WATER AND EMBEDDED ENERGY CONSERVATION IN THE INDUSTRIAL SECTOR – POTENTIALS AND CASE STUDIES

Alexander Trueblood, P.E.
Mechanical Engineer
BASE Energy, Inc.
San Francisco, CA

Sandra Chow, P.E.
Senior Mechanical Engineer
BASE Energy, Inc.
San Francisco, CA

Mark Ritchie, P.E.
Mechanical Engineer
BASE Energy, Inc.
San Francisco, CA

Ahmad R. Ganji, Ph.D., P.E.
Professor
San Francisco State University
San Francisco, CA

Industrial Energy Technology Conference 2015
New Orleans, LA
June 2-5, 2015

ABSTRACT

There is a rising national and statewide concern in the relationship between energy and water usage, especially in California. The drought in California has resulted in more focused attention to water savings and the associated embedded energy savings.

California's industrial sector uses slightly over 1% of water in the state. Many industrial processes, in particular food processing, are quite water intensive. The sources of excessive water use are poorly maintained equipment, cleaning processes, product conveyance systems, cooling systems, heating systems, single-pass cooling, and other special processes.

This paper discusses several water savings measures for various end-uses of water, the relative amount of water savings, and examples of simple payback periods for these measures. Methodologies for estimating the energy savings associated with water savings, cost savings, and simple payback periods are presented. Case studies of successfully implemented water savings projects are presented.

BACKGROUND

There is a rising national concern about water usage and the sustainability of current industrial water use practices. Drought conditions, especially prevalent in California in 2015, highlight the issues of groundwater overdraft and wasteful usage in the industrial sector. Water conservation is the most cost effective method for maintaining sustainable, low-risk practices for an environmentally friendly and profitable business.

The energy associated with water pumping in industrial facilities constitutes a majority of overall water embedded energy, although the industrial sector only consumes about 5% of the total water usage in the United States. According to the California Energy Commission (CEC), the urban sector (all end uses excluding agricultural and power generation) represents 70% of the water related energy usage in California for only 20% of the water usage (Gellings and Goldstein 2008). The water-related energy usage in the industrial sector is much higher because industrial users need to treat both the consumed fresh water and generated wastewater, in addition to heating or cooling the water immediately prior to use. This paper will discuss the background on water usage, how water is used in industrial facilities, the opportunities and specific measures for water conservation, case studies for successful water and embedded energy conservation projects, and conclusions about the overall feasibility of water conservation in the industrial sector.

Figure 1 shows a comparison of the sector fresh water usage for both the United States and California (Maupin et al. 2014). According to this figure, the majority of fresh water is used in irrigation and thermoelectric power generation for the United States and irrigation for California. Water usage intensity for electrical power generation was 13.64 gallon per generated kWh for the United States and 0.28 gallon per generated kWh for California (Maupin et al. 2014). Thus, water is indirectly conserved for every energy efficiency action. Power generation facilities that used single-pass cooling systems accounted for 92% of all fresh water withdrawals in the United States (Maupin et al. 2014). Single-pass water systems return nearly all the water to the source, which can be reused, while recirculating water systems consume water through evaporation (Dorjets 2015).

Fresh water can be withdrawn from either surface sources, such as rivers, lakes, and canals, or groundwater. The energy intensity of this water depends greatly on the source, with groundwater being the most energy intensive water supply. Groundwater withdrawals for the industrial sector are 399 million gallons per day and 2,900 million gallons per day in California and the United States, respectively (Maupin et al. 2014). Surface water

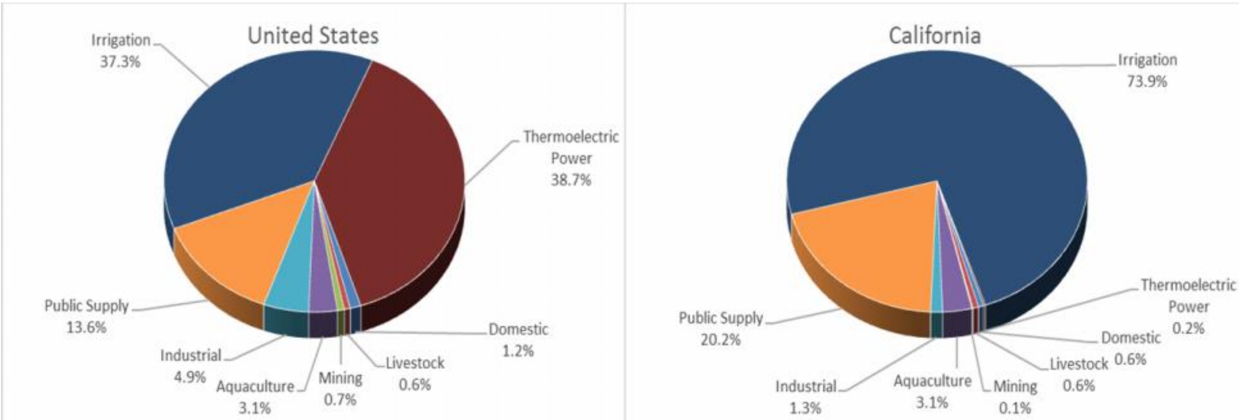

Figure 1. Comparison of Overall Water Withdrawals for the United States and California

withdrawals are 1.1 million gallons per day and 12,100 million gallons per day in California and the United States, respectively (Maupin et al. 2014). For industrial facilities, groundwater withdrawals were 99.8% of all fresh water usage in California and 19.3% of all fresh water usage in the United States (Maupin et al. 2014).

There was a severe drought in the United States in September 2012, where 64.8% of the nation's area experienced moderate to severe drought conditions (NDMC 2015). Drought conditions are reoccuring in more recent times; by the end of March 2015, 36.8% of the United States area experienced moderate to exceptional drought conditions, slightly higher than the 35.9% for March of 2012 (NDMC 2015). This data shows that throughout the nation, water conservation is a critical component of maintaining efficient and sustainable production of goods.

There is not much agreement in literature for the energy intensities of water processes, mainly due to the large diversity in operating conditions. Generally, the energy intensity of surface water supplies is 1,400 – 1,500 kWh per million gallons, while the energy intensity of groundwater supplies is 1,824 kWh per million gallons (ICF International 2008). The California Public Utilities Commission (CPUC) uses an overall water energy intensity of 9,977 kWh per million gallons for quantifying the electrical energy savings due to water savings (CSUCSP 2011). The actual energy intensity of industrial water usage depends greatly on the processes that the water undergoes before and after it is used inside an industrial plant. Table 1 summarizes various water processes and the ranges of energy intensities for each process (GEI and Navigant 2010).

INDUSTRIAL PROCESSES

Major industrial water using processes include conveying, cleaning, cooling, and heating. These end-uses will be discussed in this section, while the conservation measures for each end-use will be discussed in the following section.

Conveying

Several fruit and vegetable industries use water to convey the product from the truck unloading stations into the processing plant. The product is conveyed through flumes, or artificial open channel systems that simultaneously wash and move the product. Generally, the flume systems are arranged in multiple

Table 1. Water Embedded Energy Intensities for Various Processes

Category	Minimum (kWh/million gal)	Maximum (kWh/million gal)
Ground Water	790	3,753
Raw Water Conveyance	2	1,704
Water Distribution	37	1,524
Water Treatment	43	6,666
Wastewater Pumps	2	497
Wastewater Treatment	923	4,941
Recycled Water Treatment	984	3,771
Recycled Water Distribution	210	1,304
Desalination	3,819	3,945

stages, which can either be individually supplied with water or have water cascaded between the flumes. The last stage of product flow is generally the cleanest, and may be chlorinated for disinfection prior to usage.

Cleaning and Rinsing

Nearly every industry produces waste that must be disposed of to prevent accumulation and bacterial infection. This waste can be found on the plant floor, the surfaces of equipment, and inside product conveyance pipes or flumes. The most common method for disposing this waste is washing it into a disposal channel, where the waste is conveyed to an on-site wastewater treatment system or a municipal sewer line.

Many cleaning processes will need water that is heated or chemically treated. Water savings measures in the cleaning and rinsing end-use category can save significant costs in fuel for heating or chemicals for disinfection.

Cooling

Water is used in cooling towers and single-pass cooling systems. Cooling water usage comprises a significant portion of total facility water usage in the meat processing, dairy processing, preserved fruits and vegetables processing, high tech, and petroleum refining industries.

For wet cooling towers (direct contact between cooling water and air), the greatest water consumption processes are evaporation, blowdown, and drift. As water contacts dry air (less than 100% relative humidity), some water is evaporated and heat is removed from the cooling water. Evaporation is directly tied to heat transfer. Cooling tower blowdown is needed to prevent scaling and fouling on the heat transfer surfaces. Drift is caused by uncontrolled water droplets being removed by the air stream.

Single-pass cooling systems take water directly from the source (groundwater, surface water, or municipal pipes) and provide cooling to a process before being discharged. Water that is discharged directly into the sewer system can be a significant source of waste.

Heating

Water is used in steam and hot water boiler systems. Hot water and steam can be used for various applications in an industrial setting, including space heating, cleaning, sterilization, power generation, product cooking, meat processing scalding, and other applications. Water can be lost in the systems through steam leaks, condensate drains that are not returned, blowdown in the boiler, and excessive cleaning operations.

OPPORTUNITIES IN WATER CONSERVATION

There are several key components to water conservation: the types of projects to implement, the analysis methods for quantifying their effectiveness, the relative savings for each measure, the financial implications of each measure, as well as other concerns that factor into whether a measure will be implemented. This section will discuss water conservation measures for each industrial end-use category, as well as water recovery measures from wastewater or product water. Additionally, relative water savings and simple payback periods will be presented for the measures where applicable. Tables 2a and 2b summarize the potential water savings by industry (Gleick et al. 2003).

Table 2a. Summary of Water Savings Potential by Industry

Industry	***Meat Processing***		***Dairy Processing***		***Preserved Fruit/Vege***		***Beverages***	
Category	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***
Process	58%	25%	23%	25%	73%	25%	45%	27%
Cooling	33%	26%	71%	26%	22%	26%	5%	26%
Boiler								
Consumptive							46%	0%
Restroom	8%	49%	3%	49%			3%	49%
Landscaping	1%	50%	3%	50%	3%	50%		
Kitchen								
Other					2%	10%	1%	10%

*The water savings potential is presented as a percent of the relevant category total use, not the facility total use.

Table 2b. Summary of Water Savings Potential by Industry

Industry	*Textile*		*Fabricated Metals*		*High Tech*		*Petroleum Refining*	
Category	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***	**Percent Of Total Facility Usage**	**Water Savings Potential***
Process	90%	39%	67%	33%	70%	43%	6%	0%
Cooling	5%	26%	15%	26%	20%	26%	57%	80%
Boiler							34%	80%
Consumptive								
Restroom					5%	49%		
Landscaping								
Kitchen			1%	20%				
Other	5%	49%	17%	50%	5%	10%	3%	40%

*The water savings potential is presented as a percent of the relevant category total use, not the facility total use.

Water conservation measures have been divided into various end-use processes: (1) general maintenance practices, (2) conveying, cleaning, and rinsing systems, (3) cooling systems, (4) heating systems, and (5) general process and wastewater management. This should aid facility managers with finding specific measures relevant to processes at their plant.

Water Conservation Measures – Maintenance

This section will discuss the water conservation measures that focus on achieving water conservation through persistent equipment maintenance programs.

Repair Water Leaks

Valves, hoses, and water storage tanks can all spring leaks due to normal wear and tear. Implementing a maintenance program to repair these leaks can significantly reduce the amount of fresh water that a facility purchases from the city or pumps from the aquifer. For a typical case, repairing water leaks could save approximately 0.7% of a facility's water consumption (BASE 2015).

Maintain Steam Traps

Facilities that utilize steam systems have steam traps that periodically fail. If these traps are not maintained effectively and proactively, the number of failed traps can grow and leak significant amounts of steam and condensate. Repairing failed steam traps can save approximately 20% of the boiler system's total steam production (FEMP 1999). There will also be a significant amount of fuel savings from the boiler system, and an example simple payback period for this measure can be as low as 0.5 years (BASE 2015).

Water Conservation Measures – Conveying, Cleaning and Rinsing

This section will discuss measures that center around product conveyance systems, as well as technological or behavioral improvements to the existing cleaning and rinsing practices at a facility.

Cascade Water in the Flumes

Many food processing facilities use multiple stages of flumes to simultaneously wash and convey product. Water jets are used to unload food products from trucks, which are then conveyed into the processing facility by a series of flumes. Water can be recovered from the last stages of the flume, filtered, and sent to former stages counter-current to the flow of the product. For typical cases, recovering water from one flume and using it in another flume could save between 1.3% and 3.8% of a facility's total fresh water consumption, and could pay back in less than a year (BASE 2015).

Use Dry Cleaning Methods

Brooms, brushes, and scrapers can be used to completely clean or pre-clean surfaces of solid debris. This can significantly reduce water usage from typical wet wash-down cleaning processes. Dry cleaning is typically slightly more labor intensive, and may not eliminate fats and grease waste. Water savings for this measure ranges from 20% to 30% of the existing practice (European Commission 2006). Simple payback periods for this measure range from 1.2 years to 4.9 years (Gleick et al. 2003).

Upgrade Nozzles on Wash Down Hoses

Many facilities use open-ended hoses to wash down the plant floor or the surfaces of equipment. For a typical case, installing pressurized nozzles can reduce the amount of water used for wash down operations by 23% (Spraying Systems Co. 2008).

Additionally, if self-cleaning nozzles are installed on wash-down hoses then water consumption can be reduced by an additional 30% (Gleick et al. 2003). The payback period for this measure can be as low as two weeks, or practically an immediate return on the investment (Masanet et al. 2008).

Reuse Rinse Water

The water used in equipment rinsing is typically discharged after one use because the operators are concerned about the levels of contaminants in the rinse water discharge. Verification of the contaminant levels through the use of a conductivity sensor will allow reuse of the rinse water across multiple stages of the rinsing process. Additionally, the final rinse of one piece of equipment can be used as the first rinse for another piece of equipment. Reusing rinse water can save 40% to 50% of the total rinse water usage (European Commission 2006, Emerson Process Management 2010). An example simple payback period for this measure is approximately 3 years (BASE 2015).

Install an Automated Clean-in-Place (CIP) System in Place of Washdown

Many industries have large tanks that need to be periodically cleaned and sanitized. Often, these tanks are manually sprayed down or filled with cleaning solution and drained between uses. Installing an automated CIP system, which uses high impact washers and spray nozzles, can clean more quickly and effectively than existing practices. Additionally, there may be significant labor savings by automating tank cleaning. Water consumption of the tank cleaning system can be reduced by 20% (Spraying Systems Co. 2008) for a typical case. Simple payback period information for this measure could not be found in a literature review.

Install a Centralized CIP System for Water Reuse

Some facilities use single-tank CIP systems where the cleaning solution is used once before being discharged to the drain. Installing a centralized, multi-tank CIP system with temperature, conductivity, and flow sensors will allow CIP water to be reused between rinsing operations. Installing a centralized reuse CIP system can save 54% to 60% of the existing CIP usage (European Commission 2006, Schroder et al. 2014). An example payback period for this measure is approximately 1 year (UNEP 2004).

Install a Pipeline Inspection Gauge (PIG) System to Clean Pipes

Many facilities clean debris out of pipes by forcing water through the pipes at high velocities. A PIG system involves forcing an object through the pipes to clear the pipes, minimizing water usage and potentially enabling the recovery of product. The PIG can be made from sponge balls, rubber, metal, or ice. Typical values for water savings from installing a pigging system can reach 10% to 15% of the facility's total water usage (PG&E 2013), while an example simple payback period is approximately 2 years (EPA Victoria 2007).

Water Conservation Measures – Cooling Systems

This section will discuss measures that center around cooling systems.

Install a Conductivity Sensor on the Cooling Tower to Automatically Control Blowdown

Many uncontrolled cooling tower blowdown systems discharge much more water than required to prevent scaling in the system. Installing a conductivity sensor with a makeup water control system will allow the cooling tower to operate at the maximum cycles of concentration, which is the ratio of makeup water to blowdown water. The maximum cycles of concentration can be determined through supply water quality data and a scaling potential calculation involving maximum temperature, makeup conductivity, makeup alkalinity, calcium/magnesium hardness, and makeup silica (CSUCSP 2011). Water savings is approximately 1.29 million gallons per year for a 350 ton cooling tower, and this measure is cost effective for cooling towers greater than 125 tons (CSUCSP 2011). An example simple payback period for this measure is approximately 0.9 years (AMWUA 2008).

Install a Flow Meter on the Cooling Tower Make-up Water Line to Detect Leaks

Installing a flow meter on the cooling tower make-up water line will allow the facility to detect excessive water use for a cooling tower, signaling the need to locate a water leak. Manufacturer specifications provide calculations to determine water loss from evaporation based on the heat load of the system. These calculations, in combination with the cycles of concentration of the system, allow the facility to determine how much water the cooling tower should be using with no leaks. If the metered water use is greater than the calculated evaporation and blowdown water use, then the system has a leak which can be easily corrected.

Install a Makeup Water Treatment or Sidestream Treatment System on the Cooling Tower

Installing a water treatment system for the cooling tower can increase the cycles of concentration, resulting in a significant reduction in water usage. There are diminishing returns as the cycles of concentration increases: increasing the cycles of concentration from 3 to 6 decreases makeup water by 20%, with further increases to 10 cycles of concentration decreases makeup water by an additional 10%, and negligible changes in makeup water for higher cycles of concentration (Shi 2012). The average cycles of concentration for California cooling towers is 3.5 (CSUCSP 2011). Simple payback period information for this measure could not be found in a literature review.

Reuse Single Pass Cooling Water

Pump seal, product heat exchanger, air compressor, water-cooled chiller, and vacuum pump cooling water is often drained to the wastewater collection system. It is recommended to reroute this water back into the cooling tower or flumes to offset fresh makeup water. Reusing single-pass cooling water can typically save between 1.7% and 5.0% of a facility's total fresh water consumption. Example payback periods for this measure are between 1.0 years and 4.8 years, depending on the amount of collection points (BASE 2015).

Install an Overflow Alarm on the Cooling Tower Sump

Cooling tower makeup water supply pumps may be improperly controlled, or the makeup water control valve float may fail, which can cause significant overflow rates by continuously supplying water to the cooling tower sump after it has already been filled. Without an alarm, this overflow can occur for days or weeks before it is diagnosed by the facility. An overflow alarm system can immediately alert the facility if the makeup valve control system fails, preventing significant water loss from sump overflows. Installing an overflow alarm system can save up to 1.7% of a facility's total water consumption. Implementation of this measure will often pay back within a year (BASE 2015).

Change Evaporative Cooling to Dry Cooling

Changing direct contact or evaporative cooling towers to dry cooling towers will eliminate all water consumption from drift, blowdown, and evaporation. However, there will be a significant increase in cooling tower fan energy consumption. The Electric Power Research Institute is researching advanced cooling tower technologies, including hybrid dry/wet designs, but these technologies are still in the research stage for power generation facilities.

<u>Water Conservation Measures – Heating Systems</u>

This section will discuss measures that conserve water in the heating systems. The main savings mechanisms for these measures are fuel savings in the boiler system, although they will also result in significant water and treatment savings.

Return Steam Condensate to the Boiler System

Steam condensate is drained directly to the facility's wastewater system in many industrial facilities, especially when there is a large distance between the boiler and the steam usage point. For typical cases, returning steam condensate to the boiler system can save up to 37% of the boiler system's nominal steam output (BASE 2015). The payback period for this measure ranges from 0.5 - 0.7 years (BASE 2015, Gleick et al. 2003).

Install a Conductivity Sensor on the Boiler to Automatically Control Surface Blowdown

Many boiler systems are constantly blown down to remove dissolved solids inside the boiler, which can cause scaling and impair heat transfer. Installing a conductivity sensor can indirectly measure the amount of dissolved solids inside the boiler, and control the surface blowdown to discharge water only when needed, resulting in significant water and fuel savings. Water savings for installing an automatic blowdown control system can range from 1% to 8% of the nominal steam generation rate (SCGC 2012). The simple payback period for this measure ranges from 1 year to 3 years (NCDPPEA 2002).

Install a Boiler Blowdown Flash Tank to Recover Flash Steam

The boiler blowdown is typically discharged directly to the drain without any heat or steam recovery. Installing a blowdown flash tank, with flash steam recovery to the deaerator, can save up to 49% of the energy in the blowdown and 14% of the blowdown water (Spirax Sarco 2015). If sensible heat from the blowdown stream after flashing is recovered, total energy recovery can reach up to 87% of the total energy of the blowdown stream (Spirax Sarco 2015). For a typical case, the simple payback period for this measure is approximately 0.5 years (OIT 2002).

Install a Flue Gas Condenser to Recover Combustion Product Water

Flue gas condensers can represent a significant amount of water reclamation for direct-combustion equipment in the industrial sector. Reclaimed flue gas water can be used in non-sensitive wash processes or landscape irrigation. Carbonic acid can be easily pretreated if the water is used in quality sensitive processes or reused in the boiler. For natural gas boilers, the amount of water recovery is approximately 5% to 7% of the nominal steam generation rate of the boiler (Gellings and Goldstein

2008). For typical cases, the simple payback periods range from 2.0 – 3.9 years (Schiffhauer et al. 2009). Please note that the payback presented only involves the installation of a condensing economizer, and not the additional capital costs or cost savings of recovering and treating the condensed flue gas water.

Water Conservation Measures – General Process and Wastewater Management

This section will discuss measures that involve making improvements to process water usage and existing wastewater facilities at the plant.

Install Automatic Shut-Off Valves to Eliminate Idle Equipment Water Usage

Water using equipment will often operate intermittently, especially when there are multiple parallel lines of production. Makeup water lines are often manually controlled, and operators will not shut down the water line between periods of productivity on the equipment. As an example, food washing equipment may be left on during breaks or when product unloading is less than the capacity of the product washing stations. Installing automatic shut off valves can result in water savings up to 15% of the equipment's overall water usage (European Commission 2006). Simple payback periods for this measure could not be found from a literature review, but they are expected to be low due to the minimal equipment involved in the implementation of this measure.

Recycle Evaporator Condensate

Water is commonly evaporated and removed from the product in juice and paste facilities. In the first stages of the evaporator, the evaporated product water is relatively pure and can be condensed and used in the cooling towers, unloading flumes, and other low-grade facility applications. Further water recovery may require ultrafiltration or reverse osmosis to purify the evaporated product water, but will significantly increase the amount of hot, clean water to be used in the plant. For a typical case, this measure can reduce the plants overall fresh water consumption by up to 90%, with a payback period of approximately 4 years (Dairy Australia 2004).

Separate Wastewater Streams for Water Recovery

Wastewater can be generated by numerous processes in a single facility, and each stream can have different levels of wastewater constituents. Separating the wastewater streams can facilitate the treatment and recycling of flows with low levels of waste. Additionally, the "waste" separated from the water can be repurposed as an additional revenue source, either being added back into the product stream or used as animal feed. For a typical case, separating and treating low-waste streams can reduce a facility's overall water consumption by 19% (Masanet et al. 2008). Simple payback period information for this measure could not be found in a literature review.

Install a Wastewater Treatment System to Recycle and Reuse Water

Recycling and reusing water is the most effective and most costly method of reducing fresh water consumption. Food processors, textile manufacturers, silicon chip manufacturers, and metal finishing plants have the greatest opportunities for reusing wastewater (Gellings and Goldstein 2008). Plants can install microfiltration, ultrafiltration, reverse osmosis, and ozone treatment systems to treat the water to acceptable levels for reuse. Additionally, the solids separated from the waste stream can potentially be an economically useful product. Cost savings for these measures is highly dependent on the waste stream. Projects become much more cost effective if usable products can be separated from the water, such as milk solids in dairies, sugars in beverage processing, and phosphate for CIP systems. In poultry plants, fresh water reduction can reach up to 80% (Gleick et al. 2003). Simple payback periods range from 0.1 years to 12.4 years, with most systems ranging in depending on the solid separated and the wastewater charges at the facility (Gleick et al. 2003). The high discrepancy between the payback periods show that the feasibility of these systems must be analyzed on a case-by-case basis.

Utilize Recycled Water from a Local Municipality

It is feasible to install dedicated recycled water lines between municipal tertiary treatment plants and large industrial users. Industrial users can use recycled water for cooling tower makeup, boiler makeup, and low/medium water quality processes (Gellings and Goldstein 2008).

Table 3 summarizes all of the water conservation measures discussed in this paper. Please note that all potential savings percentages and payback periods are examples of what can be achieved in industrial applications. A detailed water audit must be performed to determine the savings and payback for any single project, as the savings and costs are highly dependent on unique circumstances at the facility.

Barriers to Implementation

There are several barriers that inhibit the implementation of water conservation measures. The first is the lack of reliable data. Often, a facility meters total influent and total effluent water, with

Table 3. Summary of Industrial Water Conservation Measures

Water Conservation Measure	Applicable Industry	Potential Water Savings Examples	Simple Payback Period
Maintenance			
Repair Water Leaks	All	0.7% of Facility's Total Consumption	Immediate
Maintain Steam Traps	All	Up to 20% of Boiler System's Steam Production	0.5 years
Conveying, Cleaning, and Rinsing			
Cascade Water in the Flumes	Fruit Processing	1.3% - 3.8% of Facility's Total Consumption	1 year
Use Dry Cleaning Methods	All	Varies	1.2 – 4.9 years
Reuse Rinse Water	Various	Up to 40% of Rinse Water Usage	3 years
Upgrade Nozzles on Wash Down Hoses	All	Up to 23% - 30% of Wash Down Water Usage	Immediate
Install an Automated Clean-in-Place (CIP) System in Place of Manual Wash Down	Various	Up to 20% of Existing Cleaning System	N/A
Install a Centralized CIP System for Water Reuse	Various	Up to 54% of Existing CIP Water Usage	1 year
Install a Pipeline Inspection Gauge (PIG) System to Clean Pipes	Various	Up to 10% - 15% of Facility's Total Consumption	2 years
Cooling Systems			
Install a Conductivity Sensor on the Cooling Tower to Automatically Control Blowdown	All	1.29 Million Gallons per Year for a 350 Ton Cooling Tower	0.9 years
Install a Flow Meter on the Cooling Tower Make-up Water Line to Detect Leaks	All	N/A	1 year
Install a Makeup Water Treatment or Sidestream Treatment System on the Cooling Tower	All	Up to 10% - 20% of Cooling Tower Water Usage	N/A
Reuse Single Pass Cooling Water	All	Up to 1.7% - 5.0% of Facility's Total Consumption	1.0 - 4.8 years
Install an Overflow Alarm on the Cooling Tower Sump	All	1.7% of Facility's Total Consumption	1 year
Change Evaporative Cooling to Dry Cooling	All	N/A	N/A
Heating Systems			
Return Steam Condensate to the Boiler System	All	Up to 37% of Boiler System’s Steam Production	0.5 – 0.7 years
Install a Conductivity Sensor on the Boiler to Automatically Control Surface Blowdown	All	1% - 8% of Boiler System’s Steam Production	1 – 3 years
Install a Boiler Blowdown Flash Tank to Recover Flash Steam	All	14% of Boiler System’s Blowdown	0.5 years
Install a Flue Gas Condenser to Recover Combustion Product Water	All	5% - 7% of Nominal Steam Generation Rate	2.0 – 3.9 years*
General Process and Wastewater Management			
Install Automatic Shut-Off Valves to Eliminate Idle Equipment Water Usage	All	15% of Equipment’s Existing Usage	N/A
Recycle Evaporator Condensate	Food Processing	Up to 90% of Facility’s Total Consumption	4 years
Install a Wastewater Treatment System to Recycle and Reuse Water	Various	Up to 80% of Facility's Total Consumption	0.1 - 12.4 years
Utilize Recycled Water from a Local Municipality	Selected	N/A	N/A

*The simple payback period for this measure does not include full project costs or cost savings; please read the explanation of this measure for a description of the payback period.

very little submetering within the plant. This makes quantifying baseline water consumption a difficult endeavor. Without a baseline condition, quantifying energy savings and cost savings for any water conservation action becomes nearly impossible, and facility management will not commit resources to these projects. The best solution is for facilities to install flow submeters on large water consuming equipment/processes, or on equipment/processes that consume high energy intensity or high cost water (chemically treated, reverse osmosis filtered, etc.). Another solution is to hire water auditing professionals to perform project scoping and spot flow measurements and calculate estimates of the water savings, cost savings, and implementation costs of projects.

Another barrier is a lack of awareness about industrial water conservation. Many facility managers do not know which actions to perform to conserve water. There is hesitation to perform new, innovative water conservation actions in industry as water is a relatively cheap resource, at first glance, and it can have significant effects on production. Case studies of successful projects are the most effective method to promote water conservation, because plant managers can see cost effective water conservation projects being implemented successfully.

The final barrier discussed in this paper is the complexity of industrial systems. There are no simple fixes, such as low-flow toilets or low-flow faucets, which can be applied to every facility across the entire sector. Every industrial facility has different processes, with different usage profiles, that make it nearly impossible to develop routine calculation methods for a measure. Water auditors can help a facility scope and quantify projects, but there also need to be "water champions" within a facility to help maintain efficient and productive operation of equipment after projects have been implemented.

Methodologies for Analysis

It is important to quantify the energy savings, water savings, and cost savings of each water conservation measure based on site-specific parameters. Electrical energy savings may either be on-site or embedded, depending on the source of the water supply and treatment (i.e. on-site or from the local municipality). Local electrical utilities may offer energy efficiency incentives for embedded energy if the project is both large enough for consideration and the energy reduction is on the utility's grid.

The general method for analyzing the on-site electrical energy savings for a water conservation measure includes the annual water conserved and the energy intensity of the supply, distribution, treatment, and wastewater treatment systems. The water savings can be quantified by fluid dynamic analyses, manufacturer specifications, or direct measurements of water flow rates. The supply energy intensity is highly dependent on the source of water (i.e. surface or groundwater). The energy intensity of distribution is dependent on the distance and height changes between the water source and the end-use. The water treatment intensity is dependent on the type of treatment used (i.e. simple filtration, reverse osmosis, disinfection, etc.). The wastewater treatment intensity is dependent on the processes required for discharge to the environment (i.e. filtration, aeration, denitrification, disinfection, etc.). Please note that there may be parasitic loads for water conservation measures, from either additional pump or fan energy, which must be accounted for when calculating the overall electrical energy savings.

Heating energy savings for water conservation projects can be quantified through the annual water conserved, the temperature of the water at the recovery point, the temperature of the makeup water, and the efficiency of the boiler or heating system.

The cost savings for water conservation projects can be quantified through the electrical cost savings, the heating energy cost savings, the cost of fresh water from the local water district, the cost of disposal from the local wastewater district, and the cost of chemicals in the water. Total wastewater costs may be divided into charges for biological oxygen demand (BOD), total dissolved solids (TDS), total Kjehdahl nitrogen (TKN), and other wastewater constituents. Please note that there may be additional maintenance or chemical costs required to implement a water conservation project, which will need to be accounted for when determining the total cost savings.

The simple payback period for water conservation projects can be quantified through the total capital cost, the incentive from the local energy utility, the incentive from the local water district, and the total cost savings. Please note that incentives from energy and water utilities may need to be negotiated, as formal incentive programs for water conservation are rare. There are other financial metrics, including return on investment, internal rate of return, savings-to-investment ratio, net present worth, etc., which may be needed to implement a project. The necessity of detailed financial analyses is determined by the capital investment procedure for a company. A detailed discussion of these metrics is beyond the scope of this paper.

CASE STUDIES

The following section showcases two case studies for food processors in California that have implemented comprehensive water conservation projects.

Tomato Processor, Central Valley, California

This tomato processing facility implemented four measures to conserve 44 million gallons per year, or 0.45 million gallons per day, of fresh groundwater. This represents 14% of the facility's overall fresh water usage. Additionally, since all water supply/distribution pumps and water/wastewater treatment facilities were on-site, the facility saved 142,000 kWh of electricity per year. With the energy incentive from the local electrical utility, the overall simple payback period for the entire project was less than one year. The measures this tomato processor implemented were:

1) Cascade water from the flume system to the truck unloading booms
2) Recover single-pass cooling water and use in the flume system
3) Recover wastewater discharged from rotary screens and reuse in the flumes
4) Reduce the over-usage of water in the pump seal cooling system

Measurement and verification of the water and energy savings was performed by either direct measurements of the recovered flow rates or engineering calculations based on pipe dimensions and pressure profiles of the system.

Winery, Central Coast, California

This winery implemented one measure to conserve 1.92 million gallons per year of fresh groundwater. This represents 26% of the facility's overall fresh water usage. Additionally, the facility saved 42,000 kWh of electricity per year from the on-site wastewater pumps and aeration equipment. There was no cost for the project, resulting in an immediate simple payback period with an annual cost savings of $5000/yr. The winery implemented an optimized sequencing schedule of their grape presses to minimize the number of presses that operate per day, and as a result reduce the total washdown water.

Measurement and verification of the water savings was performed by normalizing the measured water usage to the grape production for the years before and after implementation of the project. The facility reduced its water intensity from 273.2 gallons per ton of grapes to 201.9 gallons per ton of grapes.

CONCLUSIONS

A steady, reliable water supply is critical to the healthy operation of industrial facilities. Droughts have affected the United States in recent years, and as fresh water supplies become more limited, production may become stifled by the amount of fresh water available.

There is significant potential for water conservation across all industries. The measures outlined in this paper summarize cost effective water conservation actions for nearly all industrial processes; maintenance, cleaning, cooling, heating, general process, and wastewater management. Many facilities have already begun successful water management programs, cutting their overall fresh water consumption by significant portions with payback periods on the investments that are less than a year.

ACKNOWLEDGEMENTS

The authors would like to thank Pacific Gas and Electric (PG&E) for their support in numerous energy efficiency and water conservation projects. All authors have greatly benefited from involvement in the Industrial Assessment Center (IAC) at some point in their careers, which they are grateful for.

REFERENCES

1. Arizona Municipal Water Users Association (AMWUA). *Facility Manager's Guide to Water Management*. 2008.
2. BASE Energy, Inc. (BASE). Internal data, 2015.
3. California Statewide Utility Codes and Standards Program (CSUCSP). *Codes and Standards Enhancement Initiative (CASE): Cooling Tower Water Savings*. Pacific Gas and Electric Company, Southern California Edison, SoCalGas, SDG&E, 2011. Print.
4. Dorjets, Vlad. *Many newer power plants have cooling systems that reuse water*. U.S. Energy Information Administration, 11 Feb. 2014. Web. 27 Mar. 2015.
5. Dairy Australia. *Eco-efficiency for Australian Dairy Processors, Fact Sheet: Water Recycling and Reuse*. 2004. Print.
6. Environmental Protection Authority Victoria (EPA Victoria). *Project Outcome: Unilever.* 2007. Print. 1129.
7. Federal Energy Management Program (FEMP). *Steam Trap Performance Assessment: Advanced Technologies for Evaluating the Performance of*

Steam Traps. Washington, D.C.: U.S. Department of Energy, 1999. Print. DOE/EE-0193.
8. Gellings, C., and R. Goldstein. *Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use*. Palo Alto: Electric Power Research Institute, 2008. Print. 1016460.
9. GEI Consultants/Navigant Consulting. *Embedded Energy in Water Studies. Study 2: Water Agency and Function Component Study and Embedded Energy-Water Load Profiles.* California Public Utilities Commission Energy Division, 2010. Print.
10. Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katharine Kao Cushing, and Amardip Mann. *Waste Not, Want Not: The Potential for Urban Water Conservation in California.* Oakland: Pacific Institute for Studies in Development, Environment, and Security, 2003. Print.
11. Spirax Sarco. *Heat Recovery from Boiler Blowdown (TDS Control Only*). 2015. 10 Apr. 2015.
12. ICF International. *Water and Energy: Leveraging Voluntary Programs to Save Both Water and Energy*. Washington, DC, Climate Protection Partnerships Division and Municipal Support Division U.E. Environmental Protection Agency, 2008. Print.
13. European Commission. *Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques in the Food, Drink and Milk Industries*. 2006. Print.
14. Masanet, Eric, Ernst Worrel, Wina Graus, and Christina Galitsky. *Energy Efficiency Improvements and Cost Saving Opportunities for the Fruit and Vegetable Processing Industry*. Earnest Orlando Lawrence Berkeley National Laboratory, 2008. Print.
15. Maupin, Molly, Joan Kenny, Susan Hutson, John Lovelace, Nancy Barber, and Kristin Linsey. *Estimated Use of Water in the United States in 2010.* USGS Science Publishing Network Raleigh Publishing Service Center, 2014. Print. Circular 1405.
16. North Carolina Division of Pollution Prevention and Environmental Assistance (NCDPPEA). *Fact Sheet: Boiler Blowdown*. 2002. Print.
17. Office of Industrial Technologies (OIT). *BestPractices Technical Case Study: Forest Products*. U.S. Department of Energy, 2002. Print.
18. Pacific Gas and Electric Company (PG&E). *PIGs at Sonoma Wine Company: Using Pipeline Inspection Gauges (PIGs) at Sonoma Wine Company to Save Money, Conserve Water and Reduce Energy Use*. 2013. Print.
19. Schroder, Emmy, Amanda Peterson, and Anna Ameser. *Dairy Plant Water Conservation by CIP System Redesign and Loadout of Cow Drinkable High BOD Water*. The Ohio State University College of Engineering, 2014. Print.
20. Schiffhauer, Mark, Cameron Veitch, and Scott Larsen. *Increasing Natural Gas Boiler Efficiency by Capturing Waste Energy from Flue Gas*. ACEEE Summer Study on Energy Efficiency in Industry, 2009. Print.
21. Shi, J. *Program on Technology Innovation: New Concepts of Water Conservation Cooling and Water Treatment Technologies*. Palo Alto: Electric Power Research Institute, 2012. Print. 1025642.
22. Southern California Gas Company (SCGC). *Reduce Boiler Blowdown Water*. California Energy Commission, 2012. Print.
23. Spraying Systems Co. *Change the Way You Spray to Maximize Water Conservation*. Wheaton, 2008. Print.
24. The National Drought Mitigation Center (NDMC). *United States Drought Monitor.* 2015. Web. 26 Mar. 2015.
25. The UNEP Working Group for Cleaner Production in the Food Industry (UNEP). *Eco-efficiency for the Dairy Processing Industry*. Dairy Australia, 2004.
26. Emerson Process Management. *Water Conservation in Metal Finishing*. Irvine: 2010. Print. ADS 3300-14/rev.C.