse and Reclamation. Table 4-3 lists the suggestions made in regard to Water Use Reduction. The suggestions were all posted during the workshop, and the attendees were asked to “vote” for ideas that they felt were the most important. Subsequent analysis of the suggestions by the project team identified several recurring themes and assigned the following summary categories:

- Power Generation
- Use of Brackish Water (Desalination)
- Evolution of a Water Market
- Water & Wastewater Industry Infrastructure
- Monitoring and Controls
- Distributed Treatment Technologies
- Emerging Contaminant Treatment
- Other

Power Generation – Ways to use less water were discussed (dry cooling, more efficiency power cycles), and the need to evaluate the overall impact of cooling practices. For example: what is the real benefit/cost of once-through cooling?

Use of Brackish Water – Many potential uses were identified across multiple market segments. Lower cost and more effective ion removal technologies/processes are needed. Not only must efficiency be addressed, but also what to do with the waste brine. Minimizing brine could make for a dual benefit of system effectiveness plus low environmental impact. This also included general discussions on desalination technologies (membrane filtration, membrane distillation, and electro-deionization technologies).

Water Market – Water should be valued consistently. Water in the Agriculture market is undervalued with respect to urban wholesale prices. Most consumers do not know what the true cost of water is. Most don't know that the cost of water will be going up significantly in the future based on the status quo. A business model needs to be created that will enable water and energy utilities to work closer together to manage water resources. Consumers must be educated.

Water & Wastewater Industry Infrastructure – Major expansion and maintenance is required. This will be very expensive, and utilities/consumers are not prepared for the cost. Advanced sensors and controls need to be much more aggressively implemented in the industry to improve both water use efficiency and energy efficiency. The industry should be able to create a "smart" water grid.

Monitoring and Controls – Better utilization of sensors and controls will yield benefits in all market segments. Advanced SCADA systems will be essential to make new water recycling systems viable. The greatest needs are in the water and wastewater industry as well as in agriculture.

Distributed Treatment Technologies – Point of use water treatment was discussed. Other aspects included wastewater pretreatment, sewer water reclamation, sewage separation, and distributed energy generation.

Emerging Contaminant Treatment – There are contaminants emerging as treatment problems that have historically not been much of an issue. These will require new treatment practices. Examples include nitrates, perchlorates, chemical disinfection byproducts, and arsenic, among others.

Other – Several non-technical issues were discussed. These included regulatory hurdles, legal conflicts, public perception, access to information & lack of information availability. There was also repeated mention of the opportunity to tap into the bio-energy contained in urban wastewater.

Table 4-2
Workshop Suggestions for Water Reuse and Reclamation Opportunities

Technology or Need	Votes	Summary Category
R.O. Dual-Stage Nanofiltration	0	Desalination
Improve Efficiency of Membrane Technology	19	Desalination
Membrane Distillation	5	Desalination
Filtration Optimization	9	Desalination
Scoping Studies on Filtration	5	Desalination
Low Cost Ion Removal for Brackish Water	22	Desalination
Forward Osmosis	4	Desalination
Deionization with Carbon Aerogels	19	Desalination
Deionization with Cussler Ion Pump	3	Desalination
Ion Specific Extration for Resource Recovery	6	Desalination
Biological Nitrate Removal for Drinking Water	9	Trace Contaminant
Biological Treatment for Arsenic Removal & Other Trace Contaminants	17	Trace Contaminant
Physical Sewage Treatment - Anaerobic Processes	12	Distr. Treatment
Approaches to Take Care of All Pathogens	8	Other
Safer Chemical Treatment	5	Trace Contaminant
General Look at Disinfection Technologies	2	Trace Contaminant
New Sensors	7	Monitors/Controls
Advanced Controls Modeling & Optimization	11	Monitors/Controls
Highly Scalable SCADA	3	Monitors/Controls
Demonstrate Combination of Technologies	3	Trace Contaminant
Technologies for Distributed Treatment	8	Distr. Treatment
Business Case for Water Utilities to Encourage Power Generation	11	Water Market
Concentrate Management - Geothermal Use	0	Desalination
Combine Distributed Energy Generation with Water Treatment	2	Distr. Treatment
Use of CO2	6	Other
GHG Reductions	1	Other
Point of Use Treatment	10	Distr. Treatment
Generation of Fuels from WW Treatment	6	Water Market
Brine Minimization	14	Desalination
Improved Disposal of Waste from Inland Desal.	1	Desalination
Scrubber Water Management	0	Power Generation
Extracting Mineral Bi-Products from Brine	0	Desalination
Decentralized Reclamation from Sewers - MBR	17	Distr. Treatment
Identify Barriers for Technology Use & Development	11	Other
Reuse vs. Ocean Desalination Comparison	0	Desalination
New Business Model for Utilities - Encourage Energy Eff. & Water Eff.	1	Water Market
Water Technical Assessment Guide	0	Other
Energy and CO2 Footprint for Water Use	1	Other
Create Viable Water Market	13	Water Market
Watershed Protection	0	Other
Closer Relationship with Agricultural Side	0	Other
Integrate Upstream & Downstream (Water & Wastewater)	6	Infrastructure
Levels of Chloride and Boron for Acceptable Water Use	0	Trace Contaminant
Facilitate Exchange of Information with Industry	2	Other
One-Stop-Shop Information Source	1	Other
Market Research	0	Other
Real Comparison of Costs of Alternative Options/Technologies/Approaches	3	Water Market
Future Water/Energy Interface Design	6	Water Market
True Value of Water Resources	12	Water Market
Identify Opportunities for Partnering and Collaboration	1	Other

Table 4-3
Workshop Suggestions for Water Use Reduction Opportunities

Technology or Need	Votes	Summary Category
Ammonia System Demonstration - Medium Sized	16	Power Generation
Approaches to Address Water Consumption in Electric Power Plants	7	Power Generation
Evaluate Cooling Technologies Society Impact (Once-through)	24	Power Generation
Look at Dry Cooling & Ammonia System	16	Power Generation
Real-time Sensors in Pipeline	3	Monitors/Controls
Decentralized Systems - Better remote sensors	12	Monitors/Controls
Communications Architecture Into Water System	0	Monitors/Controls
Sensors - Salt Balance, Return Flow	5	Monitors/Controls
Residential Water Consumption Display	5	Monitors/Controls
Robust SCADA for Agriculture	8	Monitors/Controls
Leakage Detection Systems	4	Monitors/Controls
Artificial Intelligence to Evaluate Leakage	10	Monitors/Controls
Intelligent Water "Grid"	10	Monitors/Controls
Side-car for the Modelling Program	1	Monitors/Controls
Improve Irrigation Monitoring Systems	2	Monitors/Controls
Assess Moisture Capture Technologies	8	Power Generation
Reuse Water for C&I Process	0	Other
Change Farmers Attitudes about Water	3	Water Market
Helping Customeres Use Less Water with Electrotechnologies	0	Other
Hardening Water Infrastructure	6	Infrastructure
Make Existing Treatment Plants more Energy & Cost Effective	0	Infrastructure
Reducing Energy Costs for W&WW Treatment	7	Infrastructure
Efficient Water Management	5	Water Market
Improve Efficiency of Agricultural Water Use	5	Other
Demonstrations of Modeling & Controls for Agriculture	1	Monitors/Controls
Promote Domestic Horticulture	0	Other
How to Overcome Institutional User Resistence	0	Other
Understanding Market Value of Water & Passing to Farmers	8	Water Market
Transfer Information to Public Side to Generate Change	2	Other
Educate Water Consumers	10	Water Market
Changing Domestic Landscape - grow crops not grass & flowers	1	Other
Change Water Allocation Approaches	5	Water Market
Better Information for Water Management Practices	8	Other
Smart Pipes	6	Monitors/Controls
Advanced Water Technology Program	0	Other
Water Market	12	Water Market
Roadmap for Water Technologies	6	Other
Information/Data on Water&Energy Use	6	Other
Change Water Economy to Promote Advanced Technology Implementation	1	Water Market
Distributed Water Storage	3	Distr. Treatment
Streamline Regulatory & Permitting Process for New Water Sources	5	Other
Framework for Int. Res. Planning - Water & Energy, Supply & Demand	12	Water Market

EPRI Workshop to Assess Research Opportunities for Water Use Efficiency Technologies – Agenda –

Wednesday, November 14, 2007

7:30 – 8:15 am	**Registration and Continental Breakfast**
8:15 – 8:45 am	**Welcome and Introduction** **Clark Gellings**, *Vice President, Innovation*, EPRI
8:45 – 9:00 am	**Technology Innovation** **Clark Gellings**, *Vice President, Innovation*, EPRI
9:00 – 10:00 am	**Overview of Emerging Water Use Issues and Potential Solutions** ***Review of Energy Water Nexus Work*** **Dr. Robert Goldstein**, *Senior Technical Executive*, EPRI **Michael Hightower**, *Distinguished Member of the Technical Staff*, Sandia National Laboratories ***Life Cycle Assessment of Three Water Scenarios: Importation, Reclamation, and Desalination*** **Dr. John Crittenden**, *Richard Snell Presidential Chair of Civil and Environmental Engineering*, Arizona State University
10:00 – 10:30 am	**Break**
10:30 – 12:00 pm	**Session I: Opportunities for Enhanced On-site Water Reuse Technologies** Discussion of current and potential research technologies capable of treating waste streams from various sources for beneficial use. Moderators: **Ray Ehrhard**, *Water & Wastewater Program Manager*, Washington University / Global Energy Partners **Dr. Charles Noss**, *National Program Director for Water Quality*, US Environmental Protection Agency ***Photocatalytic Oxidation*** **Dr. Benito Marinas**, *Ivan Racheff Professor of Environmental Engineering*, University of Illinois at Urbana-Champaign – Department of Civil and Environmental Engineering ***Advanced Deionization*** **Dr. William Bourcier**, *Research Chemist*, Lawrence Livermore National Laboratory ***Water Reuse: Current Practices & Technology Opportunities*** **Tom Yeager**, PE, *Project Manager*, Kennedy/Jenks Consultants
12:00 – 1:30 pm	**Lunch**

12:30 – 1:00 pm	**Impact of Water on Sustainability: Nexus to the Economy, Energy and the Environment** *(Lunch Speaker)* **Dr. Mark Shannon**, *J.W. Bayne Professor & the Director of the WaterCAMPWS Center*, University of Illinois at Urbana-Champaign – Department of Mechanical Science and Engineering
1:00 – 1:30 pm	**Distributed Optimal Technology Networks: An Opportunity Framework for Advanced Technology Developments for Enhanced Water and Energy Security Sustainability** **Dr. Walter Weber**, *The Gordon M. Fair and Earnest Boyce Distinguished University Professor of Environmental and Ecological Sciences and Engineering*, University of Michigan – Department of Chemical Engineering
1:30 – 2:00 pm	**Break**
2:00 – 3:30 pm	**Session II: Potential for Use of Degraded Water Sources ("Reclamation")** Discussion of unique technology research opportunities for treating water for beneficial use from degraded sources. Moderators: **Keith Carns**, *Water & Wastewater Program Manager*, Global Energy Partners **Jerome Gilbert**, *Past President of the American Academy of Environmental Engineers and Member of the National Academy of Engineers* ***Permeable Reactive Barrier for Insitu Groundwater Remediation*** **Dr. Yongheng Huang**, *Assistant Professor*, Texas A&M University – Department of Biological & Agricultural Engineering ***Inland Groundwater Treatment: Brine Concentration Technologies, and Innovative Treatment for Perchlorates & Nitrates*** **Dr. Gil Crozes**, *Manager, Research Group*, Carollo Engineers ***Summary of Reclamation's Recent Water Treatment Research*** **David White**, *Project Manager*, US Department of the Interior – Bureau of Reclamation
3:30 – 3:45 pm	**Break**
3:45 – 4:45 pm	**Day 1 Discussion** Moderator - **Clark Gellings**, *Vice President, Innovation*, EPRI
6:30 – 9:00 pm	**Reception & Dinner** (dinner at 7:30) Spalti Ristorante – 417 California Ave., Palo Alto http://www.spalti.com/

Thursday, November 15, 2007

7:15 – 8:00 am **Continental Breakfast**

8:00 – 9:30 am **Session III: Technologies to Enhance Water Use Reduction**
Discussion of new technologies and advanced process controls for enabling the use of less water per unit output.

Moderators:
Dr. Robert Goldstein, *Senior Technical Executive*, EPRI
Michael Hightower, *Distinguished Member of the Technical Staff*, Sandia National Laboratories

Advanced Cooling
Michael Hightower on behalf of Thomas Feeley, *Technology Manager*, US Department of Energy – National Energy Technology Laboratory

EPA Initiatives to Reduce the Volume of Water and Wastewater That Must Be Treated
Dr. James Goodrich, *Director, Water Supply & Water Resources Division*, US Environmental Protection Agency – National Risk Management Research Laboratory

Remote Sensing of Moisture in Soils for Irrigation Control and Resource Planning
Dr. Amor Ines, *Assistant Research Scientist*, Texas A&M University – Department of Biological and Agricultural Engineering

9:30 – 10:00 am **Break**

10:00 – 12:15 pm **Discussion on Technology R&D Needs**
Prioritization of technology research opportunities.

Moderator - **Clark Gellings**, *Vice President, Innovation*, EPRI

12:15 pm **Adjourn**
Box lunches available for departing attendees

5
NEEDS AND OPPORTUNITIES FOR EFFICIENT WATER TREATMENT AND USE

The basic water need of any market segment is securing adequate water supply at adequate quality to facilitate the end use process. At the simplest level, this would entail ample supply of potable water for domestic consumption. Water volume and quality needs will vary significantly when considering the specific process requirements found across the various industries that depend upon water.

Opportunities for improving water use efficiency will tend to address one of three areas – the reuse of water and wastewater, the reclamation of degraded water sources, or the reduction in water use required for a given process. Within these categories, the water use technologies employed are generally aimed at either treating the impurities found in water and wastewater, or improving process efficiency such that less water volume is required.

The needs and opportunities found within the Power Generation, Water and Wastewater Utilities, Agriculture, Industrial, and Commercial & Residential market segments are presented below.

Power Generation

Total water withdrawals for power generation in the U.S. in 2005 were about 149.2 billion gallons per day of freshwater, and 60 billion gallons per day of saline water. Virtually all of the saline water was utilized for once-through cooling. About 143 billion gallons per day of the freshwater was used for once-through cooling, and 6.2 billion gallons were consumed through evaporative cooling loops and other plant processes.[23] Total freshwater withdrawals represent 39% of the U.S. total, second only to agricultural irrigation at 40%.

As one of the largest users of freshwater, the power generation segment is under much scrutiny and pressure regarding its future plans for water use efficiency. The DOE is forecasting close to a 20% decrease in the volume of freshwater withdrawn for power generation between 2005 and 2030. However, this is accompanied by a corresponding increase in the amount of freshwater consumed. Essentially, this reflects the growing trend away from once-through cooling to evaporative cooling.

[23] DOE/NETL-2006/1235.

Figure 5-1 illustrates this trend. While the decrease in water withdrawals is very positive from an environmental perspective, the increase in water consumption reflects water that is not returned to its source stream and is therefore lost from future use. This is very negative from a water supply perspective.

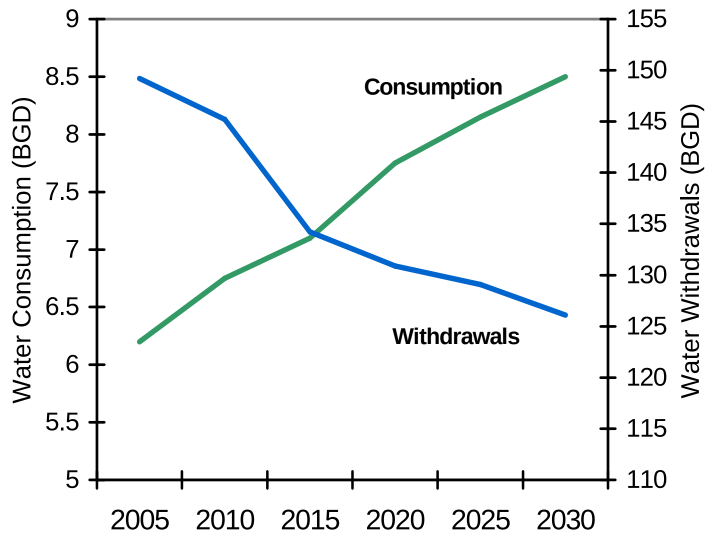

Figure 5-1
Water Demands for Future Electric Power (billion gallons per day)

Source: U.S. DOE/NETL-2006/1235

Sector Needs

The volume of water required for thermoelectric power plant cooling is the dominant concern in the industry. Alternatives to once-through cooling and evaporative-based cooling need to be developed to ensure adequate generation is achievable in the future. For reference, approximately 43% of current thermoelectric generation is achieved through once-through cooling, 42% through evaporative cooling, 14% through cooling pond recirculation, and only about 1% through dry cooling techniques.[24]

Cooling water use is obviously affected by the type of cooling technology employed, but any water-based cooling system is also impacted by the quality of the cooling water and system maintenance. Scaling and biofouling are a large concern for cooling systems. This can vary from crustaceans growing on water inlet systems, to mineral deposits and organic growth on cooling tower surfaces. These factors can greatly reduce thermal transfer efficiency and increase the consumption of water.

[24] U.S. Department of Energy, National Energy Technology Laboratory, *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*, DOE/NETL-2006/1235 (August 2006).

Environmental regulations and permitting are an ongoing concern and are expected to become more stringent in the future. These limit how much water can be withdrawn from a source, and often more importantly dictate the volume and quality of water that can be discharged. Once-through cooling facilities are often limited by the maximum allowed discharge temperature of the cooling water. This problem is greatest during hot weather when generation demands can be the highest. To mitigate the build up of dissolved solids in the recirculated water, evaporative cooling systems generate a waste stream of blowdown water containing concentrated levels of minerals and other impurities. Often times this wastewater must be treated on-site before it can be discharge to the environment or to a municipal utility.

Boiler makeup water is also a concern for power generation. Power boilers tend to run at very high pressures. This requires the use of very high quality water, free from virtually all impurities, to prevent deposits and corrosion from deteriorating surfaces within the boiler and the steam turbine. Even potable water delivered by a local water utility is generally run through a reverse osmosis process to further remove trace chemicals. While the volume of water used for boiler makeup is small compared to that used for cooling purposes, the importance is much greater. Generators must be sure that adequate water sources and/or treatment equipment is available.

Emission control requirements also place demands upon water. Wet scrubbers are used for particulate control and for sulfur dioxide removal. Emission limits are gradually becoming more stringent across the country. This subsequently requires more emission control equipment and more water use.

Opportunities for Efficient Water Treatment and Use

Cooling water use receives most of the attention in the power generation industry, but as discussed below it is not the only opportunity for water use efficiency.

Reuse

A small percentage of boiler water is regularly (sometimes continuously) discharged to allow the addition of fresh makeup water to the system, which prevents the buildup of impurities in the boiler. This discharge, referred to as blowdown, is relatively high in dissolved solids. Blowdown is also performed on recirculating cooling tower water, where the discharge effluent has even higher levels of dissolved solids and also contains organic constituents. The impurities in blowdown water must be treated either on-site or by a wastewater utility prior to being discharged into the environment. This water is available for reuse if it can be effectively treated on-site, potentially saving on disposal costs.

The water collected as part of stack emissions scrubbing must be disposed of. Treating this water to eliminate the trapped pollutants is an additional expense for plant operators. Treating at least a portion of this water for reuse would provide an additional source of water, and also reduce the net volume that must eventually be discharged to the environment. Zero-Liquid-Discharge technologies would enable the maximum amount of water to be reused, while producing a dry refuse that can be transferred to a landfill instead of having to send a highly contaminated liquid stream to a wastewater treatment facility. Similar opportunities exist for water used as part of wet ash handling operations.

Reclamation

Opportunities for the use of degraded water sources include: residual water from coal mines, co-produced water from oil and gas wells, municipal wastewater effluent, saline sources, and agriculture irrigation return water. Proximity of the power plant to the degraded source will determine what is practical, as will the availability of treatment technologies. Evaporative cooling systems have the least stringent water quality standards within a power plant, and would represent the logical first use for degraded waters.

Virtually all steam driven power plants already have a reverse osmosis system within the facility to treat the make-up feed water for the boilers. These systems can be utilized, or upgraded if necessary, to treat water from new marginal sources.

Many power plants are located near the ocean to provide a source of cooling water. Such facilities could realize synergies related to the co-production of power and desalinated water. Environmental constraints make it difficult to secure adequate ocean water inflow and discharge structures for new power plants and new large scale ocean desalination facilities. New desalination projects could utilize existing power plant inflow systems with minimal impact since the amount of water needed would be quite small compared to that required for cooling. Similarly, the discharge of brine from the desalination operation, which is usually a major environmental concern, would be highly diluted by the outflow coming from the power plant. The resulting freshwater could be used within the power plant and also used to supplement water supplies for local water utilities.

Another potential source of saline water for power plants is inland aquifers. As mentioned in the introduction, large volumes of saline groundwater exist across much of the U.S. and would prove to be a very valuable resource if a means were devised to treat the water cost effectively. The evaporative cooling need of power plants is an obvious potential end use. Much of the technology developed for ocean desalination would also be applicable to saline groundwater, but attention must be paid to the specific mineral and contaminant content of the groundwater, as they may preclude the use of some technologies. For example, saline ground water contains multivalent salts and other minerals that present challenges different from those of ocean water. Also, as with any desalination process the residual brine concentrate must be disposed of in an environmentally acceptable manner.

Utilization of Waste Heat – The waste heat from power production holds potential for driving thermal based distillation processes that could enable the use of desalinated water and reclaimed brackish water.

Synergies with Carbon Dioxide Sequestering – If the use of saline ground water progresses, there may be additional synergies associated with the emerging CO_2 sequestering sector. The same deep aquifers containing the saline water have been identified as potential locations to store CO_2 generated by power plants. Pumping in CO_2 gas would naturally tend to displace the ground water. Utilizing the water would provide additional storage space for the CO_2, and the CO_2 would help address long term concerns related to ground subsidence caused by aquifer depletion.

Flue Gas Moisture Capture – Another approach to "reclaiming" water from an alternative source for the power generation industry would be the use of moisture contained within the power plant's combustion flue gases. The moisture content of typical flue gas compositions common in fossil fired power plants can vary from 7 to 14% by volume. The majority of this moisture can be condensed and utilized as process water within the plant. This would in theory be enough water to satisfy all of the plant's non-cooling related needs.[25] To condense the moisture, the flue gas temperature must be decreased below the dew point of the water. Condensing systems can operate as low as 100^{o}F, which means that there must be a heat exchange medium available at a lower temperature. Fresh boiler make-up water is a good candidate, but the volume is relatively low for a well run power plant. Another concern is the undesired byproducts also condensed with the water, including sulfuric acid, carbonic acid, and potentially hydrocarbons.

Reduction

Advance cooling technology holds the greatest potential for water use reduction. Dry cooling systems, or air-cooled steam condensers, are currently available but are physically much larger than equivalent evaporative cooling systems and are not as efficient.

The precise monitoring and control of cooling tower blowdown can ensure that only the minimum amount of cooling water is discharge to prevent mineral deposits and biological growth from forming. To a lesser degree the same techniques can be applied to boiler blowdown water, but due to the critical nature of boiler water and its high heat content, most boilers are already equipped with very precise control systems.

Emission control scrubbers represent another common water use for coal fired boilers. For particulate matter control, water is sprayed into the boiler flue gases to capture particles and soluble chemicals. Water can also be mixed with lime to create a slurry that is then injected into the flue gases for the control of sulfur dioxide emissions. Dry scrubbing technologies exist, but wet scrubbers are still used for the majority of applications.

The use of combined cycle generating facilities reduces the amount of cooling water required per megawatt thanks to the mechanical energy created by the prime mover, generally a combustion turbine. Overall, cooling water consumption can be reduced by about two-thirds through the use of a combined cycle process. Combined cycle plants must operate with clean gas or liquid fuels due to the sensitive nature of combustion turbines. Gasified coal is a suitable fuel for use, but significant water is required in the gasification process for reaction steam, cooling, and cleaning. It is estimated that an integrated coal gasification combined cycle operation would still require about half of the water per megawatt that a standard coal thermoelectric process does.[26]

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[25] John H. Coren et al, *Principles of Flue Gas Water Recovery System*, Conference paper presented at POWER-GEN International 2005.

[26] DOE/NETL-2006/1235

Barriers to Efficiency Opportunities

Some of the chief market barriers to improved water treatment and use efficiency in the power generation sector are environmental. The volume and quality of water discharged from a power plant are tightly regulated under the Clean Water Act. Therefore, technologies that may increase net water use efficiency, but produce a new or more concentrated waste stream, may not be practical from an environmental permitting perspective. Also, when considering air emission standards, it may be more practical to utilize wet treatment systems to ensure air pollution limits are met as opposed to trying to optimize water use efficiency. Where water consumption and environmental compliance are at odds, new technology is required to ensure multi-faceted solutions are achievable.

These concerns are specifically a challenge for water reclamation opportunities such as inland brine water and ocean desalination. In these cases, the new technology must purify the water cost effectively and it must also provide a means to process the resultant brine in an environmentally sound manner.

Another obvious barrier is cost. The cost of dry cooling systems can be up to four times greater than a comparable wet system. Operating costs may be mitigated if the true value of water were factored into the business model. Operators can easily see the increase in fuel costs associated with generation efficiency losses, but cannot easily estimate the economic benefit linked to the water savings.

There are also significant costs associated with advanced water treatment hardware for use with reuse and reclamation processes. Again, the upfront and operating costs are easy to estimate, but the true cost of the avoided water is not. There is the potential for free-ridership, where a few entities spend the money to decrease water use, so more water is made available to the greater community. Under such circumstances, no one pays the true marginal cost of additional water supply, but those implementing water efficiency improvements are hit with very tangible expenses.

Water and Wastewater Utilities

Public and private water utilities account for about 21% of total U.S. water withdrawals.[27] This includes water supplied to residential, commercial, industrial and power generation customers, although the latter tend to provide most of their own supply. The water delivered by utilities is treated to potable standards, regardless of end use, and is often subjected to multiple pumping and storage stages prior to reaching the end use customer. Utility supplied water is therefore very valuable and very energy intensive. There is growing interest in disaggregating water use needs so that potable water can be delivered just for potable demand, or less valuable water can be utilized for non-potable purposes.

[27] U.S. Department of the Interior, *Estimated Use of Water in the United States in 2000*, U.S. Geological Survey Circular 1268 (Reston, VA, 2004).

Water use efficiency in the water and wastewater sector consists of finding new supplies of water to meet customer demands, and working with customers to encourage their use of more efficient practices. As such, most of the opportunities are related to advanced water treatment technologies that will in turn enable more opportunities for wastewater recycling, water reclamation, and even help with customer specific on-site reuse opportunities.

Sector Needs

The value of potable water supply continues to rise as the availability of sources diminishes and the cost to treat the water increases. Potable water treatment standards as defined by the U.S. EPA and local state agencies are becoming more stringent. These require impurities to be reduced to lower levels, and place previously unmonitored impurities under regulatory control. As an example, under the 2006 EPA Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) drinking water plants must incorporate new monitoring and treatment processes for the protozoan pathogen *Crytosporidium* that is emerging as a major problem for potable water supplies.[28] Also emerging as a new problem are trihalomethanes (THMs), which are now being regulated under the EPA's stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR).[29] The disinfection byproducts are largely a result of the use of chlorine, which has been a historical mainstay in water treatement. Water utilities must invest in new monitoring and treatment technologies to address these new requirements. To complicate matters, different treatment technologies are required for different impurities. For example, *Cryptosporidium* is very resistant to chemical treatment with chlorine, but can be treated very effectively through UV disinfection. It is just the opposite for adenoviruses, which are easily neutralized with chlorine, but are resistant to UV.

As watersheds become more stressed, water quality declines. For example, once pristine ground water sources are gradually becoming tainted with higher levels of natural and man-made impurities. Chemicals from agriculture and industry, such as nitrates and perchlorates must now be addressed with new treatment processes.

On the wastewater side, effluent discharge standards are being directed to a more watershed based approach. Watershed-based permitting is a process that emphasizes addressing all stressors within a hydrologically defined drainage basin, rather than addressing individual pollutant sources on a discharge-by-discharge basis. Watershed-based permitting can encompass a variety of activities ranging from synchronizing permits within a basin to developing water quality-based effluent limits using a multiple discharge modeling analysis. The type of permitting activity will vary depending on the unique characteristics of the watershed and the sources of pollution impacting it. Along with new regulations for controlling and managing storm water, utilities need to improve the quality of effluent and to decrease the volume of their discharge. Municipal water reuse activities will be a major opportunity for new technologies and solutions.

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[28] Global Energy Partners, *Novel Industrial Electrotechnologies for Water and Wastewater Treatment*, Technical Review (Lafayette, CA, April 2006).

[29] Global Energy Partners, "Ultraviolet (UV) Disinfection and the Water Market: The Market for UV Disinfection is Exploding," *Clear Solutions for Water & Energy*, program newsletter (Lafayette, CA, Summer 2007).

General technical hurdles currently facing water and wastewater utilities include:

- Salinity
- Toxic chemical contaminants
- Emerging pathogens
- Membrane fouling
- Regeneration of transfer medias
- Residuals disposal

Looming over all of these technical challenges is the fact that the water and wastewater infrastructure in the U.S. is in critical need of maintenance, expansion, and upgrades. For reference, the EPA estimates that drinking water and wastewater utilities will likely need to invest between $485 billion and $1.2 trillion by 2019 in order to update aging infrastructure and to keep pace with demand.[30]

Opportunities for Efficient Water Treatment and Use

Specific opportunities for water reuse and reclamation will build upon the basic water treatment technologies already being pursued for current treatment needs. Better technologies will enable water and wastewater utilities to more aggressively utilize alternative supplies and effluents.

Reuse

Water and wastewater utilities do not have much consumptive water demand. Therefore, opportunities for on-site reuse are minimal. However, their role as the conduit for wastewater effluent reuse is critical. Potential customers for recycled water include golf courses, oil refineries, textile mills, and cement plants. The most common end use to date has been for large landscape irrigation. This unfortunately produces a very seasonal demand, so other options for the effluent must be pursued during off season periods. More steady demand can be found with industrial processes such as boiler and cooling tower make-up water.

The next step for the industry would be to gain approval for the use of recycled water to augment potable water supplies. This is technically quite feasible, but it is the subject of much public resistance. A project recently launched in Orange County, California re-injects wastewater effluent back into the local groundwater aquifer. To gain approval for the project, assurances had to be made that the quantities of effluent would be limited, and also that subsequent freshwater withdrawals from the target groundwater zone would not occur for at least one year.

The U.S. Bureau of Reclamation is active in the municipal wastewater reuse market as well. A recent project sought to substantially improve the efficacy of membrane bioreactors to help “reclaim” water from urban wastewater. The Bureau hopes to encourage “sewer mining” for

[30] James A. Goodrich, “EPA Initiatives To Reduce the Volume of Water and Wastewater That Must be Treated” (presentation, EPRI water workshop, Palo Alto, CA, Nov. 15, 2007).

water for indirect uses.[31] This type of technology can be applied on a modular level, enabling water reuse at distributed locations.

Distributed treatment technologies can reduce treatment volumes and costs, and greatly increase water reuse. By applying water and wastewater treatment technologies at a local level, either within a multi-resident facility or within a community development, innovative water use practices can be employed. Local water treatment equipment enables the end user to only treat the potable water that is actually needed, saving on distribution losses. This can also increase the quality of the end use water. Even if the municipal utility treats the water to the same standards, there will inevitably be degradation within the distribution system, which is avoided with distributed treatment. Similarly, local wastewater treatment allows for separation of waste streams and prevents sewer water intrusion. This makes the wastewater treatment processes more efficient because they can be optimized for the specific task, such as treating bioorganic matter in black water or simply recycling greywater. Additional energy savings accrue at the society level as water and wastewater do not need to be pumped back and forth to a central facility. Distributed treatment technologies can complement existing infrastructure by offering a cost effective means to address demand expansion, and to help handle trouble spots within the utility's network.

At the EPRI workshop Kennedy/Jenks Consultants presented details from the Solaire apartment building project in Battery Park, New York. This facility implemented distributed wastewater treatment technologies to permit on-site water recycling. The project decreased the net water draw from the city water utility from a baseline of over 50,000 gallons per day, to just over 34,000 gallons per day.

Reclamation

Sources of reclaimed water include brackish inland water, and ocean water. While technically feasible, multiple hurdles exist to large-scale utilization of degraded water sources. Cost is often cited as the primary challenge, but concerns regarding environmental impact can also prevent project development. Also of concern is the ability to integrate large desalination facilities within existing water utility infrastructure. Additional research to evaluate the applicability of new technologies, as well as the true market potential for water reclamation at the national and local levels is needed.

Improvements in brackish water treatment are needed to increase freshwater yields and to decrease brine discharge. Technology synergies exist with the power generation segment, and in fact there would be opportunities to jointly develop projects. Near term advances need to be made in the assessment of current technologies, and how they may be better applied individually, and within combined systems. Work performed by Carollo Engineers recently demonstrated that by combining various treatment technologies significant improvements could be made with regard to how much water can be reclaimed per unit of brackish source water. This innovation

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[31] David T. White, "Summary of Reclamation's Recent Water Treatment Research" (presentation, EPRI water workshop, Palo Alto, CA, Nov. 14, 2007).

could improve freshwater yields from a baseline between 60% and 85% to between 90% and 98%. Additionally, the brine concentrate that must be disposed of can be reduced by 75%.[32]

Brackish water requires much less energy to treat than ocean water, and would seemingly be the best opportunity for cost effective desalination technologies to become commercially viable. Lessons learned could then be applied to ocean desalination operations. The relative salinity of various source waters is presented below in Table 5-1 in terms of total dissolved solids levels.

Table 5-1
Water Salinity Level Classifications
(*Water Quality Association*)

Water Source	TDS (ppm)
Freshwater	<1,000
Brackish	1,000 – 5,000
Highly Brackish	5,000 – 15,000
Saline	15,000 – 30,000
Sea Water	30,000 – 40,000
Brine	>40,000

Reduction

Monitoring and controls can help reduce water use and losses via leaks and over-pumping. In particular, water and wastewater utilities, along with other large water users, have made a massive shift to advanced Supervisory Control and Data Acquisition (SCADA) systems over the past decade. These SCADA systems provide excellent opportunities for monitoring and control of water quality and quantity. SCADA systems also provide for improved application of advanced technologies for treatment, distribution, and reuse of water and wastewater.

Advanced monitoring of water is required for many reasons including: the use of marginal water sources, the infiltration of pollutants in traditional supply, new environmental health standards, and the threat of enemy attack via water-borne pathogens. Toxins of particular concern include toxic metal ions such as lead, mercury, cadmium and arsenic; disinfection byproducts such as NDMA and N-chloramines; and organic toxins such as dioxin, phenols, pesticides, and herbicides. Advanced sensors are required to provide more real time feedback on water quality levels. Most testing for water contaminants is performed using standard laboratory style techniques. This requires samples to be drawn and then tested. Even with on-site equipment this can take hours or longer to complete. Testing is even more complicated if impurities are at very low levels.

[32] Gil Crozes, "Concentrate Minimization and Zero Liquid Discharge & Biological Perchlorate and Nitrate Removal From Groundwater" (presentation, EPRI water workshop, Palo Alto, CA, Nov. 14, 2007).

Advanced SCADA systems will be essential in the future to enable large scale adoption of water reuse projects. Tight monitoring and controls are required to ensure high quality performance and to maintain public confidence.

Better leak detection will not only save water, but energy as well. Freshwater saved is freshwater that does not have to be treated or pumped. Better monitoring and controls will also help address leaks into the wastewater system, referred to as sewer infiltration. If rainwater and other runoff infiltrates into the wastewater system then it must be pumped and treated along with all of the other effluent, resulting in higher energy costs. Other energy savings can result from better process planning that will help avoid peak period energy usage and demand charges. One estimate presented at the EPRI workshop suggested that energy savings of up to 30% could be achieved at a typical water utility if the controls were simply upgraded.[33]

Barriers to Efficiency Opportunities

Perhaps the greatest barrier facing water utilities is public perception regarding water reuse. The image of water being transferred from the "toilet to the tap" is enough to kill most urban reuse projects despite their proven merits. Unfortunately, there will be a finite demand for recycled water until the public accepts it. Ironically, current watershed management essentially entails defacto wastewater recycling. For example, a large inland municipality situated along a major river will withdraw its freshwater supplies from the river and also discharge its treated wastewater effluent back into the river. Other municipalities further downstream will also withdraw water from the river, and in effect recycle the water used upstream.

The U.S. is faced with a commitment to a centralized water and wastewater infrastructure. For economic and political reasons it would not be practical to switch to a decentralized model in the near future. As such, advanced water treatment technologies will have to be designed to complement the centralized model if they hope to achieve significant market penetration.

Resistance to price increases by water and wastewater utility customers will make it challenging to fund new technology capital projects. This exists despite the fact that water rates are forecasted to inevitably increase just to maintain the status quo infrastructure system. A more practical challenge for this market segment would be to educate the public about the actual future costs to be expected for water and wastewater services, and to highlight how such costs can be mitigated through the adoption of advanced water use technologies.

Legal barriers may emerge related to the complex array of water rights within the U.S. For example, who has first rights to recycled water? If significant water is recycled, then it is not being discharged to its previous location. This may violate legal discharge requirements – for example if a wastewater utility discharges to a river then users downstream may have a claim to that water, and if the wastewater utility stops discharging the water then they may be violating the downstream users' water rights.

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[33] Alex Ekster, day 2 discussion

Water rights can apply to point of use with respect to the location of the source. If the recycled water is used beyond the use area, or supplied to users further away from the original source, then there could be a legal issue.

Water utilities could face situations where the use of too much recycled water would be unfavorable. Many municipalities are supplied water on a needs basis. If they are able to meet a large portion of their users' demand via recycled water, then they would no longer "need" their full allocation of water. A portion of the municipalities water supply right could be redirected to another municipality under a "use it or lose it" scenario.

Lastly, if recycled water becomes more acceptable to domestic users its value will increase. This will put pricing pressure on existing recycled water users such as industrial facilities and large landscape irrigators. Historical precedents for water rights may place domestic needs above industrial customer needs and create conflict with existing recycled water supply contracts.

Agriculture

Water for agricultural uses comes from many sources including on-farm groundwater and surface water supplies, as well as off-farm surface water provided through a variety of public irrigation districts. Agriculture irrigation accounts for 80% of U.S. freshwater consumption, with livestock adding another 3%.[34]

Energy consumption associated with irrigation is also very large. Based upon a 2003 survey, the U.S. Department of Agriculture estimated that of 52.6 million irrigated acres of cropland, 42.9 million had utilized pumps to distribute the water. These pumps were powered by a variety of fuels, with a total energy cost of $1.55 billion, and an average cost of $36.13 per acre. Electricity alone powered irrigation on 24.1 million acres at a total cost of $953 million, or $39.54 per acre.[35] The energy cost per acre can vary dramatically depending upon the volume of water required for the specific crop and soil combination, the efficiency of the application of the water, the elevation rise that the water must be pumped from the source, and the additional pumping required if pressurized sprinklers are used (verses a gravity flood system).

Addressing both water consumption and energy use are of interest in the agriculture sector.

Sector Needs

Whether supplied from surface or from ground water, there are concerns about the quality of the source water. Excessive use and runoff return to the various sources can create elevated levels of salinity and other elements that can have a negative effect on crop production.

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[34] U.S. DOE, *Energy Demands on Water Resources*

[35] U.S. Department of Agriculture, *Farm and Ranch Irrigation Survey (2003)*, Volume 3, AC-02-SS-1, (November 2004).

Even with adequate volumes of quality water, irrigation practices are still a major concern because they have a direct impact upon soil erosion. The amount of water, how it is applied, where it is applied, and when, are all factors. Erosion control often limits farmers options for efficient irrigation systems. Other factors related to irrigation include control of ground saline levels, nutrient application, and concerns about limiting and controlling irrigation runoff.

As seen in Figure 5-2, U.S. irrigation efficiency has slowly improved between 1974, when about 2.1 acre-feet of water was required per acre of irrigated cropland, and 2003 when the value was 1.65 acre-feet. Crop production per acre has also steadily been on the increase, so net water consumption per crop output is even lower.

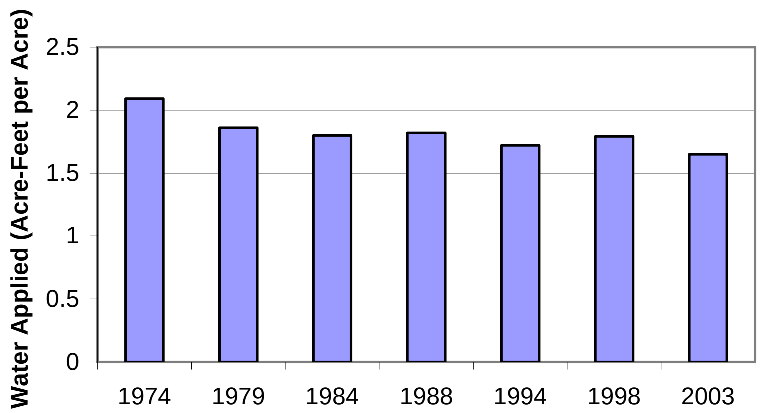

Figure 5-2
U.S. Average Acre-Feet of Water Applied per Irrigated Acre

Source: USDA *Farm and Ranch Irrigation Survey (2003)*

Efficiency gains associated with irrigation are realized through a careful balance of water flow and pressure. Generally speaking, using less water is always preferable, but utilizing less pressure might not be ideal. Sprinkler systems are designed to apply water as efficiently as possible, with respect to water use, and will vary based upon crop type, soil conditions, and ambient environment. Often times a higher pressure system can apply water much more efficiently than a lower pressure system, thereby greatly improving the water use efficiency. In these cases the energy savings realized through pumping less water more than offset the increased energy requirements associated with the sprinkler pressure. An excellent example is the conversion from flood irrigation to micro-irrigation.

The efficient application of irrigation water has several components. First the water must reach the crop. Spray evaporative loss occurs between the sprinkler system and the crop. Similarly, wind drift refers to spray that is carried away from the intended target crop. Once the water reaches the crop it can land on the leaves where it is subject to rapid evaporation called canopy loss. Through deep percolation the water that reaches the soil may penetrate beneath the crop root zone, placing it out of reach of the plant. Also, the water may not all be absorbed by the soil, resulting in runoff. Runoff in turn creates additional concerns related to soil erosion, nutrient loss, and downstream water contamination.

A water resource program guide published by the Washington State Department of Ecology illustrates just how much irrigation efficiency can vary. A sampling of the many methods discussed in the guide reveals low end efficiency numbers linked to surface flood irrigation of between 35% and 60%; mid-range numbers of 60% to 85% efficiency for a side roll sprinkler system; and high efficiency numbers of 70% to 95% for drip type micro-irrigation systems.[36] Upgrading to more efficient irrigation systems is a capital expense, but may be justified based upon pump energy savings. Unless there is simply no more water available, the cost of irrigation water is not often the primary operating concern. This is especially true for a farmer who is performing on-site pumping of groundwater, or who has rights to local surface water.

Opportunities for Efficient Water Treatment and Use

Reducing the amount of freshwater consumed for irrigation has been, and will continue to be, the focus of water use efficiency improvements in the agriculture segment.

Reuse

Much water is lost to evaporation, ground percolation, and runoff. The runoff, primarily from flood irrigation is captured in basins, but is generally returned to a water source. Elevated mineral content is a concern for this water and it is generally not reapplied to the fields. The cost of treating this water, and the lack of available treatment equipment limit the local reuse of the water. Runoff water may be a more practical option for power generation or industrial cooling water, or other less sensitive needs.

The U.S. Bureau of Reclamation has recently been involved with runoff water reuse demonstrations in California's San Joaquin Valley. Water recovery rates of up to 50% have been achieved through the use of reverse osmosis technology.

If close to a source, municipal wastewater effluent can be used for irrigation. However, attention must be paid to crop type and irrigation technique to limit exposure to edible plant surfaces and to farm workers.

Reclamation

Produced water is a potential source for reclamation in the agriculture segment. The water produced from the coal bed methane (CBM) fields in the Wyoming Powder River Basin in particular tends to be relatively fresh. With minor treatment, and or dilution with other freshwater sources, this produced water can be used for agricultural needs. Most crops tend to be sensitive to saline levels, with a desired level of total dissolved solids (TDS) of less than 700 parts per million (ppm) for high value crops such as fruits and vegetables. Grasses and grains are less sensitive, but even the most tolerant will experience poor yields with TDS levels greater than

[36] Washington State Department of Ecology, *Water Resource Program Guidance: Determining Irrigation Efficiency and Consumptive Use*, GUID-1210 (October 2005).

3,000 ppm.[37] Initial use of produced water has focused heavily on livestock watering, as acceptable TDS levels can be as high as 7,000 ppm.[38]

In most cases where reclaimed water may be used for agricultural purposes the driving factor will be, at least in the short term, the need to dispose of a marginal source of water. Dedicated reclamation projects that focus on supply side needs will tend to favor the urban market where the wholesale price of water is much higher.

Reduction

Regulated deficit irrigation (RDI) is the practice of intentionally under-irrigating crops under prescribed conditions. During such periods the crop is "stressed" to conserve water, but if performed properly, RDI can produce additional benefits while having a minimal impact on crop production. Studies have found that RDI can decrease hull rot in almonds, improve peel quality in citrus fruits, and improve juice quality in wine grapes. Past research has focused largely on high value tree crops. As such, there is still potential for developing RDI practices for field crops.

Stress monitoring technologies for better RDI hold potential. An example would be trunk diameter monitoring, which has been demonstrated on almond trees to limit the maximum daily trunk shrinkage due to dehydration. Also, stem water potential is a common metric used to determine the moisture content within the stem of a leafy crop. Typically leaf/stem samples are collected from various trees or plants and tested within a small pressure chamber. Higher pressure is applied until water begins to bubble out from the sample. The higher the resulting pressure, the lower the moisture content. These types of moisture monitoring techniques are superior to soil monitoring as they yield direct feedback on the current condition of the plant.

Current direct soil moisture monitoring technology can only sample at discreet locations, and the number of samples is limited to equipment availability, and labor to perform the samples. Additionally, soil moisture data is only a proxy for the water content of the crop itself.

Additional gains can be made through the application of advanced control systems to help apply irrigation water more efficiently, and also to help identify and control system leaks. Even well maintained irrigation systems are estimated to have a leak rate of 1-2%. Older systems can have leaks of up to 10%.[39] There is potential to implement control logic and technology developed in other industries. A primary objective would be to optimize and simplify technology for irrigation purposes to reduce costs and increase market penetration.

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[37] H.G. Peterson, *Water Quality Fact Sheet: Irrigation and Salinity* (Agriculture and Agri-Food Canada-Prairie Farm Rehabilitation Administration: 1999), http://www.agr.gc.ca/pfra/water/irrsalin_e.htm

[38] Produced Water Management Information System, *Fact Sheet – Agricultural Use*, http://web.evs.anl.gov/pwmis/techdesc/aguse/index.cfm

[39] Washington State Department of Ecology, *Water Resource Program Guidance: Determining Irrigation Efficiency and Consumptive Use*, GUID-1210 (October 2005).

Barriers to Efficiency Opportunities

Cost is a major issue in the agriculture sector. Capital expenditures for irrigation are difficult to justify when the price of water is relatively low. On-farm sources of water may have no direct marginal supply cost. Off-farm supplies were estimated in the USDA's *2002 Census of Agriculture* to average $18.29 per acre-foot. For comparison, wholesale water costs for urban water utilities can easily cost ten times this amount.

Surface water supplies are often allocated to farmers in lump quantities. During seasonal irrigation periods the farm is entitled to the predetermined volume of water. The farmer is given a relatively short window of time to receive the water. These factors tend to be counter productive to the efficient use of the water. For example, a farmer may apply all of the allocated water in a hasteful manner just to ensure that all of it is received. This will ensure that future allocations are not decreased. This creates an attitude in the segment that end users are entitled to certain water rights, and down plays any concept of marginal resource value.

The best opportunities for water use efficiency exist where there is simply no marginal water available, and/or the energy costs related to pumping are very high.

Industrial Sector

In 2000, 5% of freshwater withdrawals in the U.S. were made directly by self-supplied industrial users. This represented 19.7 billion gallons per day. Another 2 to 4 billion gallons per day were supplied through public water utilities to their industrial customers. The large volume of water consumed through agriculture may seem to make industrial (and other uses) less significant, but most irrigation water is not treated before use, nor does it produce wastewater that must be processed. The California Energy Commission (CEC) estimated that energy used to pump, treat, heat, or chill water for agricultural applications in California is only about 20% of the total water related energy use in the state. The CEC found that water related energy use is dominated by urban and industrial applications that require significant treatment and pumping of water (upstream) and wastewater (downstream), as well as a very large amount of energy committed to the water on-site in the form of heating, cooling, and additional pumping. Even though 80% of freshwater in the state is consumed by agricultural irrigation, 70% of water related energy is consumed through urban use.[40] Industrial water use efficiency therefore has a significant impact on the overall water and energy equation.

Industries that use large amounts of water include food processing, pulp and paper, chemical manufacturing, petroleum refineries, and primary metals producers. Typical water use processes include cleaning, rinsing, conveying, chilling, heating, and scalding. All of these hold great potential for advanced water use techniques. Since most industrial water consumption eventually leads to wastewater discharge, improvements made in water reuse and water use reduction can offer significant cost savings associated with both freshwater supply and sewage charges. Large on-site energy savings can also be realized if hot or chilled process water use can be reduced, and/or if the water can be reused.

[40] CEC, *California's Water-Energy Relationship*

Sector Needs

Within the industrial segment there are similar environmental constraints related to water withdrawals and discharges as found in the power generation market. Many industrial users will treat their own wastewater and discharge the effluent to the environment. Small users may discharge to a municipal wastewater utility, but could perform on-site pretreatment of the effluent to avoid a higher service rate.

Health and safety regulations also apply to some of the water used in the industrial sector. Within the food processing industry standards may be present for the minimum amount of water required for washing a given commodity, or the water temperature at which it must be washed.

Steam generation is a critical component of many industrial operations. As with power generation, steam cycles require significant amounts of water for cooling. Therefore, many of the concerns regarding cooling water found in the power sector are also shared in the industrial market. The scale is much smaller with industrial end users, and there are unique challenges. For example, smaller industrial cooling towers are often constructed with wood. Bioorganisms found in recirculated cooling water, such as molds, can attack the wood and lead to rot. Environmental regulations also apply to cooling towers related to air quality. The “drift” of water mist from wet cooling towers is closely regulated by local air quality boards and must be monitored and controlled by end users.

Opportunities for Efficient Water Treatment and Use

Because of the many varied processes found in the industrial segment, there are many unique opportunities for water use efficiency. Industrial users are heavily motivated by operating cost, and can appreciate more than any other market segment the value of saved water and reduced wastewater. Tapping in to this motivation should be a priority for water utilities, as well as regulators and energy utilities.

Reuse

There is great potential for on-site reuse within many industrial facilities. Industries with good opportunities include food processing, textile manufactures, silicon chip manufacturing and metal finishing. Food processing entails many rinsing and washing production stages. This water can be captured and reused for preliminary stages or used outside of the process. This water may need to receive disinfection treatment due to contact with food and natural microbes.

Textile manufacturing entails many washing, dying, and/or bleaching processes. Coarse filtration, deionization, and ph control are required for on-site water reuse.

The pulp and paper industry already performs much on-site water recycling, but the water withdrawals of the industry are still quite high. More opportunity exists to utilize recycled water from off-site sources, as well as reusing on-site water. Synergies for capturing additional water for reuse exist through the need to treat significant amounts of process wastewater on-site. Technologies that could improve sludge dewatering while capturing the moisture would reduce waste discharge cost as well as freshwater supply draws. Opportunities exist in other industries as well to “mine” useful water from waste streams.

Silicon chip manufacturing requires very pure water pretreated on-site via reverse osmosis. This water is then used as part of very sensitive chip rinsing processes. The recaptured rinse water is still of relatively high quality. It can be retreated for process use, or used directly for secondary purposes such as landscape irrigation.

Metal finishing utilizes plating baths and rinse cycles. The rinse water gradually builds up high concentrations of suspended and dissolved metals. These can be removed through deionization, allowing the rinse water to be recycled back into the process.

There are many large boilers in the industrial segment, representing an opportunity to reuse water on-site for cooling tower water, and for boiler make-up water. Industrial boilers operate at much lower pressures than power generation boilers, so the water chemistry requirements are slightly less stringent, making water pretreatment easier.

Large industrial end users are ideal customer for utilizing recycled municipal wastewater effluent as well. Thanks to their relatively large demand, it is practical to construct dedicated recycled water supply and distribution piping. Also, there is little chance that the recycled water will become commingled with potable water supplies. Uses for recycled water include cooling tower water, boiler makeup water, and low to intermediate quality process water needs often found in the pulp and paper, textile, and metal fabricating industries.

Reclamation

Many industrial processes can tolerate relatively high levels of total dissolved solids (TDS), making them ideal users of reclaimed water. Generally speaking, the chemical, petrochemical, and cement industries have processes that are tolerant of higher TDS levels. Desalted water for these purposes would not be as energy intensive because the water would not need to be treated to potable standards.

Flue gas moisture capture is an opportunity in the industrial segment due to the large number of combustion based processes. Further synergies result from the fact that natural gas is a primary industrial fuel in the U.S. and affords the benefit of relatively clean flue gas condensate. Carbonic acid in dilute concentrations is the main impurity, which is not a problem for non-sensitive wash processes or landscape irrigation. For sensitive water uses, the acid is easily neutralized as part of a water pretreatment process. Estimates for the amount of water easily recovered from the flue gas of an industrial boiler firing natural gas are between 5% and 7% of the nominal steam production rate. Utilizing this condensate would offset the water lost through boiler blowdown, which is about 4% to 8% of steam production.[41]

[41] DOE-EERE, *Energy Tips – Steam: Minimize Boiler Blowdown*, DOE/GO-102006-2254, Steam Tip Sheet #9 (January 2006).

Product dryers, like those found in the food processing and paper industries produce an exhaust stream with very high moisture content. This moisture could be captured through the use of condensing heat exchangers or advanced desiccant based processes.

Reduction

There are many opportunities for specific industrial process improvements that will enable more efficient use of water. More precise control and distribution of water in spray systems is a good example, as is the design of more efficient product conveyance systems. Applications that use water for product washing can be improved with advanced disinfection technologies. The use of ozonation or UV disinfection can make wash processes more efficient, thereby reducing the volume of water required to achieve the desired product quality.

Employing advanced cooling technologies similar to those being developed for the power industry would translate into direct water use reductions. Albeit on a smaller scale most of the advanced cooling technologies being pursued in the power generation market can be applied to industrial applications as well. Near term opportunities exist for air cooled condensers and for hybrid wet/dry systems. Space constraints may be a greater concern within industrial facilities due to a lack of expansion room for the larger hardware.

Common measures currently employed in the industry still hold much potential for water savings including monitors and controls for cooling tower blowdown and boiler blowdown, and energy saving measure like condensate return and steam trap maintenance.

Barriers to Efficiency Opportunities

The availability of reliable information is a challenge for many industrial end users. Unless the facility can afford to employ an engineer, or team of engineers, committed to water use management, it is very difficult to assess the real benefits of process improvements or hardware changes. Every industrial process is slightly different, and the entire process much be considered when making efficiency improvements. This is beyond the scope of individual equipment vendors, so evaluating water savings claims are not easy for facility management.

Opportunities exist within similar industries to share experiences and knowledge regarding water use efficiency improvements. Often times it is less risky to maintain an inefficient existing process than to experiment with a new configuration. Better information exchange could mitigate these risks.

Commercial and Residential Sectors

Commercial and residential water consumption accounts for about 8% of the total U.S. water consumption. Water is commonly used for drinking, food preparation, personal hygiene, washing, landscape irrigation, and as a heat transfer media within HVAC systems.

According to the EPA, each American uses an average of 100 gallons of water per day at home. However, by taking just a few simple steps this could be reduced by 30%. The average household spends as much as $500 per year on their water and sewer bill and can save about $170 per year by using water more efficiently. Since approximately 80% of municipal water processing and distribution costs are for electricity, there is also a large energy savings potential associated with water use efficiency. Nationwide, drinking water and wastewater systems use 50 billion kilowatt-hours per year – enough electricity to power more than 4.5 million homes for an entire year. If only one out of every 100 American homes retrofitted with water-efficient fixtures, the savings would be about 100 million kilowatthours per year. This would avoid 80,000 tons of greenhouse gas emissions – equivalent to removing nearly 15,000 automobiles from the road for a year.[42]

Sector Needs

Consumers in the commercial & residential sector expect to receive high quality water with very high reliability. Within the U.S. there is no tolerance by end users for supply interruptions or occasional dips in water quality. Similarly, consumers expect 100% reliability with wastewater systems. As such, water and wastewater utilities are very risk averse when dealing with this sector, as the political pressure resulting from unsatisfied customers can be quite significant.

Environmentally conscious consumers who wish to improve their water use efficiency are growing in number. These individuals represent an opportunity for advanced water treatment and use technologies to be applied at the local level.

Opportunities for Efficient Water Treatment and Use

Most water use efficiency efforts to date within the commercial & residential sector have focused on the application of more efficient appliances and fixtures. Low flow toilets, showerheads, and faucets have all achieved high market penetration, and significant improvements have been made to the water efficiency of clothes washers. Additional opportunities exist though for advanced water reuse and reclamation technologies to be employed at the end use level.

Reuse

On-site water reuse in the commercial & residential sector represents a large and virtually untapped market opportunity. Distributed water and wastewater treatment technologies would enable effective and efficient water processing at the local level. As previously outlined in the Water and Wastewater Utilities section, there needs to be better integration between the current centralized utility base infrastructure and the development of distributed technologies. New advanced technologies must be capable of complementing the existing ones.

[42] James A. Goodrich, "EPA Initiatives To Reduce the Volume of Water and Wastewater That Must be Treated" (presentation, EPRI water workshop, Palo Alto, CA, Nov. 15, 2007).

Reclamation

The residential and commercial sectors offer few opportunities for water reclamation since more than 90% of domestic water is supplied by local water utilities. Nonetheless, there would be opportunities amongst many of the domestic self-suppliers for advanced treatment technologies, which would enable them to utilize marginal quality water sources.

Reduction

The application of high efficiency appliances and fixtures in the commercial and residential sectors has been a primary contributor to reduced urban water usage. Clothes washers, dishwashers, rinse valves, toilets, and faucets have been the focus of improvements. Emerging opportunities for on-site reuse and for advance landscape irrigation controls are becoming more popular. Community-wide water use efficiency programs, including promotion and incentives, exist in many metropolitan areas in the U.S. but are limited by funding and staff. Efforts have been made to combine energy savings and water savings through common measures to increase the value proposition to end users, but these have generally been limited to just hot water applications.

Barriers to Efficiency Opportunities

Many commercial & residential end users have a very unfavorable perception of water reuse. They consider it to be dirty and unhealthy. Opportunities for on-site reuse would be more practical if greywater from sinks and clothes washers could be easily separated from toilet water and kitchen waste. The greywater could be recycled for outdoor uses and toilet flushing. Unfortunately, consumers tend to resist innovations that increase the cost of plumbing systems or require technical interface to maintain and operate.

6
ADVANCED WATER TREATMENT TECHNOLOGIES

Water treatment technologies remove or neutralize impurities, making the water suitable for either consumption (freshwater) or discharge (wastewater effluent). Advanced water treatment technologies enable the reuse of wastewater effluent as well as the reclamation of alternative water sources. Often times, the quality of treated wastewater effluent can exceed that of a public water source. This exemplifies why it is important to consider the entire water use cycle when evaluating opportunities for additional supply and/or means of effluent disposal.

Fundamental water treatment concerns are the same for most purposes, even though the quality requirements will vary. Standards for drinking water are quite high, but not as high as those for sensitive industrial processes like silicon chip manufacturing and high pressure boilers. Less stringent standards apply to irrigation water, and non-sensitive industrial processes like cooling tower makeup water. Matching water quality needs to end use is one means of improving water use efficiency.

Basic Water Treatment Needs

Water treatment techniques must address the following impurities to a lesser or greater extent depending upon the water use needs.

Turbidity – This is a measure of how cloudy water appears. It is caused by suspended and dissolved organic and inorganic matter. Silt is a common example, as are microorganisms. Some components contributing to turbidity are also included within the categories below.

Oil & Grease – This is a general category for common waste material or spillage associated with petroleum products and animal fats. This can include used cooking oil, gasoline, and hydraulic fluid. Oils and greases generally must be separated early in the treatment process to prevent these components from fouling processes used to treat other impurities.

Harmful Microorganisms – These include bacteria, viruses, parasites (protozoa and helminthes), algae and fungi. They can represent a health hazard to humans if ingested or allowed to come in contact with skin. Fine water spray can produce aerosols that can contain and convey microorganisms to personnel via inhalation as well.

Heavy Metals – These can be any metallic chemical elements that have relatively high density and are toxic or poisonous at low concentrations. Included would be arsenic, barium, beryllium, cadmium, chromium, lead, mercury, and thallium.[43]

[43] http://www.lenntech.com/heavy-metals.htm

Nutrients – Common concerns are nitrogen, phosphorus, and potassium. These are often associated with agricultural irrigation runoff. While essential as soil nutrients for crops and landscape plants, in high concentrations they are toxic to animals and humans.

Organics – This category includes all biodegradable material, which could be anything from harmful microorganisms that pose a threat to public health, to nuisance bioorganisms that contribute to physical system fouling. Biodegradable material will continue to serve as a food source for other organisms, and will continue to draw from available oxygen sources until it is removed. Other classes of organics include volatile organic contaminants such as benzene, styrene, toluene, and vinyl chloride; and synthetic organic contaminants such as pesticides and herbicides. A special class of organics that is emerging as a treatment challenge are disinfection byproducts. Trihalomethanes (THM) and N-nitrosodimethylamine (NDMA) are organics of special note, as they are formed as an unintended consequence of the chemical treatment of water and wastewater with chlorine and chloramines. THMs and NDMA are carcinogens, and are coming under closer scrutiny and regulation from the EPA and state environmental regulators.[44]

Dissolved Inorganics – These are often expressed by a measure of total dissolved solids (TDS), and refer to any mineral, salt, or metal dissolved in water. Typical minerals of concern include sodium, calcium, magnesium, chlorine, potassium, and boron.

Endocrine Disrupters – Several types of chemicals can have adverse effects on human hormonal systems. These chemicals can disrupt the production and function of hormones. Examples include synthetic steroids, certain pesticides, phthalates, alkylphenolics, and phytoestrogens. Monitoring and removing these chemicals is an emerging challenge. Currently it is not possible to remove a high percentage of endocrine disrupters (EDs) with the use of a single technology. Due to variability in the chemical composition of EDs, some treatment technologies are effective at treating certain ones, but have minimal impact on others. A combination of technologies is required, which increases treatment costs. Improved monitoring would enable utilities to only target the EDs that are present, potentially reducing costs.

Odor & Taste – These are affected by the above factors, but are a special concern for drinking water. Odor and taste concerns may require additional treatment beyond levels suitable for health standards.

Water treatment technologies are usually associated with the equipment and techniques employed by water and wastewater utilities. However, large self-suppliers must perform all of their own treatment, and many small consumers perform supplemental treatment via point of use filters and purifiers. The scale of treatment will vary, but the end goal is to address the impurities outlined above.

Common water treatment techniques are included in Table 6-1 along with the impurities they are generally utilized to treat. These techniques are used to treat water and wastewater and would be used in various combinations for enabling on-site water reuse and the reclamation of alternative supplies. Descriptions of these common water treatment technologies are included in Appendix A.

[44] http://www.epa.gov/safewater/hfacts.html

Table 6-1
Common Water Treatment Techniques for Various Impurities

	Separation	Filtration	Biological Treatment	Deionization	Oxidation	Disinfection	Adsorption
Turbidity	•	•	•				
Oil & Grease	•	•	•				•
Microorganisms		•	•		•	•	
Dissolved Inorganics		•		•			
Heavy Metals	•	•		•			
Nutrients		•	•				
Organics		•	•		•	•	•
Endocrine Disrupters		•				•	•
Odor & Taste		•			•	•	•

Advanced Treatment Technologies Reviewed

Many advanced treatment technologies were identified during the initial review stage of the project, as outlined in Table 2-1, and were also discussed during the workshop. Further analysis was performed to identify emerging technologies that are the subject of current research and development activities. The most promising technologies include:

- Membranes
- Membrane Bioreactors
- Advanced Adsorption
- Advanced Deionization
- Advanced Oxidation Processes
- UV Disinfection
- Bacterial Fibers
- Advanced Tertiary Filtration
- Thermal Driven Distillation
- Dehumidification Technology for Flue Gas Moisture Capture

Descriptions of these technologies, the benefits or applications they enable, and the barriers to their further development are presented below.

Membranes

There is potential for membrane technology to handle virtually all water treatment needs. Reverse Osmosis is the best current example of membrane technology that can remove most impurities from water. The goal of current research is to achieve water purity levels at greatly reduced costs. Specialized membranes are being developed to serve as stand alone treatment technologies or to work in concert with other treatment technologies.

Significant research is focused upon techniques for reducing the rate of membrane fouling. Benefits include reduced maintenance, higher operating efficiencies, and longer membrane life. Example research includes the work Sandia National Laboratories are performing on a new enzyme cleaning procedures for membrane biofouling within reverse osmosis systems.[45] Also, the Massachusetts Institute of Technology is developing new nano-filtration membrane materials that will better resist the buildup of biomolecules in the first place.

A primary benefit sought through new membrane technology is a much more cost effective means of desalinating water than is currently available with reverse osmosis and nano-filtration systems. The University of Illinois is developing a novel thin film composite membrane system that promises to advance this interest. The UCLA Polymer and Separations Research Laboratory has been working with unique ceramic supported polymer membranes, and the Michigan State University Environmental Nanotechnology Research Group is using insight into emerging nanotechnology to devise better membrane based filtration systems as well as hybrid systems.

Membrane Bioreactors

Membrane bioreactors (MBRs) are employed to treat municipal and industrial wastewater. They are comprised of a biological treatment vessel with a submerged membrane filter. The benefit is that multiple water treatment processes can be accomplished with one vessel and within a much smaller physical space. Improvements associated with membrane bioreactors will advance the opportunities for wastewater effluent reuse by increasing the efficiency and decreasing the cost of treatment systems.

By combining a micro-filtration or ultra-filtration membrane within an aeration tank, the solids separation and biologic treatment stages can be performed simultaneously. The drawback is that the membrane fouls quickly. A cleaning cycle must be built into normal operating procedures to backwash or air scour the membrane regularly.

[45] http://www.sandia.gov/water/desal/research-dev/membrane-tech.html

The University of Illinios, the University of Michigan, the Massachusetts Institute of Technology, and Yale University are working on developing a new type of nano-filtration membrane for use within membrane bioreactors that promises to significantly reduce biofouling and improve wastewater effluent quality.

Advanced Adsorption

Adsorption traps organics that may escape other treatment processes by bonding them to an inert media. Activated carbon filters are the most common example of this technology, although other inorganic media are available. The arrangement of the media can vary from simple granules in bulk volume to filtration fibers coated with the media. Adsorption is often used as a final step to polish water prior to use. Over time the media loses its effectiveness as its surface area fills with bonded impurities. Adsorption systems require periodic replacement or regeneration of the media, which presents additional operating costs.

Most adsorption research still focuses on the utilization of activated carbon. However, there are many variations on the geometry of the carbon itself and how it is physically introduced to the treatment water. The surface area of the carbon and the size and spacing of pores within the carbon have significant impact on performance.

The University of Illinois has developed activated carbon filters that improve the adsorption of herbicides, chlorinated solvents, and MTBE. The technology is referred to as chemically activated fiber (CAF) filters. Performance is based upon increased surface area of the activated carbon through optimum deposition upon fiber substrates contained within the filter. Similar fiber filter strategies are being researched in various other laboratories as well.

Another University of Illinois project developed fiberglass adsorption fibers coated with polyethylenimine and epoxy, instead of activated carbon, for the removal of humic acid from drinking water. There is still much potential for the development of new sorbent material for use with current and emerging contaminants. The capacity of the sorbent surface for adsorbed impurities can also be increased. Research synergies will exist with nano-technology developments in the material sciences field.

Advanced Deionization

There is an interest in being able to selectively target certain chemicals either with ion exchange or deionization. Cost effectively removing all ions is an ongoing interest for desalination and ultra-pure water needs.

Capacitive deionization is based on the principles of electrodeionization wherein ion species are removed from liquids using active media and an electric potential to influence ionic transport. The key to capacitive deionization is utilizing advanced media material that can more effectively capture ions and retain more prior to recharging. Research has focused on advanced materials that have consistent pore sizes optimized for receiving ions and high surface areas per gross volume to increase ion capacitance. Practical use of the technology has been limited to treating water with low total dissolved solids concentrations, such as brackish water, due to the limited ion capacitance of current media material. Technology improvements could enable the treatment of higher concentrations, such as that found in ocean water.[46]

Lawrence Livermore National Laboratories (LLNL) has performed extensive research on capacitive deionization using carbon aerogel as the media material. Carbon aerogel has extremely high porosity and a high surface area to volume ratio. It also serves as a very effective electrode material thanks to its excellent dielectric properties. The technology has been deployed in the water treatment market through CDT Systems Incorporated, but high material costs and operating expense have limited deployment to niche applications. Market opportunities have been associated with the treatment of brackish water, and for polishing water for high purity applications. High energy intensity is also a concern; CDT claims 6,000 kWh/MG of treated water.

TDA Research, Inc. has developed mesoporous carbons for use as a media material. This material is intended to improve upon carbon aerogels by increasing surface area, and decreasing manufacturing and operating costs for water treatment hardware.

LLNL is also performing new work based on the Cussler Ion Pump technology in an effort to develop a more efficient means for water desalination. As shown in Figure 6-1, through a combination of electric charge and water flow pulsations, ions can be separated from the treated water and discharged with the concentrate. Advantages include the facts that there is no membrane involved with the process and there is no ion exchange medium to be recharged.

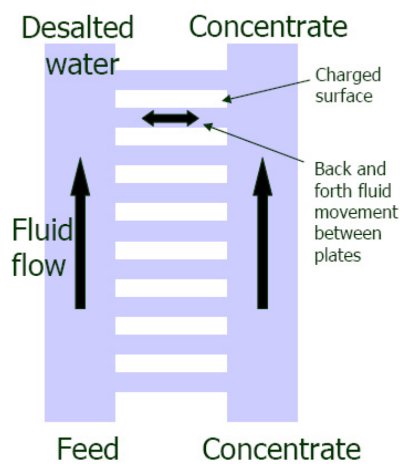

Figure 6-1
The Cussler Ion Pump

Source: Lawrence Livermore National Laboratories

[46] California Energy Commission and EPRI, *Emerging Environmental Technologies: An Analysis of New Treatment Technologies for the California Energy Commission*, report number 1007411 (May 2003).

Argonne National Laboratory is working on a hybrid approach combining electrodeionization with ion exchange to meet the needs of the chemical manufacturing industry. The technology has proven effectiveness when treating high purity water. However, it has not been deemed acceptable for chemical product treatment as of yet due to high leakage rates, product loss, and hardware serviceability. The technology eliminates the need for regenerant chemicals for the ion exchange resin, reduces disposal waste, and uses significantly less energy than current industry practices.[47]

Sandia National Laboratories is developing new membrane technology that promises to reduce the cost and energy use associated with electrodialysis. The goal is to make desalination more affordable.

> *We are developing advanced ion exchange membranes using nanometer-scale self-assembly techniques, to achieve significantly higher efficiency than current membranes. Lower electrical energy consumption will result in decreased cost for desalinated water, and higher ion selectivity will result in more efficient separation of salts for product recovery and waste minimization.*[48]

Advanced Oxidation Processes

Many research teams are looking at photocatalytic oxidation, or photocatalysis, as promising technology for highly effective and efficient elimination of organic material, and in some cases limited inorganic impurities. Most research builds upon previous success with TiO_2 catalysts, and seeks to improve performance by varying the catalyst chemical composition and/or depositing additional chemicals onto the surface of the catalyst.

The University of Illinois has conducted multiple research projects in this field. One outlined the benefit of adding SiO_2 to a Ta_2O_5 catalyst with respect to increased photoactivity. This was part of a larger effort to develop catalytic material that will generate hydroxyl radicals with only visible light serving as the required activation energy. Current market ready technology relies on UV light or another external energy source. Other work has looked at the benefits of doping catalyst with niobium and alumina.

The Argonne National Laboratory is looking at combining the benefit of organics oxidation and heavy metals removal with an innovative photocatalysis system. The TiO_2 surface of a typical catalyst is modified with various organic compounds to alter its reduction and oxidation properties. This enables metal ions in solution to first be adsorbed by the catalyst, and then reduced to their metallic form when illuminated with light of the proper frequency.[49]

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[47] http://www.es.anl.gov/Energy_Systems/Biodefense/Chemical_&_Biological/Current_Programs/4.%20Electrodeionization.htm

[48] http://www.sandia.gov/water/desal/research-dev/membrane-tech.html

[49] http://www.es.anl.gov/Energy_Systems/Biodefense/Chemical_&_Biological/Current_Programs/6.%20Heavy_Metals.htm

Arizona State University has developed a hybrid technology that employs both photocatalysis and biological treatment in one process referred to as photobiocatalysis. This technology offers the benefits of organic oxidation unachievable through standard biological treatment, while producing treated water at a fraction of the cost achievable with photocatalysis alone. The market focus is the treatment of wastewater for reuse.[50]

Others means of advanced oxidation that have been pursued in the past include supercritical water oxidation and electron beam irradiation. Both have been considered emerging water treatment technologies for over a decade but still lack commercially viable processes. As with many treatment technologies, high energy intensities are a significant limiting factor.

Like other disinfection technologies, advanced oxidation holds much potential for providing cost effective water treatment technology that could be used on a localized level in support of distributed treatment processes. The technology could greatly impact emerging economies worldwide where access to clean water is often a problem.

UV Disinfection

Short wavelength ultraviolet light in the range of 250 – 275 nm is commonly used for disinfecting drinking water and for other disinfection processes. UV light can penetrate the cellular structure of bacteria, viruses, and other microorganisms and alter their DNA. This disables the organisms' ability to reproduce. While the disinfection mechanism is well defined, the UV light source is a focus of continued research and development.

The most common UV source in the market currently is mercury vapor lamps. Emerging technology includes microwave powered bulbs and pulsed UV systems. Concerns for all available technology is energy consumption and physical space requirements for the UV lamps. Not only must adequate levels of UV light be generated, it must be spread over an area adequate to treat the entire volume of water. Current research into solid state UV sources address both of these problems. Higher energy efficiency is achieved through more effective light generation with the new solid state technology. Further efficiency gains are realized by narrowing the bandwidth of light wavelengths generated to just the target range, thereby avoiding the generation of wasted light.[51] Due to the compact size of solid state UV generators, they can be precisely placed to meet specific process needs, greatly increasing the functionality and flexibility of the technology.

Research on the generation of UV light through the use of aluminium gallium nitride LEDs has been conducted over the past several years at Sandia National Laboratories, the University of Maine, the University of South Carolina, and at other laboratories. Obvious synergies exist with the solid state lighting industry.

[50] http://www.biodesign.asu.edu/centers/eb/projects

[51] Global Energy Partners, "Ultraviolet (UV) Disinfection and the Water Market"

Bactericidal Fibers

Many metals have antibacterial characteristics. These include cobalt, copper, mercury, nickel, silver, titanium, and zinc. Work performed at the University of Illinois deposited silver nano-particles upon fiberglass fibers for use in a water filter. It was found that when exposed to the water in this fashion, the silver was a very effective at inactivating *E. coli* and *Aeromonas hydrophila*. The combination of surface metal and fiber material was very critical to the performance of the filter.

Much research must still be performed to develop a disinfection device utilizing this technology, but the promise of an energy efficient antibacterial process that does not involve harmful chemicals is very appealing. There is also potential for use for air purification.

Advanced Tertiary Filtration

Most urban end uses for recycled water require effluent that has been disinfected and also treated to tertiary levels for suspended solids. Disinfection can be achieved through chemical (chlorine), oxidizing (ozone), or disabling (UV) techniques. Suspended solids are removed through filtration or chemical coagulation followed by filtration. While achievable with conventional filtration techniques, current technology is often bulky and expensive. Opportunities exist for advanced tertiary filtration technology to achieve recycled water treatment requirements at lower cost and with higher energy efficiencies.

As depicted in Table 6-2, tertiary standards require more solids removal than primary and secondary treatment. This places additional burden on the filter media, both in terms of the particle sizes that must be retained as well as the mass of material that must be captured. Eventually, the filter media must be backwashed or replaced to remove the trapped material. This function introduces additional operating costs.

Table 6-2
Suspend Solids in Treated Effluent

Wastewater Treatment Level	Suspended Solids Limit
Primary	30 mg/l
Secondary	10 mg/l
Tertiary	< 4 mg/l

Improvements to conventional sand filtration systems are being researched by Washington University and the U.S. EPA. The technology, referred to as electro-filtration, incorporates custom electrodes within a sand filter. The electrodes produce an electric potential within the sand filter that facilitates ion separation. This enables a relatively cost effective filtration system to also remove trace elements that would otherwise simply pass through.

Thermal Driven Distillation

Power generation as well as many industrial processes generates large amounts of waste heat that users are always trying to put to good use. New distillation technologies that can operate at lower temperatures will be able to purify water without the need to consume additional energy at the power plant or industrial facility. Thermal distillation is one of the oldest and least efficient means of purifying water, yet even an inefficient process that utilizes otherwise wasted heat would be valuable. A diffusion driven desalination (DDD) process was detailed in a 2004 paper from the University of Florida.[52] Similar in concept to earlier applications that utilize a combined evaporation followed by condensation process, DDD can utilize lower grade waste heat resulting in less overall heat loss. An example given by the NETL suggests that the waste heat resulting from a 100MW power plant could be used to generate one million gallons of water per day. Even as such, the DDD process is still only reported to have a net efficiency of 8%. New thermally driven processes are emerging that promise to be more efficient including membrane distillation, which benefits from technology advances from the filtration sector.

The distillation process could be used to treat on-site process water for reuse or for water reclamation. Even industries such as petro-chemical and pulp and paper that already aggressively pursue on-site water reuse could still benefit from better waste heat recovery. Opportunities exist for industrial users with high waste heat availability to partner with water treatment entities for mutual benefit.

The availability of affordable distillation technologies would provide a means to effectively remove dissolved solids from industrial reuse water, something that is currently challenging and expensive. It is relatively simple to filter out oils and suspended solids, but ion removal must be performed with energy intensive electrodialysis or reverse osmosis processes.

Dehumidification technology for Flue Gas Moisture Capture

Work is being performed under the NETL by the University of North Dakota's Energy and Environmental Research Center to evaluate a liquid desiccant-based dehumidification technology to recover water from plant flue gas. An evaluation project was completed in 2006 to identify optimal desiccant composition. The process works by using the desiccant to first remove the water vapor from the flue gases without retaining significant impurities. The clean vapor is then removed from the desiccant and condensed for process use. The process avoids condensing sulfuric acid along with the water as would happen with a simple flue gas condensing arrangement.

The technology was demonstrated in a pilot project, but more field testing is required to develop optimal desiccant and process design. Maximizing the water recovery, and minimizing the capture of undesirable chemical species from the flue gas would be the main focus of future research.

[52] James F. Klausner, Mohamed Darwish, and Renwei Mei, *Innovative Diffusion Driven Desalination Process* (Gainesvill, FL: University of Florida, Department of Mechanical and Aerospace Engineering, 2004).

7
ADVANCED WATER USE TECHNOLOGIES

The second category of water technologies reviewed as part of this project relates to the efficient use of the water itself. Many industrial processes and consumer appliances utilize water to achieve a desired output. Advanced processes and technologies can reduce the volume of water needed to achieve these results. Technologies currently under development that hold significant potential include:

- Advanced Condenser Cooling Systems
- Advanced Power Generation Systems
- High Efficiency Appliances and Fixtures
- Sensors and Controls

Advanced Condenser Cooling Systems

Advance cooling technology holds great potential for water use reduction in the power generation sector as well as the industrial sector. Dry cooling systems, or air-cooled steam condensers, for power generation applications are currently available but are physically much larger than equivalent evaporative cooling systems and are not as efficient. These cooling systems can reduce power generation efficiency several percentage points, especially during hot weather. The complexity of air-cooled systems make them more expensive, and the loss in efficiency increases fuel consumption and operating costs and also raises air emission concerns.

Dry cooling technology for power plant steam condensers is becoming common for new plants constructed in the western U.S. In California, the use of air-cooled condensers is required by the California Energy Commission. The impact on overall plant efficiency is mitigated to some extent by the fact that virtually all new fossil fired power plants in California are combined cycle gas turbine units.

Near term opportunities exist to apply hybrid wet/dry systems. These systems try to take advantage of the relative strengths of dry and wet designs, respectively. Essentially, a hybrid system will operate with an air-cooled condenser for the majority of the year, relying on the wet evaporative cooler during peak ambient temperature periods. While more complex, these systems can save up to 80% of the water that would otherwise be consumed in a wet system over the course of a year.[53] Advances can still be made regarding how to size, apply, and select hybrid system components for specific ambient conditions and cooling loads.

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[53] Brent Barker, "Running Dry at the Power Plant," *EPRI Journal* (Summer 2007).

The development of advanced heat transfer material holds potential for making dry cooling technologies more effective and affordable. The NETL is involved with research into advanced carbon foams, which are being made available through new work in nano-scale material science. Applying laboratory scale work to field prototypes represents the next challenge.

Work is being performed under the NETL by SPX Cooling Systems to evaluate the performance of new proprietary technology that is expected to reduce cooling tower evaporative loses by condensing and reusing a portion of the evaporated water. Concerns to be addressed include seasonal variability in performance, moisture plume, and freezing weather operation. The vendor claims 20% annual water savings are possible within most regions of the continental U.S. Ambient temperature and humidity impact the amount of moisture that can be reclaimed.

Advanced Power Generation Systems

Another approach to water use efficiency focuses on the specific power generation system employed. More efficient systems will inherently require less cooling, and many technologies require no cooling at all. Examples of the water required for various types of power generation systems are illustrated in Figure 7-1. These data consider water withdrawals for use within closed-loop, evaporative cooled plants. It is noteworthy that many renewable generation technologies require large volumes of cooling water, such as solar thermal and biofuel fired boilers.

The use of combined cycle generating facilities reduces the amount of cooling water required per megawatt thanks to the mechanical energy created by the prime mover, generally a combustion turbine. This energy is applied directly to a generator, avoiding the need to generate steam as an intermediate step. To optimize plant efficiency, heat is generally recovered from the combustion turbine exhaust in the form of steam, which can be run through a steam turbine for additional power generation. This steam requires condensing just like any other thermoelectric process, but is a much smaller component of the net power generation than a traditional "steam" plant. Overall, cooling water consumption can be reduced by about two-thirds through the use of a combined cycle process.

Combined cycle plants must operate with clean gas or liquid fuels due to the sensitive nature of combustion turbines. Gasified coal is a suitable fuel for use, but significant water is required in the gasification process for reaction steam, cooling, and cleaning. It is estimated that an integrated coal gasification combined cycle operation would still require about half of the water per megawatt that a standard coal thermoelectric process does.[54]

[54] DOE/NETL-2006/1235

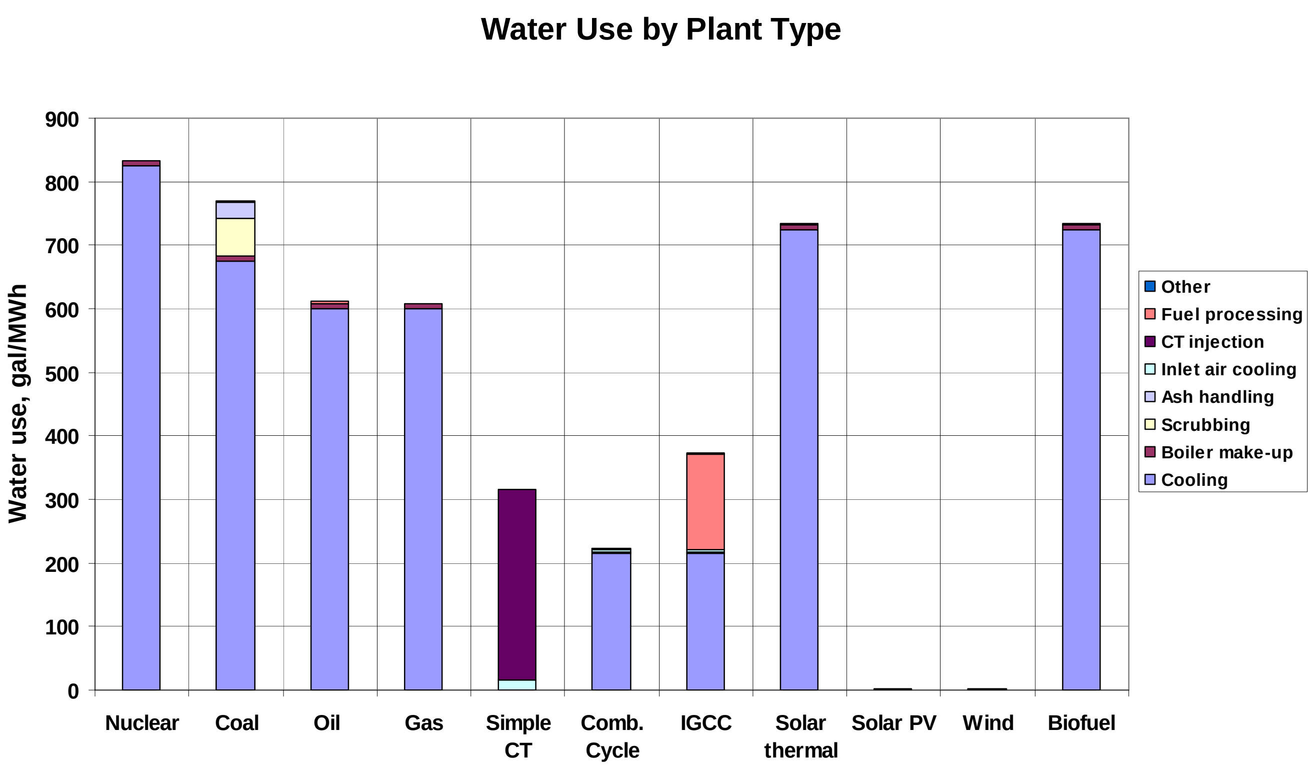

Figure 7-1
Water Use Efficiency for Different Power Generation Plant Types

Source: Goldstein (EPRI), Hightower (Sandia), *Energy/Water Nexus*, presented at EPRI water workshop, Palo Alto, CA, Nov. 14, 2007.

There is also potential for combination steam and ammonia Rankine power cycles for increased efficiency and reduced cooling water needs. The addition of an ammonia based Rankine cycle down stream of the steam cycle can absorb heat from the turbine exit steam as well as from the boiler exhaust gas. Because of the low boiling point of ammonia, the cycle can absorb and utilize much more heat. The additional heat absorbed from the steam reduces the cooling load placed on the steam condenser, and therefore reduces the amount of cooling water required. Additionally, the overall power generation efficiency increases, further improving the ratio of kWh generated to water consumed. Estimate water saving are 60%.[55] The technology also has synergies with flue gas moisture capture, as the ammonia cycle can lower the combustion exhaust gas temperatures below the water vapor dew point.

[55] http://www.wipo.int/pctdb/en/wo.jsp?IA=WO2004067918&DISPLAY=DESC

Distributed Power Generation

The majority of distributed power generation technologies use significantly less water per kWh of production than central generation plants. Solar PV is an excellent example, requiring no water at all, and even fossil fired generators may consume minimal to no water. Consider a combined heat and power application at an institution like a hospital or university. The prime mover would likely be an internal combustion engine or small combustion turbine. The waste heat would be used to heat domestic hot water or to supplement steam production from another boiler. In either case, the generation of power produces no new need for steam, and hence no cooling. Furthermore, emission control on these smaller engines is generally performed via “dry” techniques, meaning there is no water used for inlet air pre-cooling or turbine combustor injection.

A link with water savings could make distributed power generation technologies more appealing in water stressed regions. Factoring in the cost of new water supplies could help overcome the price penalty usually associated with distributed power generation systems. More work needs to be done though to accurately determine the water use benefits and costs attributable to distributed generation.

High Efficiency Appliances and Fixtures

Many common commercial and residential activities require water, from washing linens and dishes, to cleaning food prep surfaces and community areas. The machines and tools that facilitate these activities are regularly being improved by manufactures. Examples include high efficiency commercial dish washers, low flow pre-rinse spray nozzles, and the water-broom. There are great synergies between reducing hot water consumption and saving energy. As such, many water reduction measures have been focused primarily on saving hot water.

The EPA launched the WaterSense program in 2006, which is intended to be the water use efficiency counterpart to the EnergyStar program. Products that comply with the program requirements can receive a WaterSense label. Products in the program are able to:

- Perform as well or better than their less efficient counterparts
- Be about 20% more water efficient than average products in that category
- Realize water savings on a national level
- Provide measurable results
- Be independently certified

The estimated water savings achievements for the initial program are 155 billion gallons on an annualized basis. The long term potential is much greater. For example, if all non-compliant toilets in the U.S. were converted to WaterSense models the savings would be 950 billion gallons per year.[56]

Recent success in this segment has been driven through a combination of demand side incentive programs and new state and federal appliance standards. One limitation though is the fact that products are intended to simply replace less efficient ones (i.e. a toilet). To achieve greater water use efficiency in the future, it will be necessary to develop new appliances that can integrate with more efficient processes. For example, developing clothes washers that can integrate with an automated on-site water reuse system.

Sensors and Controls

Water Quality Monitoring and Control

Monitoring of water quality holds great potential for improving the operating efficiency of water treatment facilities. Most often water is over-treated to ensure that all potential contaminants are addressed, even if they are not actually present in the water. This is an important consideration since multiple treatment processes must be employed to treat different types of impurities. When considering overall energy efficiency, as little amount of treatment processing as possible should be employed.

The goal of research is to make testing for contaminants faster and more accurate at low concentration levels. Much research is looking to find intermediary reactants that can be used as a proxy for measuring the target contaminants. For example, there is a strain of *E. coli* bacterium that emits high levels of potassium when exposed to certain toxins. This bacterium can be intentionally introduced to the water being analyzed to determine if there are toxins present for it to react with. While measuring the trace levels of the toxins in the water is difficult, measuring the level of reactant potassium is not. Virginia Tech University is currently working on this technology.

Another means of detection is to obtain "functional" DNA from an in vitro process that can bond with a target toxin. The DNA can then be "labeled" with nanoparticles that in turn can be detected with a new class of sensor. This technology holds much promise for the detection of metal ions such as lead and uranium. Work conducted in part by Clark Atlanta University developed advanced sensors based upon the analysis of catalytic DNA. Specific technology includes colorimetric DNA biosensors and fluorescent DNA biosensors. The technology holds promise for water treatment process monitoring and control, and also for testing the effectiveness of new advanced treatment technologies.[57]

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[56] James A. Goodrich, "EPA Initiatives To Reduce the Volume of Water and Wastewater That Must be Treated" (presentation, EPRI water workshop, Palo Alto, CA, Nov. 15, 2007).

[57] http://www.watercampws.uiuc.edu/media/uploads/research_posters/wernette_et_al_-_dna_biosensors.20070205.45c7a063e298c6.54566625.pdf

Soil Moisture Monitoring and Control

Monitoring and irrigation controls have received much attention in recent years in the agriculture sector. The ability to keep track in virtual real-time of weather conditions, plant evapotranspiration, and soil conditions enables farmers to better control crop irrigation and to minimize excess water application. Minimizing water use also has a large energy benefit for irrigators who pump from ground water sources and/or utilize pressurized sprinkler irrigation systems. Despite efforts to date, much improvement can still be made.

Ongoing work at Texas A&M University on the science of remote soil moisture sensing uses optics to monitor reflected wavelengths from targeted crop lands. The signature of the wavelengths corresponds to the relative moisture of the soil. Monitoring can be performed via aircraft or satellite. This technique must be calibrated to the specific location and crop type through iteration to optimally correlate the measured wavelengths to the actual soil moisture levels. The technology is limited to monitoring conditions near the surface of the soil and only represents a sample of the current conditions. Time based water dynamics linked to weather patterns and irrigation schedules must be considered by the operator or through a “smart” control system. Nonetheless, remote sensing can be a key low cost component of an advanced irrigation needs model.

The NETL is evaluating three remote sensing technologies with the intent of improving overall watershed management, but these technologies may hold specific benefits for agriculture. These include: thermal infrared (TIR) imagery and two geophysical techniques – electromagnetic (EM) conductivity and very low frequency (VLF) conductivity.

Advanced Controls for Water Infrastructure Management

The adoption of advanced control systems for water and wastewater operations can have multiple benefits. The first is the improved performance of existing utility facilities. Advanced SCADA systems can improve the energy efficiency of water and wastewater utilities quite significantly in many cases. Better controls and monitoring will also help identify and contain system leaks. For many utilities this could reduce system loss by over 10%.

Secondly, the incorporation of advanced communications technology will enable water utilities to monitor and control processes at multiple locations remotely. This will help improve process quality, as system upsets can be identified quicker, and will improve staff productivity, as operators can now monitor multiple operations simultaneously.

Lastly, advanced monitoring and computing power will help enable the adoption of distributed water and wastewater treatment facilities. New, more powerful controls systems will overcome the logistical need to have a central facility based infrastructure. This in turn could translate into additional energy savings. If water and wastewater treatment facilities are strategically located the distance that the water must be distributed will be greatly reduced.

8 RECOMMENDATIONS

The purpose of this project was to identify technology research opportunities where advanced technologies could improve the efficient use of water through water reuse, water reclamation, and water use reduction. Opportunities within five major U.S. market segments were considered. These markets include: Power Generation, Water and Wastewater Utilities, Agriculture, Industrial, and Commercial & Residential. Opportunities were found to be related to either enhanced water and wastewater treatment technologies or to technologies that enhance the efficient use of water by using less for a given process.

The findings contained in this report were based upon an examination of available secondary research information. This included a review of published research studies and reports, a survey of trade journals and conference papers, as well as direct contact with industry experts via the EPRI water workshop and personal communications. Multiple workshop participants have been in contact with the project team to express interest in specific research areas. Additionally, some have offered to explore joint project opportunities with EPRI. These interests were also assessed as part of the review process.

The end result of this review was the generation of recommendations for additional technology research and development contained in this chapter. These recommendations are based upon the potential for market impact and the synergies that exist with EPRI program areas and development capabilities. Recommendations include further research in the following areas:

- Advanced Cooling
- Brackish Water Reclamation
- Advanced Tertiary Filtration
- Distributed Power Generation
- Distributed Water & Wastewater Treatment
- Waste Heat Utilization
- Irrigation Management

The recommendations reflect seven technology-based opportunities that hold exceptional water efficiency potential. Some of the opportunities relate to more than one technology as identified within the recommendations. A focus on technology application opportunities (such as a specific end use, process, or approach) as opposed to just a specific technology was done to establish a context for evaluating the potential benefits and for defining future development project goals. For example, a recommendation is made to pursue advances in the utilization of brackish water. This is an opportunity for desalination technology, but is much more specific and actionable than considering all sources of saline waters. It also establishes more clarity on which specific desalination technologies need to be improved to satisfy the opportunity.

Some opportunities that hold large water efficiency potential were not recommended because they are already the subject of much research attention, or would not realize a significant development boost if EPRI were to become more involved. For example, the application of more efficient agriculture irrigation sprinkler systems has outstanding potential for reducing water consumption. However, advanced technology already exists and the market need relates more to adoption of those technologies than to further technology development needs. On the other hand, it is recommended that EPRI monitor the agriculture sector to determine if EPRI's experience with advanced monitoring and controls could be utilized to help improve irrigation management.

Many recommendations are directed at a specific market segment but will also yield benefits for other segments. For example, advances made in the power generation market to reclaim brackish water sources will also provide technical insights for municipal water and wastewater utilities as well as for large industrial end users.

Table 8-1 outlines the various recommendations and indicates which market segments will benefit from advances in the respective technologies.

Criteria were developed to evaluate the relative importance of the recommended opportunities and related technologies. These considered the potential market impact of the new technology, the time required to develop the new technology, and the need for additional R&D resources. A three-tiered valuation was assigned for each criterion. For example, under market impact, each technology was ranked as either High, Medium, or Low (all of the recommendations happen to have at least a Medium or High rating). Under time horizon, each was rated as either Near, Mid-term, or Long. Lastly, under R&D need, each was rated as either High, Moderate, or Low. Table 8-2 summarizes the criteria evaluation for each recommended technology.

Research opportunities with high R&D needs and a high market impact include:

- Brackish Water Reclamation
  - Advanced Membrane Filtration
  - Electro-deionization
- Distributed Water & Wastewater Treatment
  - Advanced Oxidation
  - Advanced Adsorption
  - Advanced Biological
- Irrigation Management
  - Remote Sensors

Research opportunities with moderate R&D needs and a high market impact include:

- Advanced Cooling
- Distributed Water & Wastewater Treatment
  - Membrane Bioreactors

Table 8-1
Recommended Technologies by Market Segment

Technology		Market Segment				
		Power Gen.	**Water & WW**	**Agric.**	**Industrial**	**Comm. & Res.**
Advanced Cooling	Various	•			•	
Brackish Water Reclamation	Combination of Technologies	•	•			
	Advanced Membrane Filtration	•	•		•	
	Electro-deionization	•	•		•	
Advanced Tertiary Filtration	Electro-filtration		•		•	•
	Advanced Media Materials		•		•	•
	Combo-Technologies		•		•	•
Distributed Generation	Various Power Generation Techs.	•	•	•	•	•
Distributed Water & Wastewater Treatment	Membrane Bioreactors		•		•	•
	Advanced Oxidation		•		•	•
	Advanced Adsorption		•		•	•
	Advanced Biological		•		•	•
	Contaminant Sensors		•		•	•
	Control Systems		•		•	•
Waste Heat Utilization	Low Temp Distillation	•	•		•	
	Advanced Desiccants	•			•	
Irrigation Management	Advanced In-Situ Moisture Sensors			•		
	Remote Sensors			•		

Table 8-2
Criteria Ranking for Recommended Technologies

Technology		Criteria		
		Market Impact	**Time Horizon**	**R&D Need**
Advanced Cooling	Various	High	Near	Moderate
Brackish Water Reclamation	Combination of Technologies	Medium	Near	Moderate
	Advanced Membrane Filtration	High	Long	High
	Electro-deionization	High	Long	High
Advanced Tertiary Treatment	Electro-filtration	Medium	Long	High
	Advanced Media Materials	Medium	Mid-term	Moderate
	Combo-Technologies	Medium	Near	Low
Distributed Generation	Various Power Generation Techs.	Medium	Near	Low
Distributed Water & Wastewater Treatment	Membrane Bioreactors	High	Mid-term	Moderate
	Advanced Oxidation	High	Long	High
	Advanced Adsorption	High	Long	High
	Advanced Biological	High	Long	High
	Contaminant Sensors	Medium	Long	High
	Control Systems	High	Near	Low
Waste Heat Utilization	Low Temp Distillation	Medium	Mid-term	Moderate
	Advanced Desiccants	Medium	Long	Moderate
Irrigation Management	Advanced In-Situ Moisture Sensors	Medium	Mid-term	Moderate
	Remote Sensors	High	Mid-term	High

Some opportunities do not require significant R&D and/or have a high market impact, but are still worth considering by EPRI. For example, the application of distributed power generation technologies is recommended. Commercial DG technologies already exist, but the water efficiency benefits have not yet been valued into the technology's benefit/cost equations. EPRI is in a unique position to lead the industry in the development of new guidelines and practices to reap the water efficiency benefits of the technology.

As a final exercise, EPRI's future role in support of the recommended technologies was considered. Based upon EPRI's experience with the specific technology, other players involved with the technology, and the relative importance of the technology, one of four "roles" are recommended for EPRI. The roles are defined as:

Observer – Monitor technology developments, attend related conferences, and look for opportunities to utilize technology within current program areas.

Participant – Pursue an active role in support of industry research and information exchange.

Partner – Work with one of more leading technology or market actors to aggressively pursue the development and market acceptance of the new technology.

Leader – Commit to being the industry champion for the new technology.

The recommended EPRI role for each technology is summarized in Table 8-3.

Table 8-3
Recommended EPRI Role for the Development of Technologies

Technology		EPRI Role			
		Observer	**Participant**	**Partner**	**Leader**
Advanced Cooling	Various			•	
Brackish Water Reclamation	Combination of Technologies			•	
	Advanced Membrane Filtration		•		
	Electro-deionization		•		
Advanced Tertiary Treatment	Electro-filtration		•		
	Advanced Media Materials		•		
	Combo-Technologies		•		
Distributed Generation	Various Power Generation Techs.				•
Distributed Water & Wastewater Treatment	Membrane Bioreactors		•		
	Advanced Oxidation		•		
	Advanced Adsorption		•		
	Advanced Biological		•		
	Contaminant Sensors	•			
	Control Systems	•			
Waste Heat Utilization	Low Temp Distillation			•	
	Advanced Desiccants		•		
Irrigation Management	Advanced In-Situ Moisture Sensors	•			
	Remote Sensors	•			

A review of each recommendation is included below, along with specific suggestions for next step activities.

Advanced Cooling

A large Energy-Water Nexus initiative is already underway through the U.S. DOE, the NETL, Sandia Nation Laboratories, and several other organizations, including EPRI.[58] It is highly recommended that EPRI continue to participate in this program, which aims to develop and promote new opportunities for water efficiency within the energy market in general, and new advanced cooling technologies in particular.

Near term opportunities exist through the application of current dry and hybrid cooling technology, while even greater long term benefits exist if new cooling technologies can be developed. Opportunities for technology demonstrations abound, and should be pursued.

In addition to being an active partner for specific project opportunities that grow out of the Energy-Water Nexus program, it is recommended that EPRI also monitor the industrial market segment for opportunities to introduce advanced cooling technologies developed through the power segment.

Next Steps

- Conduct advanced cooling technology demonstration projects.

Brackish Water Reclamation

Brackish water sources exist throughout the U.S. These occur at the confluence of freshwater streams and the ocean, near inland bodies of water, and within many groundwater sources. Opportunities exist to significantly advance the desalination market by focusing on near term success through the implementation of brackish water treatment projects. The lower salinity levels found in brackish water will make such projects technically less challenging and economically more cost effective than ocean desalination. Widespread adoption of brackish water treatment technology will also provide a proving grounds for more advanced desalination technologies.

The utilization of inland brackish water is a largely untapped opportunity, which holds the potential to address multiple concerns. Inland power plants are not near the ocean, and have limited options for once-through, as well as limited supplies of water for evaporative cooling. Similarly, any discharge streams are a challenge to dispose of. Most current systems must pipe brine concentrate to the ocean, requiring long distance piping and high pumping costs. Therefore, technology that will enable the use of brackish water and will help manage the brine concentrate would be very valuable.

[58] http://www.sandia.gov/energy-water/

The power generation segment has the opportunity to lead the development of advanced water reclamation applications. The potential market impact is huge in the power generation segment alone. Lessons learned could easily be applied to the water and wastewater market as well as the industrial segment. The great need for cooling water and the size of power plants provide economies of scale unavailable in most markets.

Displacing a small amount of current freshwater consumption with reclaimed water will have a major impact. If proven viable, the consumption of reclaimed water will not only provide an alternative to freshwater, but will also help enable and encourage the switch from once-through cooling to evaporative cooling by ensuring that water supplies are available.

Water reclamation presents both near and long term technology needs. Current technology may be applied in innovative combinations that could produce very cost effective results. Examples presented by Carollo Engineers at the EPRI workshop illustrate how reverse osmosis, chemical precipitation, filtration, and ion exchange can collectively produce more efficient desalination systems than the individual technologies can achieve on their own. Long term developments in specific technologies, such as advanced membranes for ion separation, and advanced electro-deionization techniques will provide much less energy intensive tools for desalination system integrators.

It is recommended that partnership opportunities be pursued to support the demonstration of innovative combination technology processes. Interested parties would include hardware manufactures, system integrators, government agencies (such as the EPA and Bureau of Reclamation), and end users found in the power generation and water utility segments. Longer term participation in technology research is recommended for techniques aimed at more efficiently de-ionizing (i.e. desalting) water.

It is recommended that efforts to utilize brackish water be coordinated between the power generation and water utility markets. Opportunities exist for partnerships to help develop and fund new technologies and practices. One potential outcome could entail the use of waste heat from power plants to drive thermal distillation processes. The resultant water could be sold as a wholesale water supply to a regional water utility.

Next Steps

- Conduct brackish water reclamation combination-technology demonstration projects.
- Pursue research involvement in advanced membrane technology for deionization. Conduct a scoping study to determine specific technology R&D needs.
- Pursue research involvement in electro-deionization technology. Conduct a scoping study to determine specific technology R&D needs.

Advanced Tertiary Filtration

Existing separation technology, such as cartridge filters and sand filters can meet tertiary treatment levels in wastewater effluent, but capital cost and operating cost limit adoption. Opportunities exist to improve the economics of tertiary filtration, which would then increase the viability of water reuse. Urban reuse will typically require suspended solids levels in the effluent to be reduced below 4 mg/l. Filters should be capable of capturing particles in sizes down to 5 microns. Electrofiltration, advanced filter media such as styfofoam and plastics, and combination technologies should be pursued through support of demonstration projects and technology research.

Advanced filtration technologies will complement current wastewater effluent reuse programs in the water and wastewater utility segment. The technologies will also support more cost effective water reuse within the industrial segment. In the commercial and residential market, scaled down technology could find its way into appliances like clothes washers with built-in greywater reuse cycles.

Next Steps

- Pursue research involvement in advanced tertiary filtration. Conduct a scoping study to determine specific technology R&D needs.

Distributed Power Generation

A growing market that EPRI is already involved with is distributed power generation. Distributed Generation (DG) technologies already have well document potential for addressing environmental needs as well as helping to address grid management issues. The water use efficiency benefits associated with DG are also quite significant and should be factored in to the overall value of the technologies.

Properly valuing the water savings linked to DG could increase the cost effectiveness of individual technologies, making the difference between a viable and unviable project. At the macro level, water use efficiency benefits could greatly accelerate market transformation for DG. It is recommended that EPRI seek to quantify the water savings linked to DG and to educate the industry regarding these benefits.

Synergies exist between distributed power generation and distributed water treatment technologies. Just as efficiency gains exist for DG, so do water efficiencies for distributed water treatment. Additionally, distributed water treatment technologies will also tend to be more energy efficient. Projects that employ distributed water treatment will also be inclined to pursue distributed power generation as part of larger “sustainability” goals. Therefore, the availability of affordable DG technologies can serve as a market complement to help encourage the distributed water treatment industry.

Next Steps

- Conduct a study to research and present the links between distributed power generation and water use.

Distributed Water & Wastewater Treatment

Distributed water and wastewater treatment holds outstanding potential for on-site water reuse, and also provides synergies with other environmentally positive initiatives. On-site water and wastewater treatment is a very attractive component to include within new "sustainable" developments. Distributed treatment also complements distributed power generation as both a source, through bio-generated power, and a use for the electricity.

Benefits and synergies of distributed treatment include:

- Final treatment of water can be performed at the local level. Only the water that will be used for potable purposes will need to be treated to high quality levels, reducing overall water treatment requirements.
- Potable water can also be of higher quality. The water will not be subject to potential degradation within a lengthy distribution system, and it will be more practical to treat smaller quantities of water to higher quality levels.
- Distributed wastewater treatment can incorporate systems to segregate wastewater. This will enable efficient processes to be employed for greywater reuse and will enable concentrated streams of organic material to be fed to digesters for local bio-gas production. This in turn will support distributed power generation.
- Distribute water and wastewater treatment can be applied strategically to complement existing utility infrastructures. Distribute technologies can help address demand growth and also improve reliability. Treatment costs associated with serving remote locations can be reduced by lowering the output quality requirements from the central plant. On-site water reuse will also reduce the demand for freshwater from the water utility as well as the resulting sewage flow sent to the wastewater utility. Furthermore, on-site wastewater treatment will reduce the organic levels in the wastewater that is finally discharged to the wastewater utility, further reducing treatment requirements.

Near term opportunities exist for demonstration projects that utilize current technologies. Such projects would address the optimal combination of technologies and processes to maximize performance for the specific end use application. New multifamily housing projects or small single family home developments would be ideal candidates.

Long term research needs exist to ensure new advanced technologies are developed that will further enhance distributed treatment processes and improve overall water use and energy efficiencies. Key technologies include membrane bioreactors, advanced oxidation, advanced adsorption, advanced biological treatment, contaminant sensors, and control systems.

Next Steps

- Pursue research involvement with membrane bioreactors, advanced oxidation, advanced adsorption, and advanced biological treatment. Conduct a scoping study to determine specific technology R&D needs.
- Investigate technology developments and market needs related to contaminant sensors to identify opportunities for participation.
- Investigate technology developments and market needs related to control systems to identify opportunities for participation.

Waste Heat Utilization

The power generation segment produces vast amounts of waste heat. According to the *U.S. Energy Flow Trends-2002* prepared by Lawrence Livermore National Laboratory, about 34.7 Quads of thermal energy is consumed for power generation within the U.S., or about 36% of total fuel use. Greater than 50% of this energy is lost on-site in the form of waste heat. Technologies, such as thermal distillation, that can utilize this heat for water purification would provide a very affordable means for water reclamation and reuse.

Thermal distillation also has synergies within the industrial segment. The distillation process could be used to treat on-site process water for reuse or for water reclamation. Even industries such as petro-chemical and pulp and paper that already aggressively pursue on-site water reuse could still benefit from better waste heat recovery.

Specific technologies to pursue include:

Low Temperature Distillation – Several processes are under development that utilize heat to simply help evaporate water, as opposed to boiling it, and then re-condense the vapor. Advanced heat exchanger designs and new membrane technologies are playing a role.

Advanced Desiccants – Transferring moisture through the use of desiccants is a technique that has been used in the HVAC industry for years. Advances in material design could make the technology applicable for the production of distilled water. Desiccants can capture moisture in power generation and industrial plant exhaust and use process waste heat to separate and capture the vapor. Technology developments could feedback benefits into the commercial HVAC market.

Next Steps

- Conduct demonstration projects of low temperature distillation technologies.
- Conduct a study to determine the technical potential for advanced desiccants.

Irrigation Management

At 40% of U.S. freshwater withdrawals and 80% of net water consumption, irrigation in the agriculture sector represents one of the greatest opportunities for water savings. Water application technologies (i.e. sprinklers) are already achieving relatively high efficiencies, although low market penetration is still an issue. Recommendations for EPRI involvement are directed at improving monitoring and controls for irrigation management. Great sprinkler systems can not prevent a user from applying too much water or irrigating at non-optimal times. New technologies that enable farmers to precisely discern the irrigation needs of their crops will produce direct water use reductions.

Direct crop moisture monitoring through in-situ sensors represents significant opportunities but also great technical challenges. Building on previous stem water potential and trunk diameter shrinkage work can lead to more precise and timelier feedback on crop water needs. This will avoid irrigating before it is necessary and will reduce over-irrigation.

Work on remote soil monitoring seeks to find a reliable proxy for crop moisture levels. Such technology can save on the cost of local hardware requirements, and one system could serve the needs of many end users. New technologies could better leverage the capabilities of internet protocols and network computing power. Monitoring data from multiple sensors and sources can be integrated and utilized within a “smart” control system. Information on past and forecasted weather patterns, soil conditions, crop conditions, availability and price of irrigation water and energy, and many other factors can all be considered when determining irrigation requirements.

Next Steps

- Investigate developments in the agriculture irrigation sector related to in-situ and remote soil moisture monitoring technology to identify opportunities for participation.

9
REFERENCES

American Petroleum Institute. *Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States*. Prepared by ICF Consulting. Washington, DC, May 2000.

Barker, Brent. "Running Dry at the Power Plant." *EPRI Journal* (Summer 2007): 26-35.

California Department of Water Resources. *Water Desalination: Findings and Recommendations*, by Charles F. Keene. Sacramento, CA, October 2003.

California Energy Commission. *California's Water-Energy Relationship*. CEC-700-2005-011-SF. Sacramento, CA, November 2005.

California Energy Commission. *Energy-Efficient Process for Using Membrane Technology to Treat and Recycle Agricultural Drainage Water*. Prepared by WaterTech Partners by Ronald J. Enzweiler. CEC-500-2005-092. Moraga, CA, May 2005.

California Energy Commission. *Refining Estimates of Water-Related Energy Use in California*. Prepared by Navigant Consulting, Inc. CEC-500-2006-118. Sacramento, CA, December 2006.

California Energy Commission. *Technology Roadmap: Water Use Efficiency in California Agriculture*. Prepared by California Polytechnic State University, Irrigation Training and Research Center, by Charles Burt. CEC-400-2005-002. December 2004.

California Energy Commission and EPRI. *Emerging Environmental Technologies: An Analysis of New Treatment Technologies for the California Energy Commission*. Prepared by Global Energy Partners. 1007411. Sacramento and Palo Alto, CA, May 2003.

California Energy Commission and EPRI. *Use of Degraded Water Sources as Cooling Water in Power Plants*. Prepared by MND Consulting. 1005359. Sacramento and Palo Alto, CA, 2003.

Cohen, Ronnie, Barry Nelson, and Gary Wolff. *Energy Down the Drain: The Hidden Costs of California's Water Supply*. Oakland, CA: Natural Resources Defense Council and Pacific Institute, August 2004.

Cooley, Heather, Peter H. Gleick, and Gary Wolff. *Desalination, with a Grain of Salt: A California Perspective*. Oakland, CA: Pacific Institute, June 2006.

Electric Power Research Institute (EPRI). *Water & Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply & Treatment: The Next Half Century*. Prepared by ICF Consulting. 1006787. Palo Alto, CA, March 2002.

Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katherine Kao Cushing, and Amardip Mann. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Oakland, CA: Pacific Institute, 2003.

Global Energy Partners, LLC. *Membrane Treatment Technologies for Water Treatment and Reuse*. (Technical Review). Lafayette, CA: December 2006.

Global Energy Partners, LLC. *Novel Industrial Electrotechnologies for Water and Wastewater Treatment*. (Technical Review). Lafayette, CA: April 2006.

Hightower, Mike. "At the Crossroads: Energy Demand for Water Versus Water Availability." *Southwest Hydrology*, May/June 2007.

Means, Edward. *Water and Wastewater Industry Energy Efficiency: A Research Roadmap*. Denver: Awwa Research Foundation, 2004.

Seneviratne, Mohan. *A Practical Approach to Water Conservation for Commercial and Industrial Facilities*. Oxford: Elsevier Ltd., 2007.

U.S. Department of Agriculture. *Farm and Ranch Irrigation Survey (2003)*. Vol. 3. AC-02-SS-1. November 2004.

U.S. Department of Energy. *Energy Demands On Water Resources: Report to Congress On the Interdependency of Energy and Water*. December 2006.

U.S. Department of Energy. Energy Information Administration. *Annual Energy Outlook 2007: With Projections to 2030*. DOE/EIA-0383. February 2007.

U.S. Department of Energy. Energy Information Administration. *Annual Energy Review 2006*. DOE/EIA-0384. June 2007.

U.S. Department of Energy. National Energy Technology Laboratory. *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*. (DOE/NETL-2006/1235). Prepared by Research and Development Solutions, LLC, by Gary J. Stiegel, Jr. et al. August 2006.

U.S. Department of the Interior. *Estimated Use of Water in the United States in 2000*, by Susan S. Hutson et al. U.S. Geological Survey Circular 1268. Reston, VA, 2004.

U.S. Department of the Interior. *Ground-Water Depletion Across the Nation*, by J.R. Bartolino and W.L. Cunningham. U.S. Geological Survey Fact Sheet-103-03. November 2003.

U.S. Department of the Interior. Bureau of Reclamation. *Desalination and Water Purification Technology Roadmap*. Prepared in cooperation with Sandia National Laboratories. Denver, January, 2003.

U.S. Environmental Protection Agency. *Clean Watersheds Needs Survey 2004: Report to Congress*. January 2008.

U.S. Environmental Protection Agency and U.S. Agency for International Development. *Guideline for Water Reuse*. EPA/625/R-04/108. Washington, DC, September 2004.

Westerhoff, Paul. "Removal of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products During Water Treatment." *Southwest Hydrology*, November/December 2003.

A

OVERVIEW OF COMMON WATER TREATMENT TECHNOLOGIES

Separation

This is a very broad category that entails physically separating impurities from the treated water. Large particulate matter can be removed by screening, while fine suspended solids and dissolved compounds can be removed through chemical reaction that induces coagulation or precipitation. This category would also include flocculation, sedimentation, flotation, settling, skimming, and centrifugation. Separation is generally a first step in water treatment.

Separation processes are the primary means of reducing water turbidity. Oil and greases are generally removed early in the process via floatation and skimming techniques. Heavy metals and nitrates can also be addressed through chemical precipitation and settling.

Filtration

Filtration could be considered a very fine form of separation, since the filter media is intended to physically remove impurities. However, filtration is intended to remove very small impurities that remain after the separation process. Various filtration technologies can target very fine particles such as sand and silt, microscopic particles such as bacteria and algae, molecular constituents such as viruses and acids, and even ionic impurities such as salts and metals. The costs associated with filtration greatly increase as the targeted impurities decrease in size. Example technologies include sand filters, cartridge filtration, online filtration, and membrane filtration. As illustrated in Figure A-1, filtration membranes are in turn classified by their pore size, placing them in the subcategories of micro-filtration, ultra-filtration, nano-filtration, and reverse osmosis.

Filtration processes can remove virtually all water impurities when properly applied. Fouling is a common problem, so impurities usually need to be removed in stages such that any one filtration media is not overwhelmed. For example, if reverse osmosis is being used for ocean water desalination, the water should be run first through at least a conventional filtration process to ensure the proper function and longevity of the system. Despite the impressive results achievable through filtration, there are large energy costs associated with pressurizing the water to the required process levels. As depicted in Table A-1, the pressure and energy requirements greatly increase with finer filtration. One of the main goals of membrane filtration research is to devise a means to achieve cost effective desalination processes.

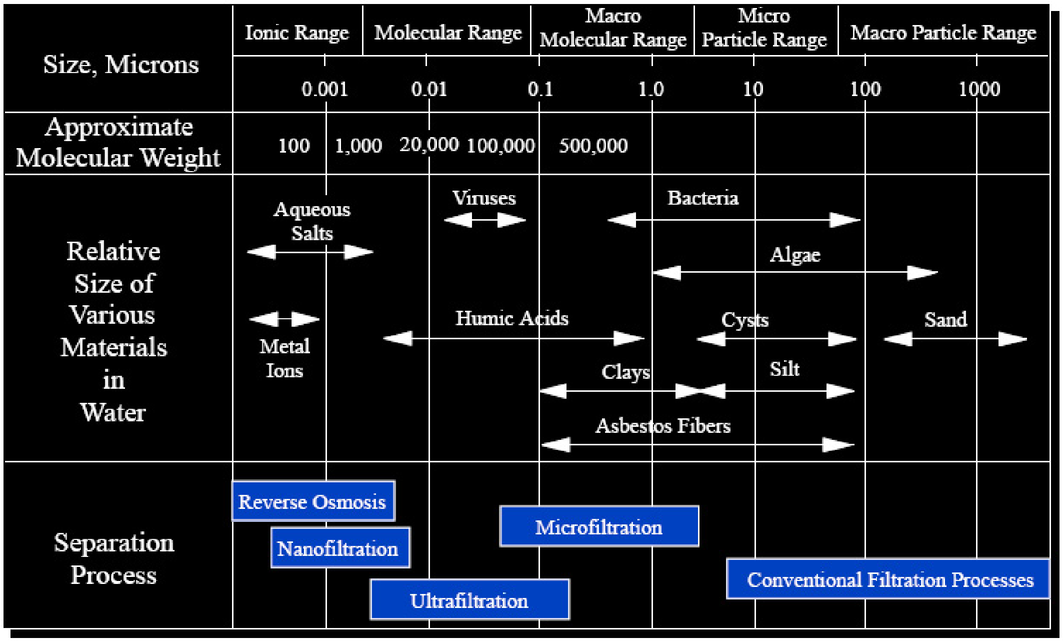

Figure A-1
Relative Size of Particles Removed by Membrane Processes

Source: EPRI, *The Desalting and Water Treatment Membrane Manual*, 1999

Table A-1
Pressure and Energy Requirements for Membrane Filtration Processes[59]

Membrane Process	Typical Operating Pressure (psi)	Typical Energy Use (kWh/MG)
Microfiltration	3-30	100
Ultrafiltration	5-75	800
Nanofiltration	50-150	1,400
Reverse Osmosis	125-1,200	2,700-12,300
R.O. pressure depends on feed water quality; the greater the salt content, the higher the pressure.		

Evaporation

Evaporating moisture from contaminated water and subsequently re-condensing the distilled water is a very old and generally inefficient technology. However, variations on thermal based distillation that utilize waste heat have received attention in recent years. Mechanical vapor compression has also been used to condense water, but has yet to be proven economically viable for large scale water reuse.

[59] Global Energy Partners, *Technical Update: Advanced Membranes in Water and Wastewater Treatment*, 2005

Adsorption

This technique traps organics that may escape other treatment processes by bonding them to an inert media. Activated carbon filters are the most common example of this technology, although other inorganic media are available. The arrangement of the media can vary, from simple granules in bulk volume, to filtration fibers coated with the media. Adsorption is often used as a final step to polish water prior to use. Over time the media loses its effectiveness as its surface area fills with bonded impurities. Adsorption systems require periodic replacement or regeneration of the media, which presents additional operating costs.

Adsorption is regularly used to remove volatile organic chemicals as well as pesticides and herbicides. Activated carbon is also an excellent means of reducing unpleasant odor and taste in drinking water.

Deionization

This category includes ion exchange as well as ion removal techniques. With ion exchange, water for treatment is passed through a resin bed. The resin is initially charged with inert ions, generally salt, that exchange places with the target ions, often calcium and magnesium, in the water. The target ions are then retained on the resin. As with adsorption medias, ion exchange resins must periodically be recharged or replaced.

Removal of ions can be achieved through electrodeionization wherein a combination of electric charge, selective membranes, and electrode surfaces drive the separation and capture of target cations and anions. Electrodialysis is a mature technology that uses selective membranes that enable one-way passage respectively for anions and cations. Energy intensity and membrane costs tend to be high. Many electrodeinonization technologies exist with variations on membrane and electrode design. Much research is currently being conducted in this field. Newer technology eliminates the need for membranes and relies upon advanced electrode materials to attract and retain the ions.

Filtration processes like reverse osmosis can also be considered a deionization process. As with filtration research, much deionization work is focused on the opportunities for advanced ocean water desalination technologies.

Biological Treatment

Utilizing the ability of naturally occurring microbes to degrade organic mater is a common practice for treating water and wastewater. Many inorganic compounds are also biodegradable. Common techniques use aerobic digestion, anaerobic digestion, or a combination of the two. Supplying adequate oxygen through aeration to support oxidation is the key for aerobic digestion. Anaerobic digestion occurs in the absence of oxygen and produces many byproduct gases such as methane. Anaerobic digestion is often utilized for biogas production.

Opportunities also exist to mimic natural microbes by engineering man-made custom enzymes for specific water treatment needs.

Nutrients such as nitrogen and phosphorus, while not organic material, can also be reacted in biological processes that convert them into separable solids. New processes are being developed to also treat nitrates and perchlorates in groundwater.

Membrane bioreactors represent a hybrid treatment technique that combines the use of micro- or ultra-filtration within an aerobic process tank. In addition to the joint benefits of biological and membrane filtration treatment, membrane bioreactors are also effective at removing oil and grease.

Advanced Oxidation

Similar to aerobic digestion, this technique degrades organic material by encouraging the chemical oxidation of the target impurity's molecules. Unlike aerobic digestion, advanced oxidation techniques generally entail injecting ozone or hydroxyl radicals into the water being treated. Conversely, ozone or hydroxyl radicals can be generated within the water by an external energy source such as UV light, electron beams, gamma radiation, or soft X-rays. A common technique is photocatalysis in which UV light is applied to a metal oxide catalyst, such as TiO_2, to produce the hydroxyl radicals. New technologies are being developed that will enable visible light to be used instead of UV.

Advanced oxidation techniques are generally used for treating target organics, and are not intended to remove all the biodegradable material in the water. The technique is often used as a means of disinfection when targeting specific pathogens after the water has already been treated to relatively high purity levels.

Disinfection

The goal of disinfection is to destroy, debilitate, or remove pathogenic microorganisms. This is achieved by killing the organism, preventing its development, or impeding its reproduction. Water disinfection can be achieved through chemical or physical means. The most common form of chemical disinfection is the use of chlorine within municipal water systems. Physical means include heat, pressure, acoustics, electronic radiation, gamma rays, and ultraviolet light.[60]

[60] http://www.lenntech.com/water-disinfection/what-is-water-disinfection.htm

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