

Reducing Electricity Grid Imbalances through Energy Demand Management of Water Delivery Infrastructure

Robert T. Good, Erin N. Musabandesu, Kendra C. Olmos, Drew Atwater, and Frank J. Loge

ABSTRACT

The feasibility of a water supply utility to perform energy load shifting into periods of energy imbalance on California's statewide energy grid was investigated for the reclaimed water distribution system operated by the **Moulton Niguel Water District (MNWD)** using an offline hydraulic model. The energy generation, curtailment, and **greenhouse gas (GHG)** emission trends of California's statewide energy grid operated by the **California Independent System Operator (CAISO)** were investigated to determine the key time periods to target with energy load shifting. The offline simulation demonstrated that it is possible for water delivery utilities to shift energy loads to address statewide energy imbalances.

INTRODUCTION

As energy sources in California have shifted towards solar and wind power, short-term intermittent changes to energy production are leading to an imbalance between energy supply and demand. Energy imbalance is currently managed with the practice of *curtailment*, where the CAISO sells excess electricity at modified production costs (**Figure 1**). *Overgeneration*, which occurs when excess electricity is not completely consumed or curtailed, has the undesirable potential to reduce the reliability of electricity supply. One way to reduce the impact of overgeneration is to shift energy consumption to eliminate energy imbalance (Jan Paul Action, 1983).

This "load shifting" approach, referred to in the energy sector as Demand Management, presents a unique challenge in the case of California's energy-intensive water system which accounts for nearly 20% of the state's electricity use, with pumping for water distribution, supply, and conveyance alone representing nearly 5%. If water utilities had the tools and knowledge to shift energy consumption into periods of renewable energy generation, they might be able to reduce their GHG emission and simultaneously reduce the energy imbalance in the statewide energy grid.

SPONSORS

California Energy Commission
Moulton Niguel Water District

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METHODS

Time Periods to Target. Problems of energy imbalance, including curtailment (**Figure 2**) and overgeneration (**Figure 3**), have grown in magnitude since 2014 while occurring at consistent, reliable hours. Meanwhile, the Locational Marginal Prices (**Figure 1**) of electricity generation operated by the CAISO captures increased occurrences of high and negative pricing which indicate growing imbalance on the statewide energy grid.

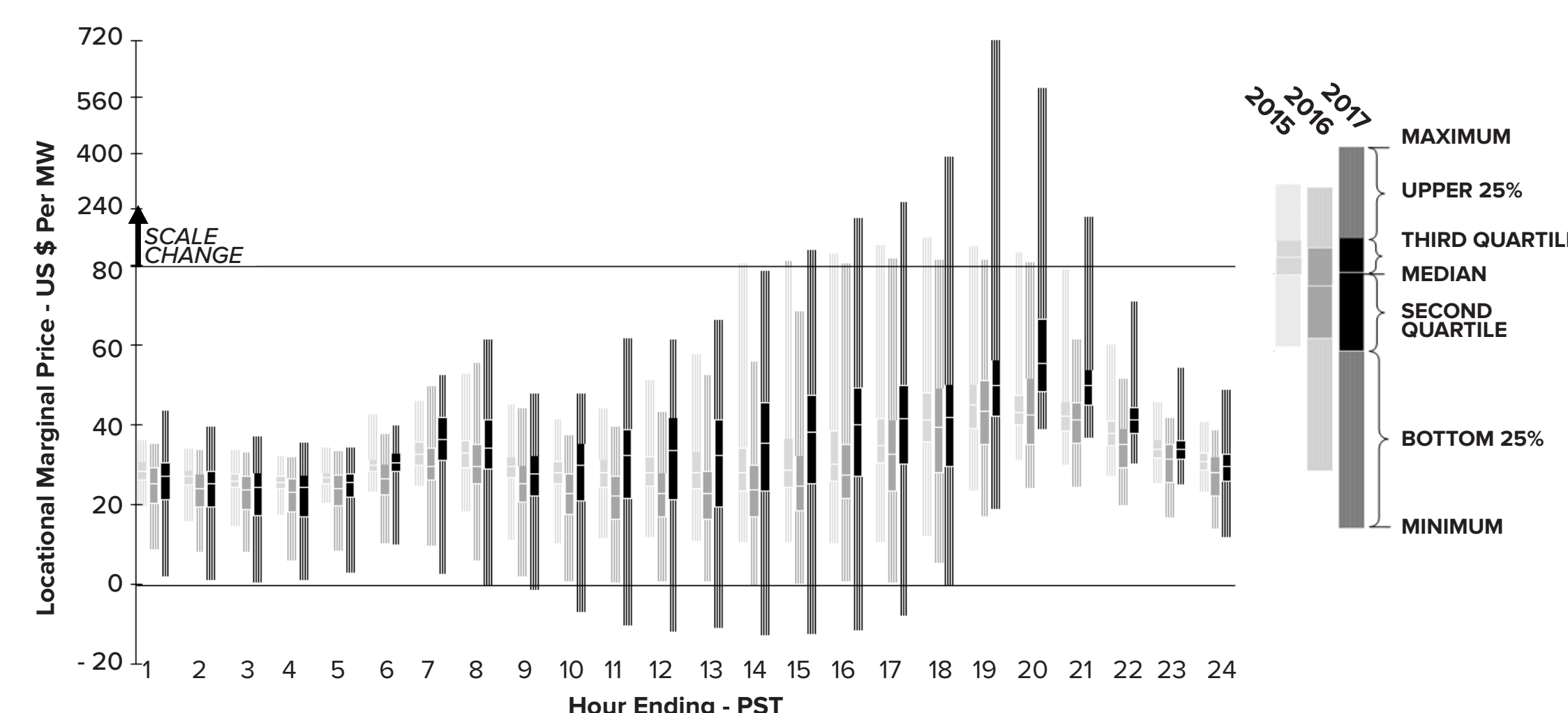


FIGURE 1 Observed statistical distributions of the Locational Marginal Pricing (LMP) values generated by CAISO from January 2015 to September 2017 at all participating generating units. Data Source: California Independent System Operator (Price, 2017)

Offline Energy Load Shifting. Leveraging a hydraulic water distribution model developed to accurately simulate the reclaimed water system operated by the MNWD, potential control and operating schemes of system elements, including pumps and valves, were simulated. By utilizing optimization procedures within the hydraulic modeling software, energy load shifting was simulated by replacing the existing cost of purchasing electricity at MNWD with similar-cost energy rates which promoted energy consumption at new time periods. These optimizations were repeated under new water customer demand profiles (Shifted Demands) to simulate the impact of water demand shifting on the success of energy load shifting.

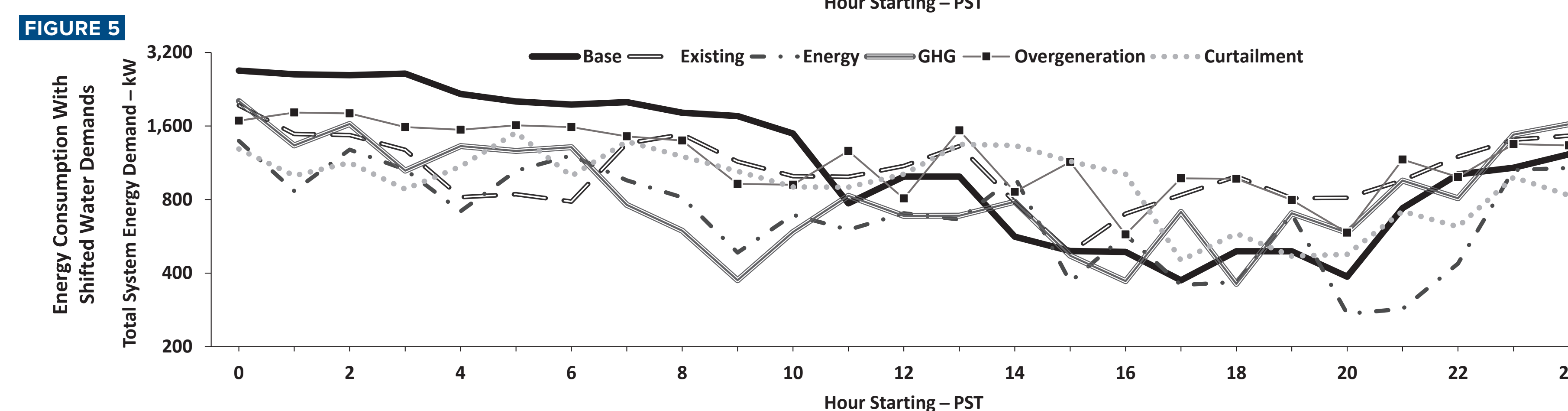
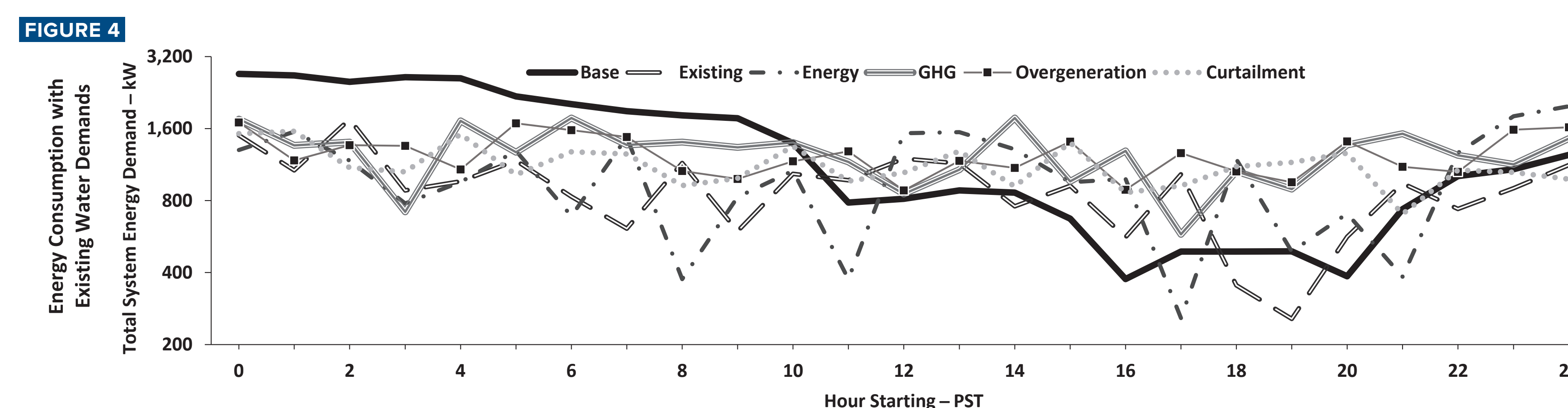


FIGURE 4 Energy Consumption with Existing Water Demands

FIGURE 5 Energy Consumption with Shifted Water Demands

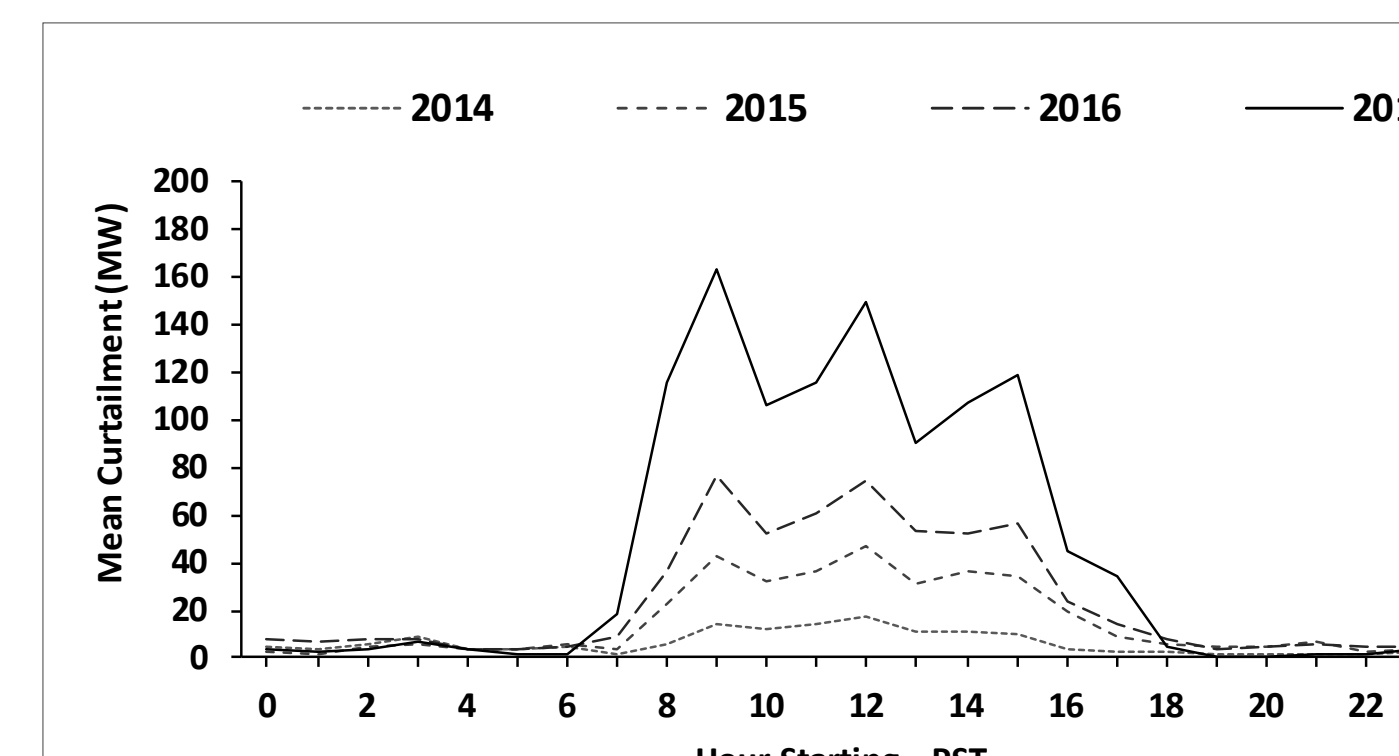


FIGURE 2 Observed statewide scheduled curtailment. Data Source: California Independent System Operator (CAISO, 2017)

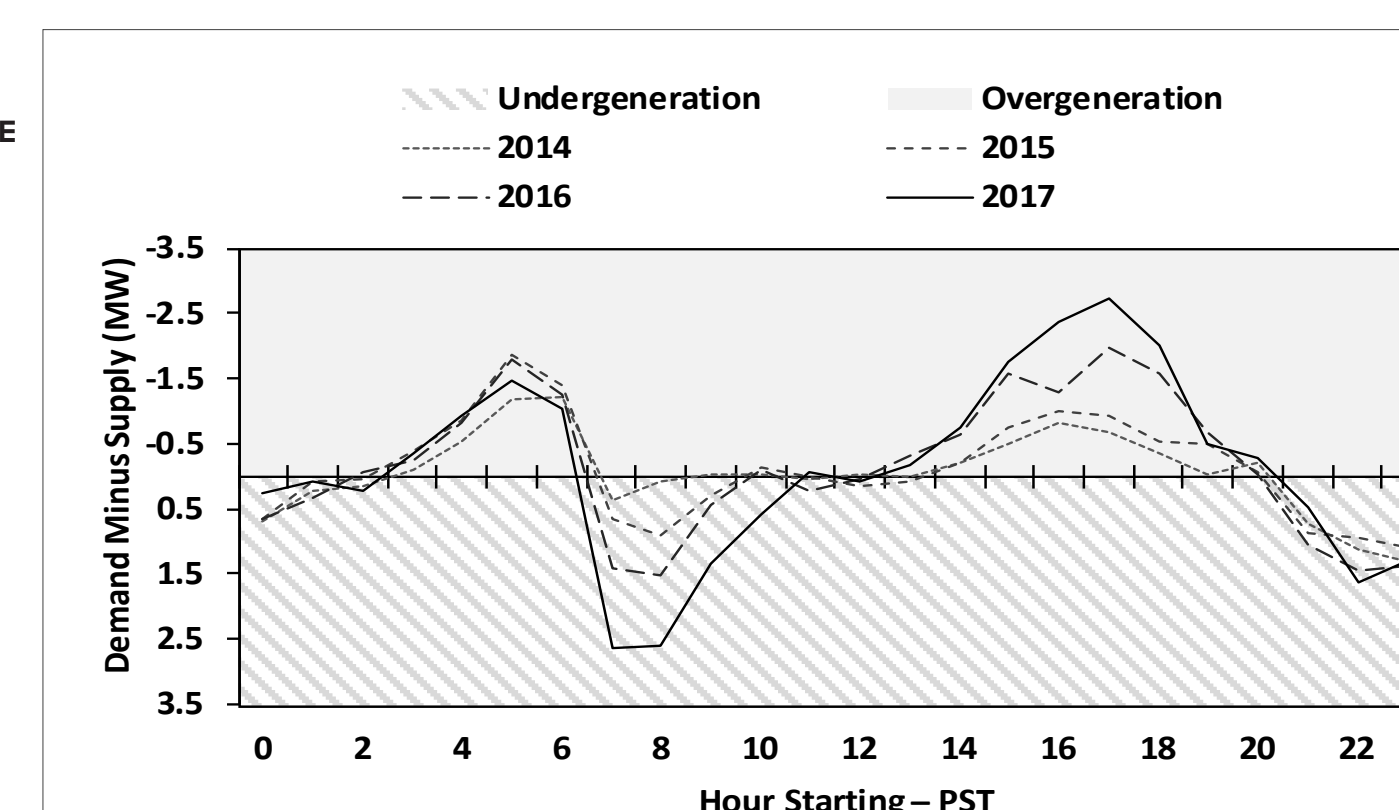


FIGURE 3 Observed statewide overgeneration. Data Source: California Independent System Operator (CAISO, 2017)

RESULTS

Energy load shifting was demonstrated to achieve several objectives: minimize operating costs under existing energy rates (Existing), minimize total energy use (Energy), minimize total emissions produced to meet demand (GHG), maximize use of scheduled curtailed energy (Curtailment), and respond to unscheduled overgeneration (Overgeneration). The utility was capable of increasing energy demand from 10am–Midnight; and decreasing energy demand from Midnight–10am (**Figures 4 and 5**). Generally, further energy savings and load shifting were possible with water customer demand shifting.

Highly dependant on the load shifting objectives, the total energy use (MWh) and total associated emissions (mTCO₂) of operating the water system were reduced by 7% – 44% and 11% – 46%, respectively (**Figure 6**).

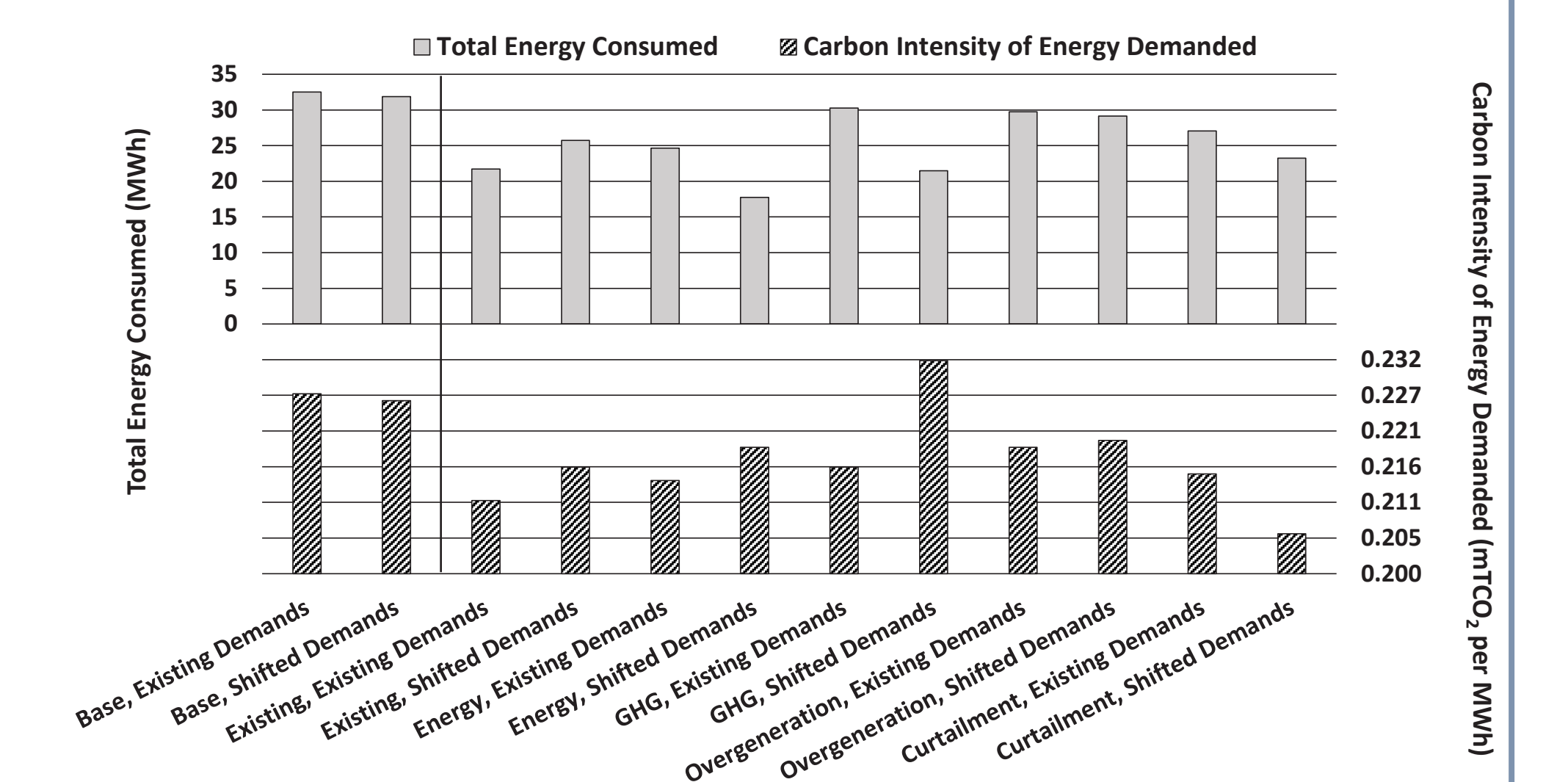


FIGURE 6 Performance of all optimizations in comparison to the base operating conditions (left). Total energy consumption (top) and aggregated carbon intensity of the electricity generated to meet energy demand (bottom) for the 24-hour simulations.

CONCLUSIONS

Energy load shifting for water delivery infrastructure is plausible and can produce short payback periods which reduce operating costs for a water utility. However, significant concerns relating to the repeatability and complexity of optimized operating schemes indicate the need for future research into both the technology and methodology. The results of this study suggest that rules-based operating configurations developed from groups of optimized operating schema may be a fruitful direction of research to achieve this multi-objective challenge.

Onsite Non-Potable Water Recycling: Overcoming the Barriers

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ABSTRACT

Alternate water reuse systems, such as those using gray water or rainwater, are difficult to get permitted and limited in how they can be used. Barriers such as unclear regulations, non-standard requirements, and poor knowledge dissemination are preventing their growth. In order to overcome these obstacles, trainings and documentation for regulators, installers, and operators need to be created, coordination and cooperation between local regulators need to be facilitated, and new regulations that standardize and require these systems are necessary.

INTRODUCTION

Alternative water sources are sustainable and drought resilient and currently being sent to centralized wastewater treatment facilities and then often discharged as shown in **Figure 1**. If, instead, that water was used onsite as irrigation, toilet flushing, or industrial water, the overall water demand would be significantly reduced and would alleviate pressure on California's water stores.

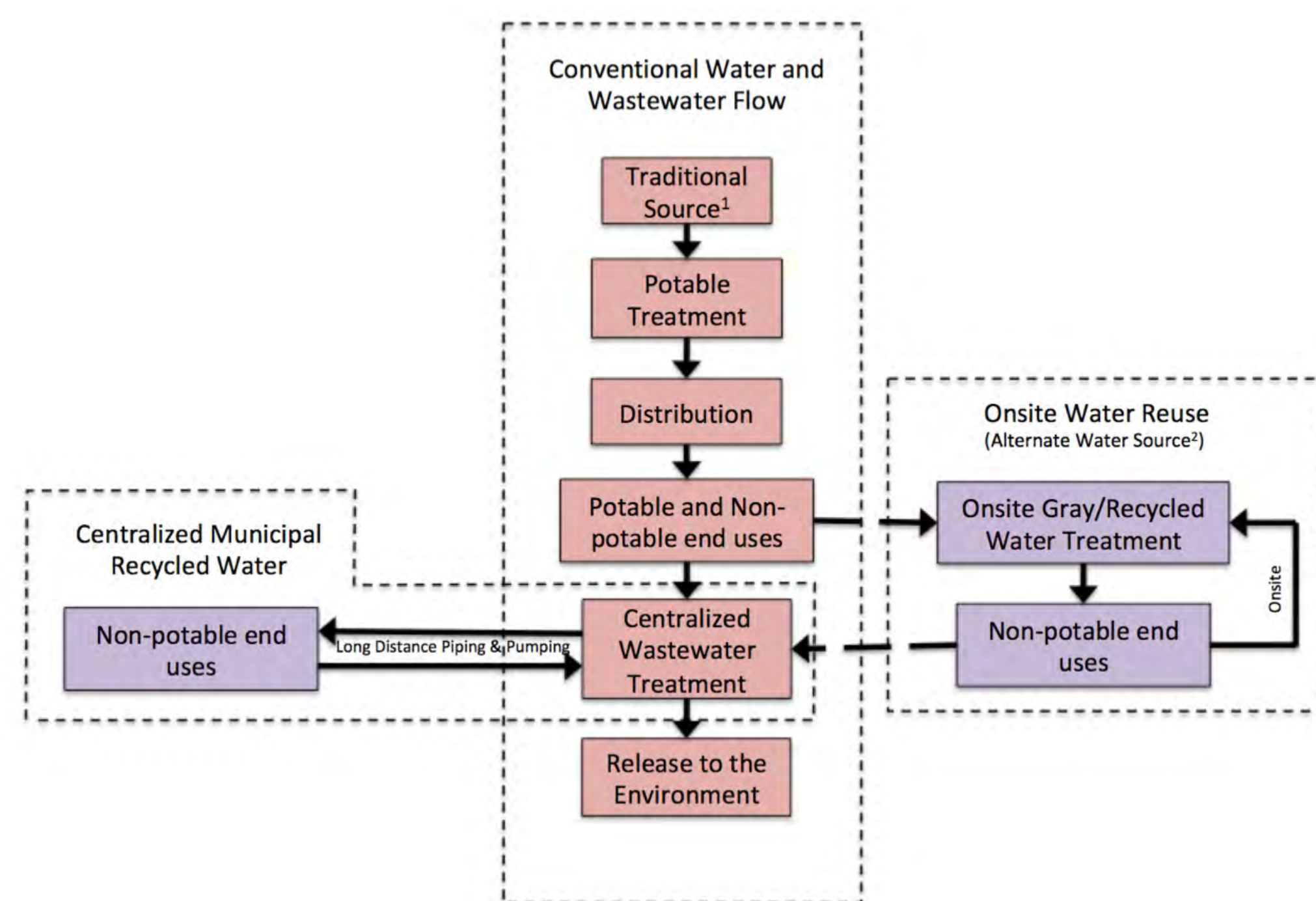


Figure 1. Depiction of conventional water and wastewater flow and how decentralized (onsite) vs. centralized water recycling fit in.

DEFINITIONS

Alternate Water Source: black water, gray water, recycled water, storm water, and rainwater sources.

Gray Water: wastewater generated in households or commercial facilities from streams without fecal contamination

Onsite Non-Potable Water Systems (ONWS): systems that treat and reuse water from local sources for reuse in non-potable applications.

Non-potable applications: irrigation, toilet flushing, industrial cooling, process water, and others.

WATER USE IN CALIFORNIA

- Irrigation accounts for roughly 50% of a household's total water demand (Brandt et al., 2014, WRF 2016).
- For a typical home, about 60% of its indoor water use generates graywater (**Figure 2**) (WRF, 2016).
- Commercial properties could reduce potable water demands by as much as 75% by recycling onsite (EPA Water Sense)

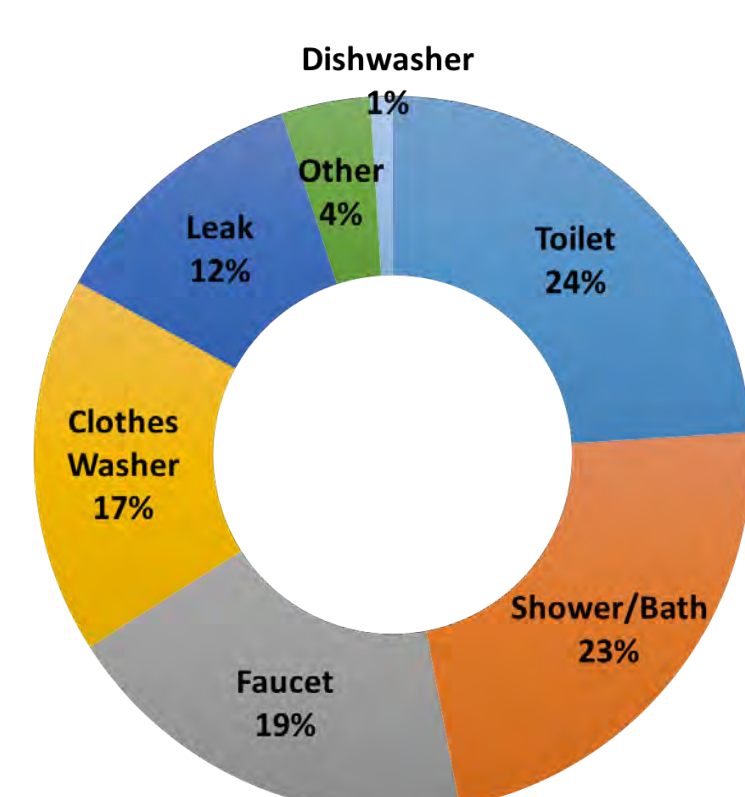


Figure 2. Typical Indoor Residential End Uses of Water (Adapted from WRF, 2016)

THE BARRIERS

In spite of the positive potential of ONWS, many challenges and barriers still exist that are slowing their acceptance and widespread implementation such as:

- Real and perceived risk of alternate water sources.
- Over restrictive requirements.
- Lack of knowledge transfer between local regulatory authorities.
- Lack of monitoring and reporting provisions.
- Non-standardized water quality requirements.
- Lack of support and direction for system installers and owners.

OVERCOMING THE OBSTACLES

- Provide trainings on the creation of ONWS programs for local health departments
- Develop documentation about installation, general requirements, and the permitting process with the installers and potential system owners as the target audience.
- Facilitate interagency cooperation with all local authorities having jurisdiction over non-potable onsite systems so that everyone is brought to the table to safely and efficiently permit these systems.

CURRENT REGULATORY ENVIRONMENT

The current California Plumbing Code allows for non-black water sources, such as rainwater, storm water, and graywater, to be used for different applications as determined by local authorities (2016). **Figure 3** highlights how each regulation applies to each water source, the water quality criteria that is enforced, and the approved reuse types.

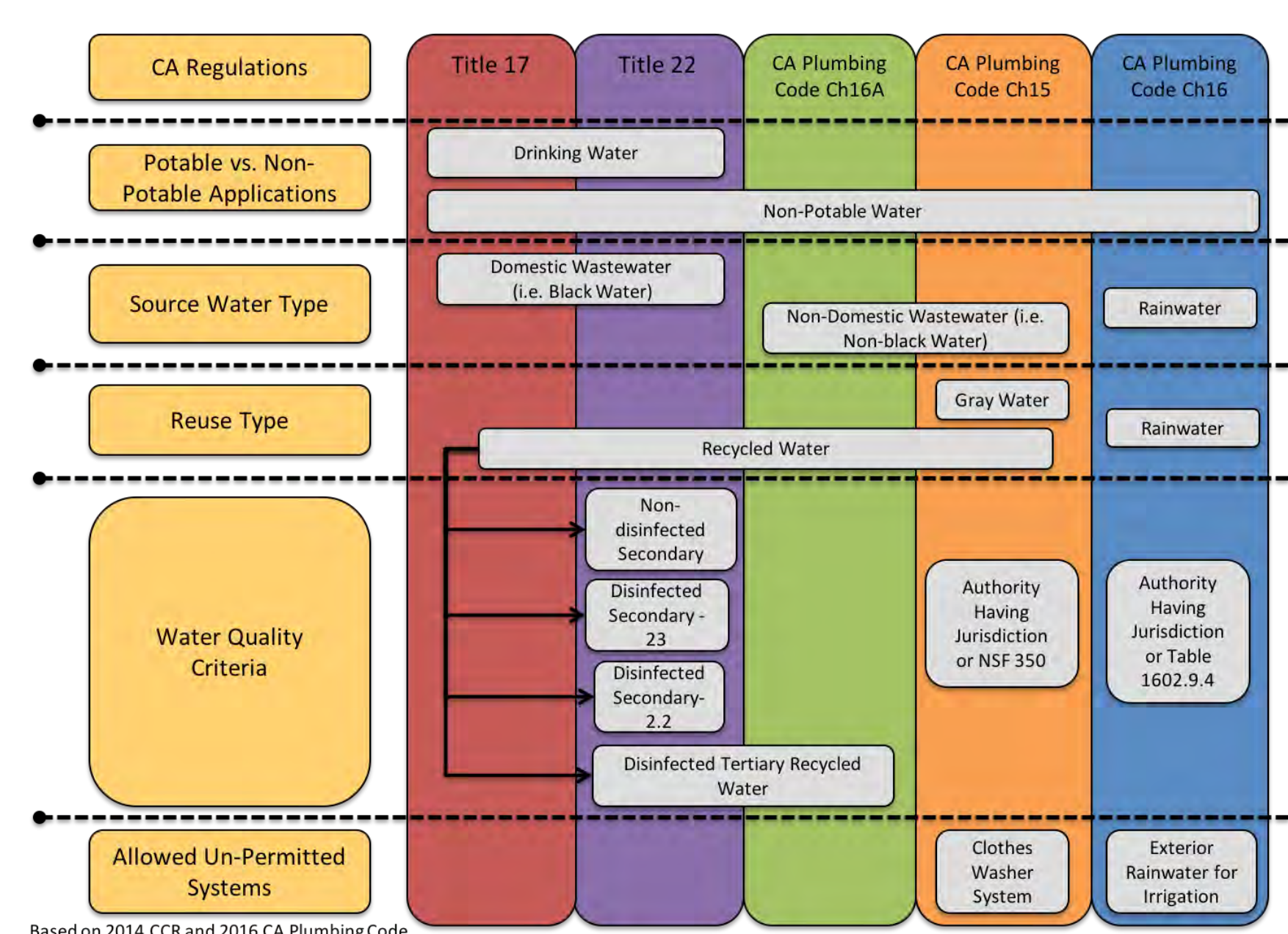


Figure 3. The five regulatory documents dealing with alternate water sources and how they are related.

CASE STUDY

- Partners: Jackson Family Winery, California Energy Commission, Center for Water-Energy Efficiency.
- Goal: Track energy and water savings and document the permitting process and barriers faced.
- Alternate Water Source and End Use: barrel and tank wash water.
- Treatment: Vibratory Sheer Enhanced Process (**VSEP**®, New Logic) reverse osmosis filter (**Figure 4**).
- Projected Savings: 1.4 million gallons of water and 42,000 kwhr annually.

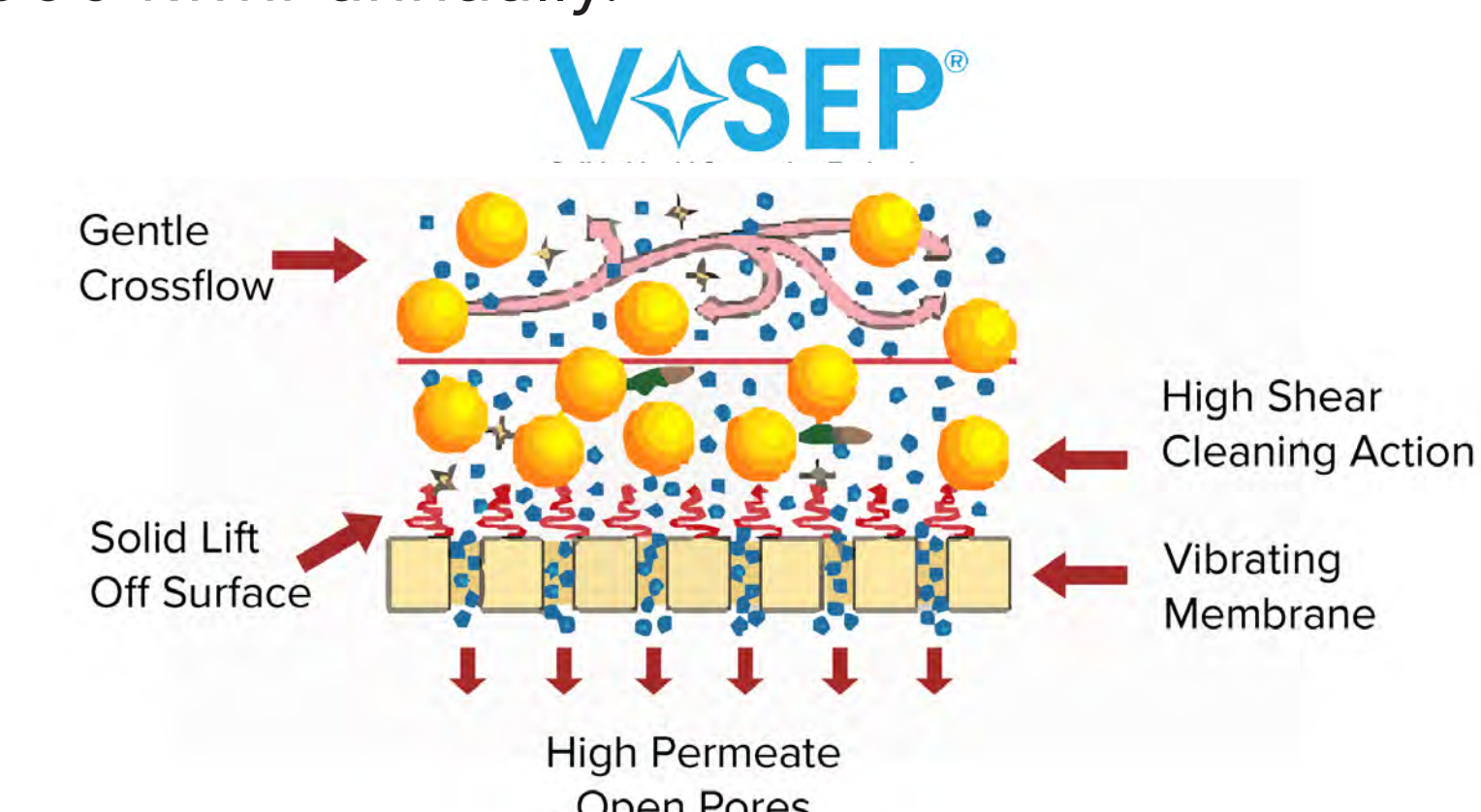


Figure 4. VSEP® filter process. The vibrations create a shear at the surface, which reduces fouling.

POTENTIAL AND BENEFITS

- Reduced potable water demand. Up to 358 billion gallons annually in California for residential alone. (US Census Bureau, 2016, WRF, 2016).
- Reduced overall energy consumption when considering the energy embedded in pumping, treating, and delivering potable water.
- Increased stability and allowance for incremental growth within the water sector.
- Increased resiliency and reliability of the water sector.

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- NRC. Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits. National Research Council, National Academies Press: Washington, DC, 2016
- Water Research Foundation. Residential End Uses of Water, Version 2: Executive Report, 2016. Retrieved from <http://www.waterrf.org/PublicReportLibrary/4309A.pdf>

SPONSORS

California Energy Commission
in collaboration with Jackson Family Winery

Demonstrating the potential for on-site electricity generation from food waste using containerized anaerobic digestion units

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Department of Food Science & Technology, University of California, Davis

BACKGROUND

Forty percent of food is lost or wasted across the food system life cycle and most goes to the landfill (Gunders, 2012).

- Landfills release methane gas, a potent greenhouse gas (GHG), into the atmosphere as food waste degrades
- Anaerobic digestion (AD) is an alternative to landfill disposal—it can treat food waste and produce electricity, heat, and fertilizer
- Hauling food waste to centralized landfills and centralized AD systems generates GHGs from the transportation
- Decentralized AD systems may reduce environmental and economic impact compared to conventional AD systems

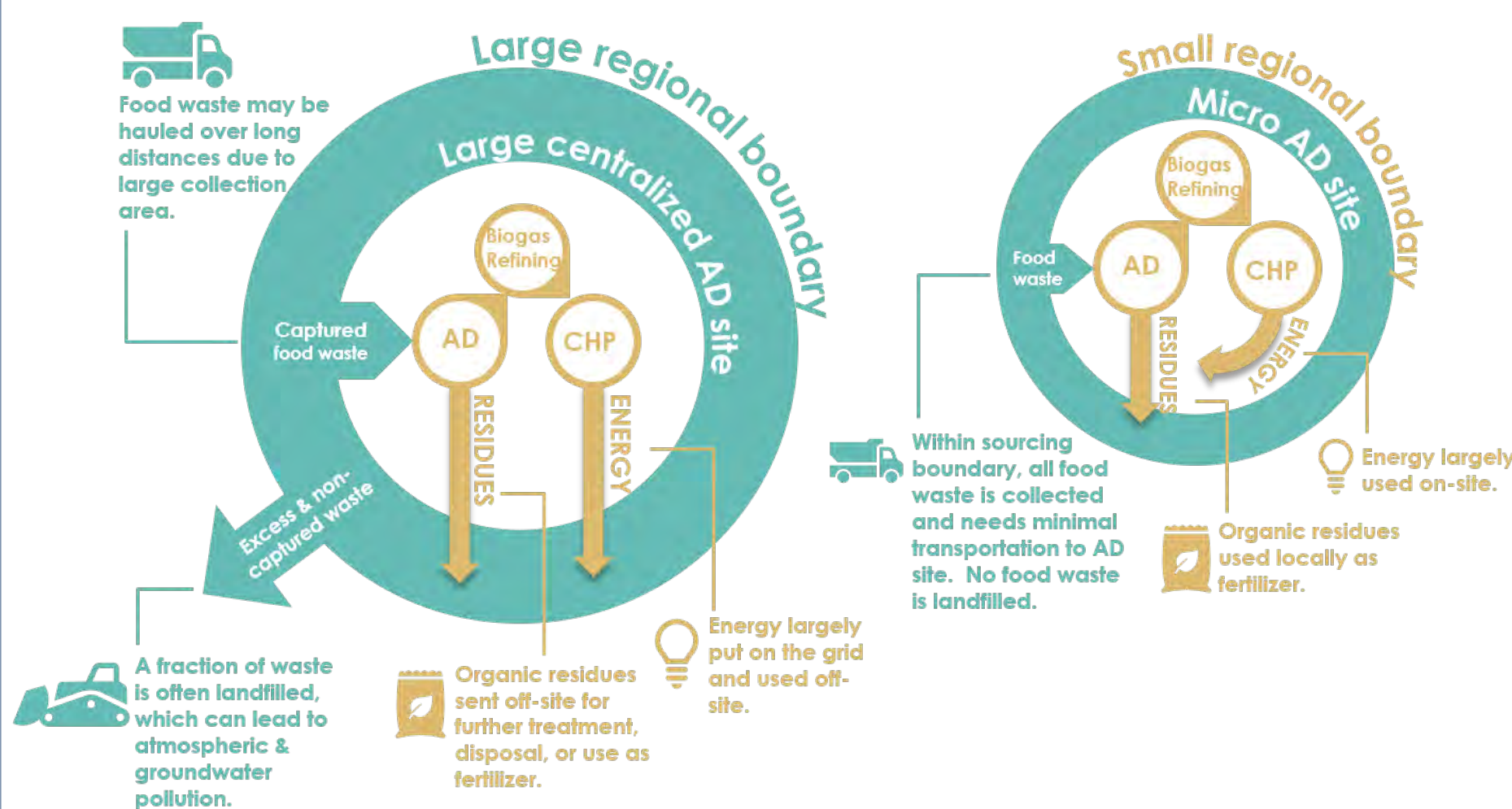


Figure 1. System and scale of proposed AD technology relative to large-scale, centralized AD

GOALS

Increase the deployment of cost-effective, small-scale AD systems to reduce environmental impact.

Objectives:

- Install and operate innovative, AD solution to process food waste
- Monitor and enhance pilot AD system performance
- Evaluate technology benefits
- Outreach and knowledge transfer

RESULTS



Figure 2a. Small-scale containerized AD unit. This image shows 5 digesters, 1 gasholder, a mouth unit, command unit, and a CHP unit.



Figure 2b. Mouth Unit



Figure 2c. CHP Unit

PROJECT BENEFITS

Deployment Scenarios	Electricity Savings (MWh/year)	Cost Savings (\$/year)	Demand Reduction (MW)	GHG Emissions Reduction - CO ₂ e (M metric tons/year)
1% Market Penetration	35,370	\$5.38M	450	9,967
50% Market Penetration	1,768,500	\$269M	22,500	498,365
100% Market Penetration	3,537,000	\$538M	45,000	996,730

Table 1. Estimated cost and emissions benefits to ratepayer from electricity savings achieved by small-scale AD systems (SCE, 2013). 1% market share represents 5400 homes in California.

Containerized AD units installed at U.S. Naval Base Ventura County.

System capability:

- Treat up to 6,700 lbs/day (min. 70% food waste)
- 64 kW combined heat and power (CHP) system generates
 - 479.5 MWh/year electricity
 - 27,740 therms of heat energy

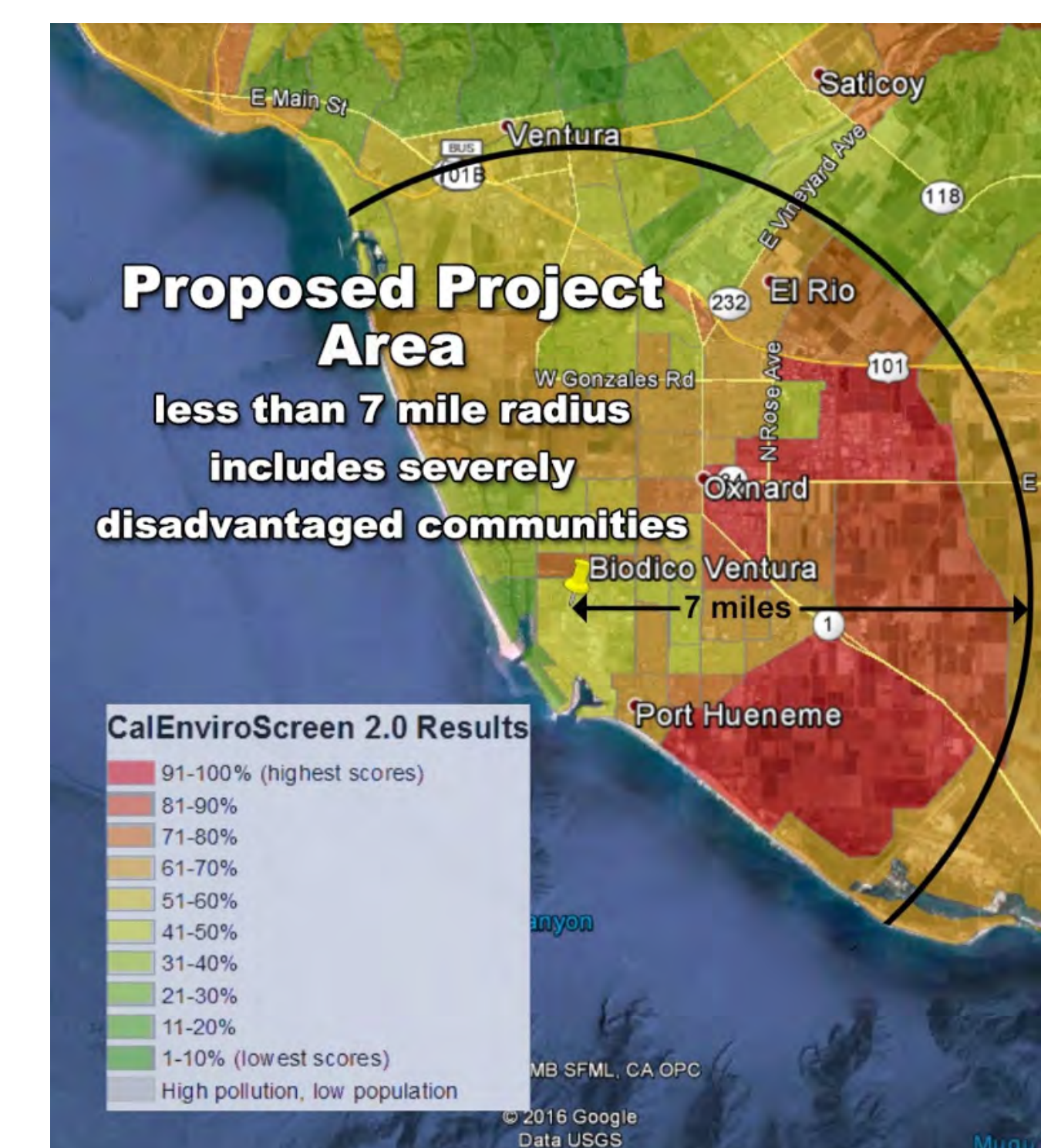


Figure 3. Food waste collected from local enterprises, including grocery stores, restaurants, and cafeterias. Food waste collected is considered non-recoverable for human consumption.

Levelized Cost of Energy (LCOE)

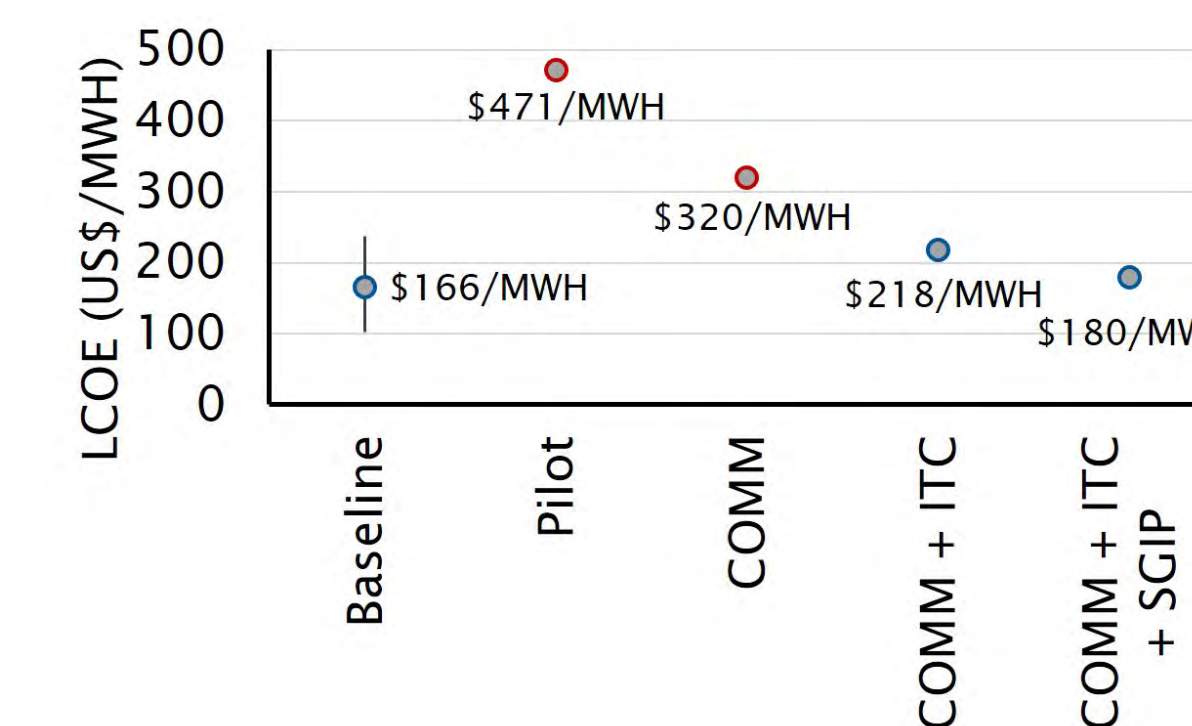


Figure 4. Levelized cost of energy scenarios for small-scale AD-CHP systems for food waste. Baseline represents current food waste-based systems, Pilot represents current small-scale AD-CHP technology, COMM includes commercialization efficiencies from scaling technology production, ITC represents the Federal Investment Tax Credit, and SGIP represents California's Self Generation Incentive Program.

DISCUSSION

The current LCOE for the small-scale AD system is \$471/MWh. After increased commercialization efficiency and financial incentives, the LCOE becomes competitive at \$180/MWh. Additionally, based on electricity savings alone, this system can generate up to \$538M cost savings and 996,730 M metric tons CO₂e GHG emission savings each year.

CONCLUSIONS

Decentralized, small-scale AD systems have the potential to produce positive local benefits from the "low-value" food waste stream. These systems can jointly optimize waste management and renewable electricity, heat, and fertilizer production for local California communities and additionally lead to cost savings for ratepayers.

As this system becomes more widely adopted, the levelized cost of energy will become economically competitive with existing technology in the market with some investment in scaling the production and installation. This technology may also provide additional environmental benefits, including reduced GHG emissions.

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- SCE electricity pricing forecast, 2017 commercial estimate: http://www.energyca.gov/2013_energypolicy/documents/demand-forecast/mid_case/

SPONSORS

California Energy Commission

In collaboration with Biodico Sustainable Biorefineries, SEaB Energy, and U.S. Naval Base Ventura County.

Nexus of Beer, Water, and Energy

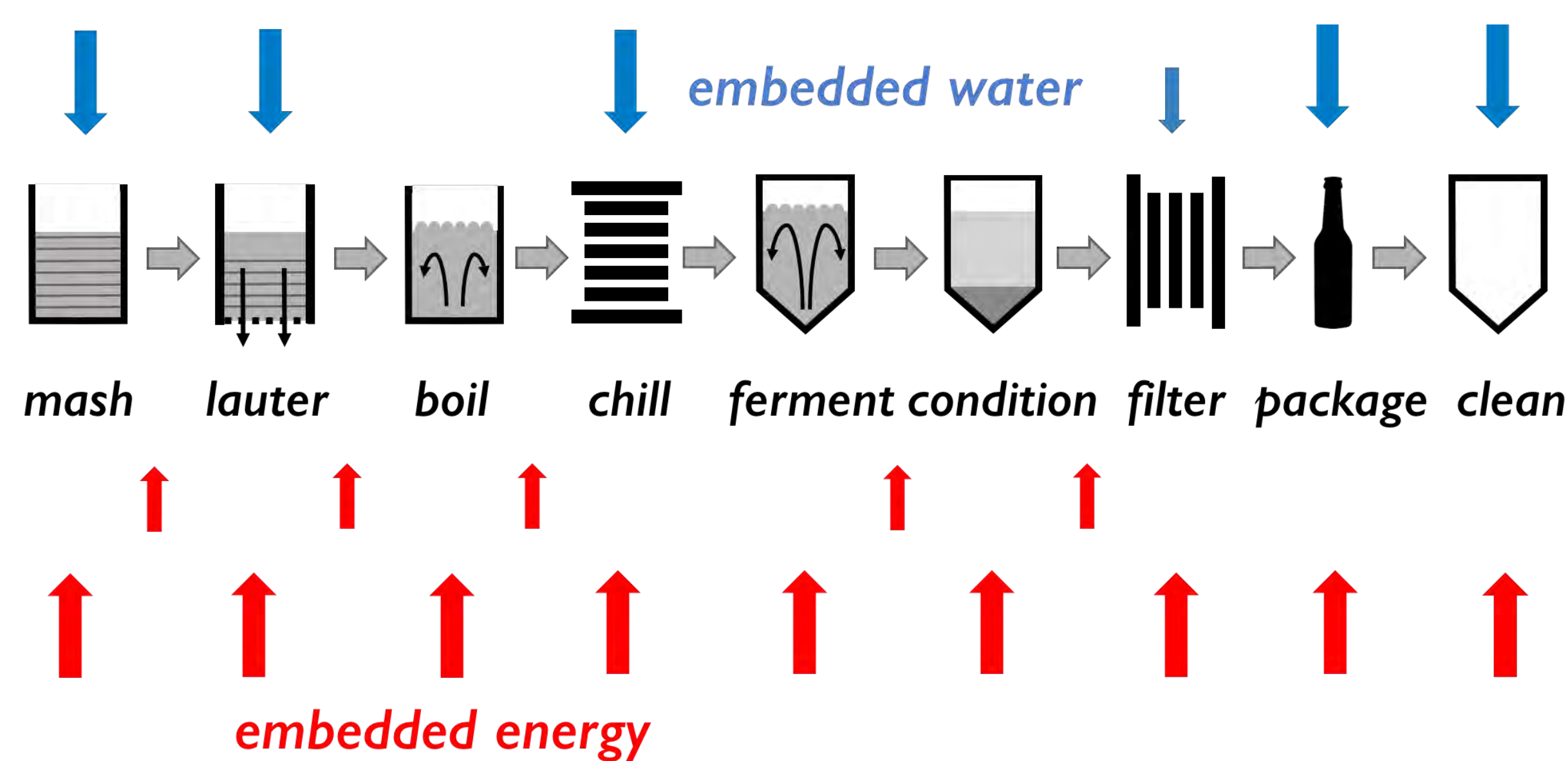
Case Study of a California Lager Microbrewery

Scott Peterson, Department of Food Science & Technology, University of California, Davis

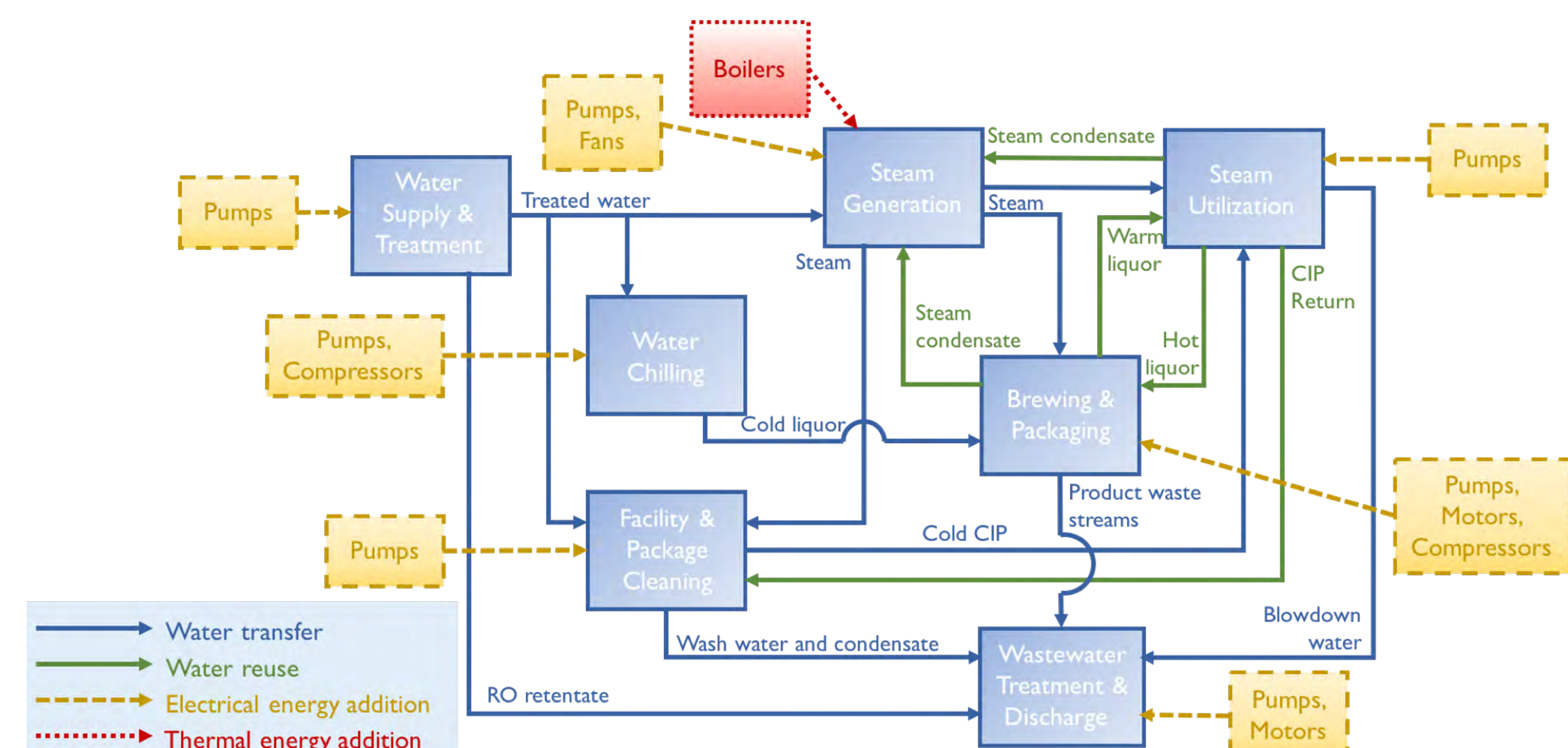
ABSTRACT

Understanding the consumption of water and energy in the brewing process is becoming increasingly important for brewers as they seek to reduce costs as well as respond to consumers' raised expectations for breweries to be environmentally conscious. However, brewing beer is inherently energy- and water-intensive: many multiples of water relative to the volume of finished beer are utilized and discharged during the brewing process, which also requires several energy-hungry heating and cooling stages. Recovery of waste heat and tiered usage of water may benefit small and medium-sized breweries who suffer from reverse economies of scale. This study investigates a microbrewery in Davis, California to quantify its water and energy usage compared to peer facilities, understand how these resources become embedded in its lager beer, and identify unnecessary resource waste. A water-energy-nexus (WEN) approach is taken to consider how each resource is consumed, independently or together, across unit operations of the brewery system. Structured pumping system and steam system assessments are conducted following guidance from the American Society of Mechanical Engineers. Resource efficiency measures are proposed based on the WEN analysis to deliver energy and monetary savings for the facility.

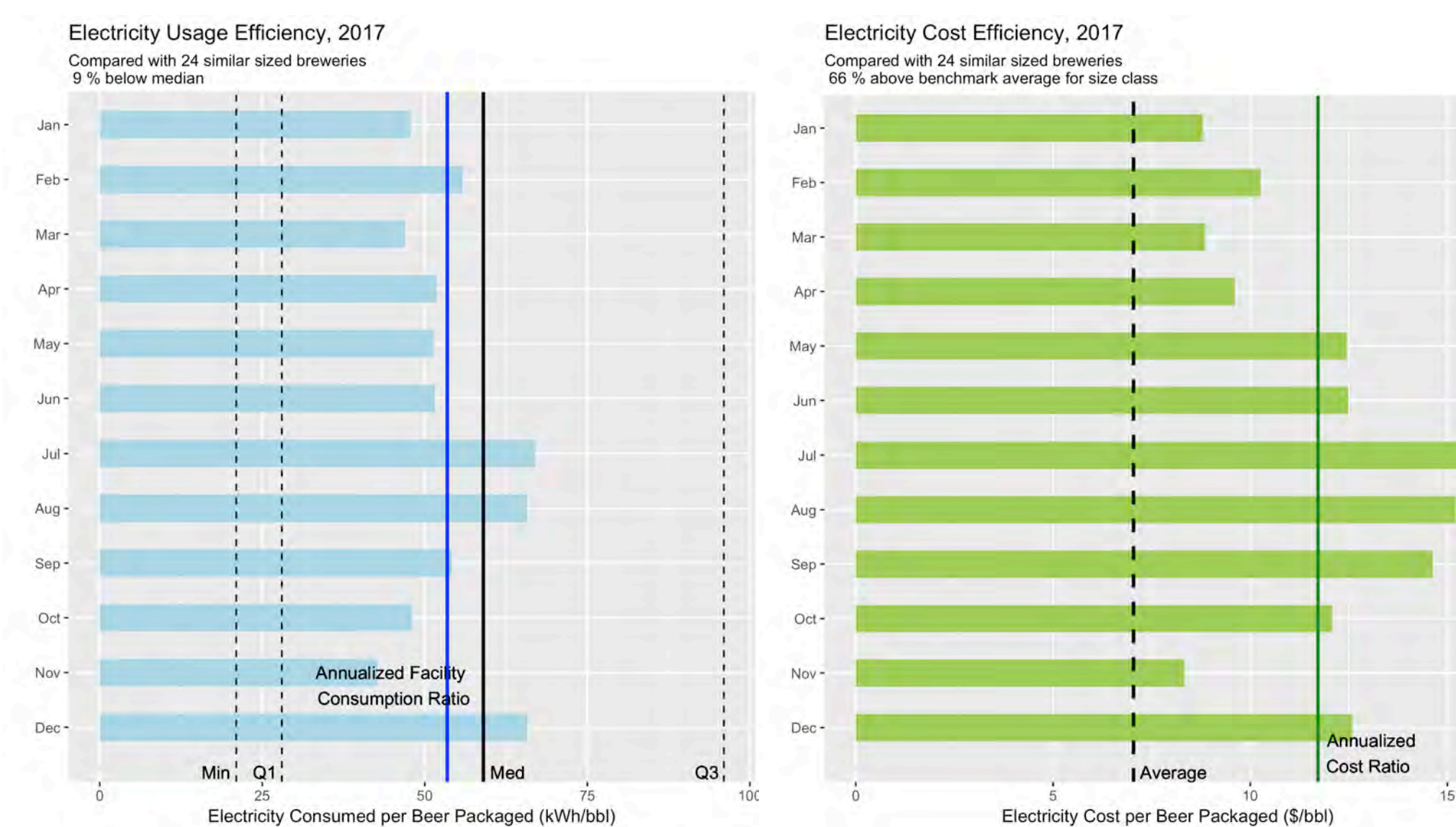
THE BREWING PROCESS



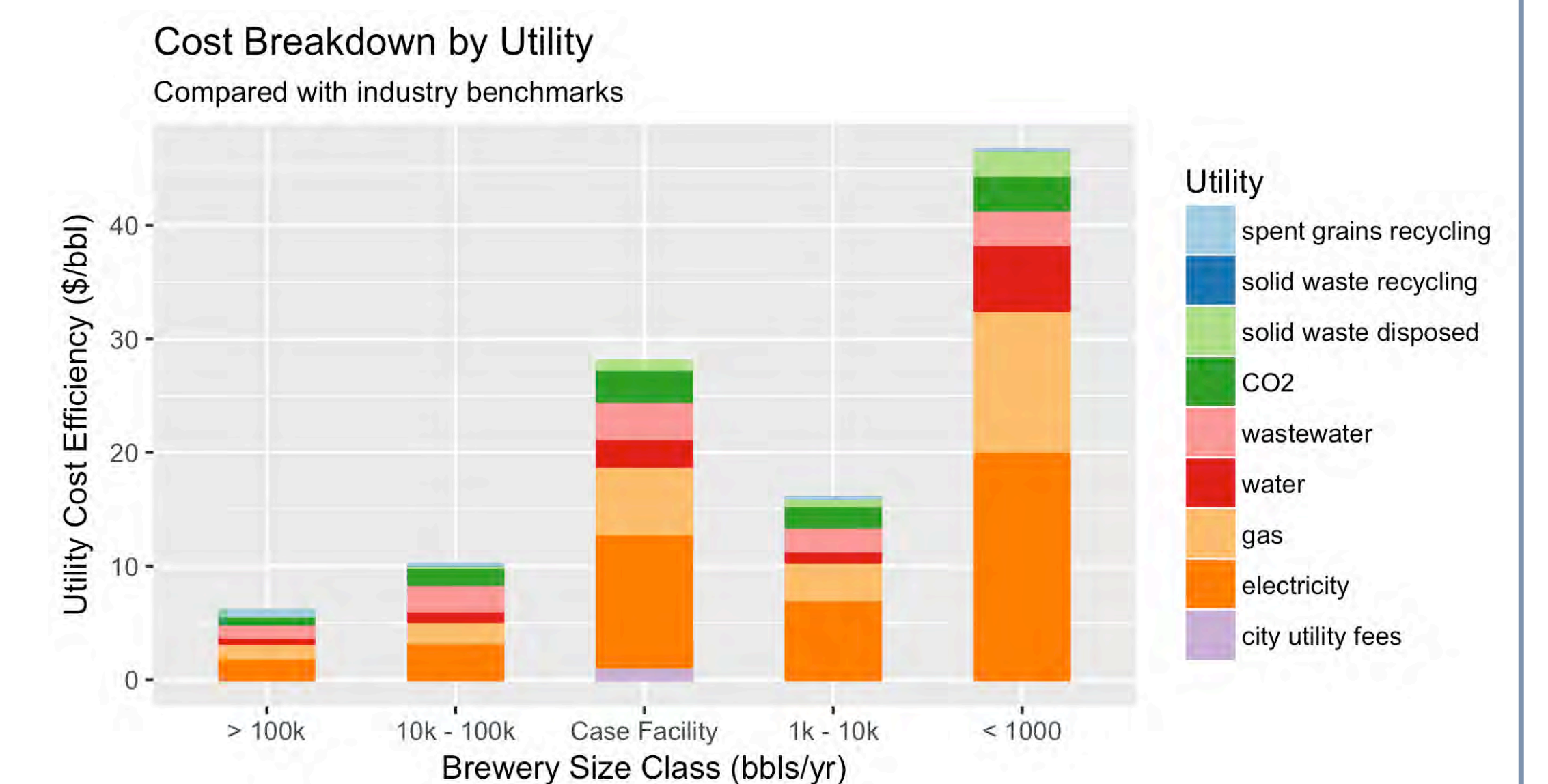
THE FACILITY



RESULTS - ELECTRICITY



RESULTS - ALL UTILITIES



CONCLUSIONS / FUTURE WORK

- Electrical use is in-line with peers; peak charges during summer months lead to cost penalties
- Consumption of other resources (water, natural gas, CO₂) is high relative to peer facilities; further investigation and investment are required to reduce these footprints
- Pump and steam system assessments must be finalized and water-energy intensity quantified
- Power metering is required to breakdown electrical consumption by process
- Water and energy balance must be constructed to identify resource efficiency measures
- Resource efficiency measures should be facility-specific as well as applying more broadly to the brewing industry

METHODS

- ASME Energy Assessment for Steam Systems
- ASME Energy Assessment for Pumping Systems
- Resource consumption benchmarking compared to industry peers
- Water-Energy Nexus Assessment

RESEARCH TEAM

- Scott D Peterson, UC Davis
- Ricardo Amón, UC Davis
- Christopher W Simmons, UC Davis,
- Edward S Spang, UC Davis
- Tony Wong, KWW Energy Services LP
- Mike Maulhardt, UC Davis
- Charles W Bamforth, UC Davis

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- Amón, R., T. Wong, D. Kazama, M. Maulhardt, T. Maulhardt, and C. W. Simmons. 2017. Assessment of the Industrial Tomato Processing Water Energy Nexus: A Case Study at a Processing Facility. Journal of Industrial Ecology.

SPONSORS

- Peter J. Shields and Henry A. Jastro Research Award
- Anheuser-Busch Endowed Chair of Malting & Brewing Sciences

In partnership with Sudwerk Brewing Co.

Water Energy Nexus in Informal Water Systems

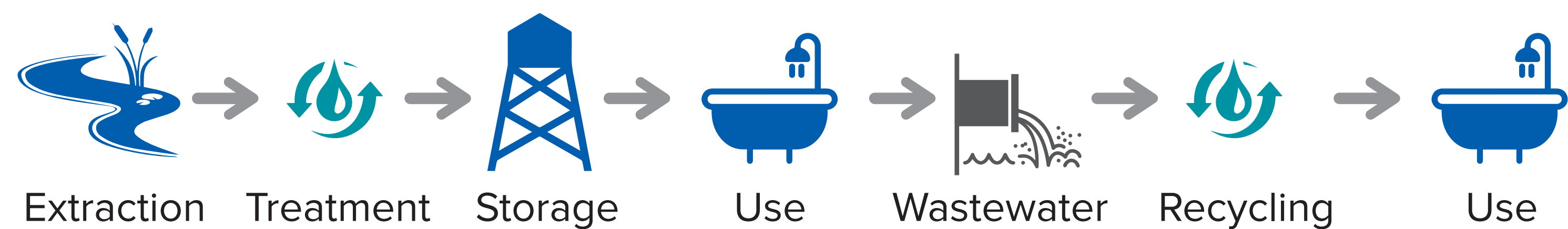
Yasmina Choueiri, Geography Graduate Group, University of California, Davis

RESEARCH FOCUS

Water and energy are interdependent systems. Research projects usually study their nexus in conventional water systems by identifying the correlation between water and energy of large scale supply systems and residential water systems.

This research looks at the water energy nexus in informal water systems.

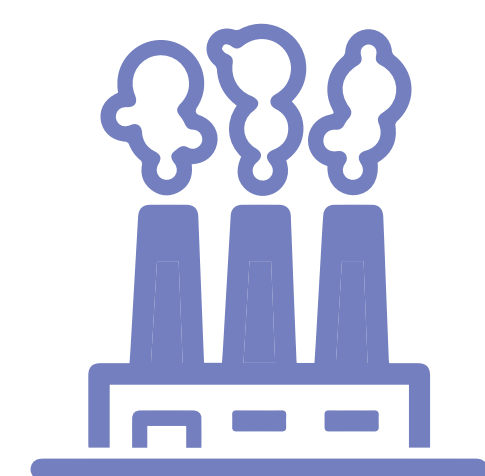
CONVENTIONAL WATER SYSTEM / WATER ENERGY NEXUS



Energy is used at all phases of conventional water distributions systems



Residential Demand Side



CO₂ Emissions

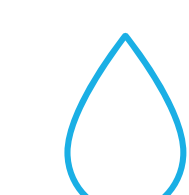


Energy Bills

INFORMAL SYSTEMS

“Ever-shifting relationship between what is legal and illegal, legitimate and illegitimate, authorized and unauthorized” (Roy, 2009).

- Usually fills the gap of a failing system or infrastructure
 - Stems from weak governance
 - Complex: legal and illegal
- Coined in 1970 (Hart): informal employment in Ghana
 - Flexible and Resilient



Water



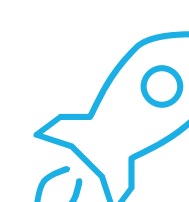
Wastewater



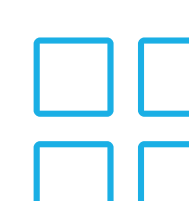
Solid Waste



Energy



Transportation



Public Spaces

CASE STUDY: INFORMAL WATER SYSTEMS IN LEBANON

Alternative water sources:



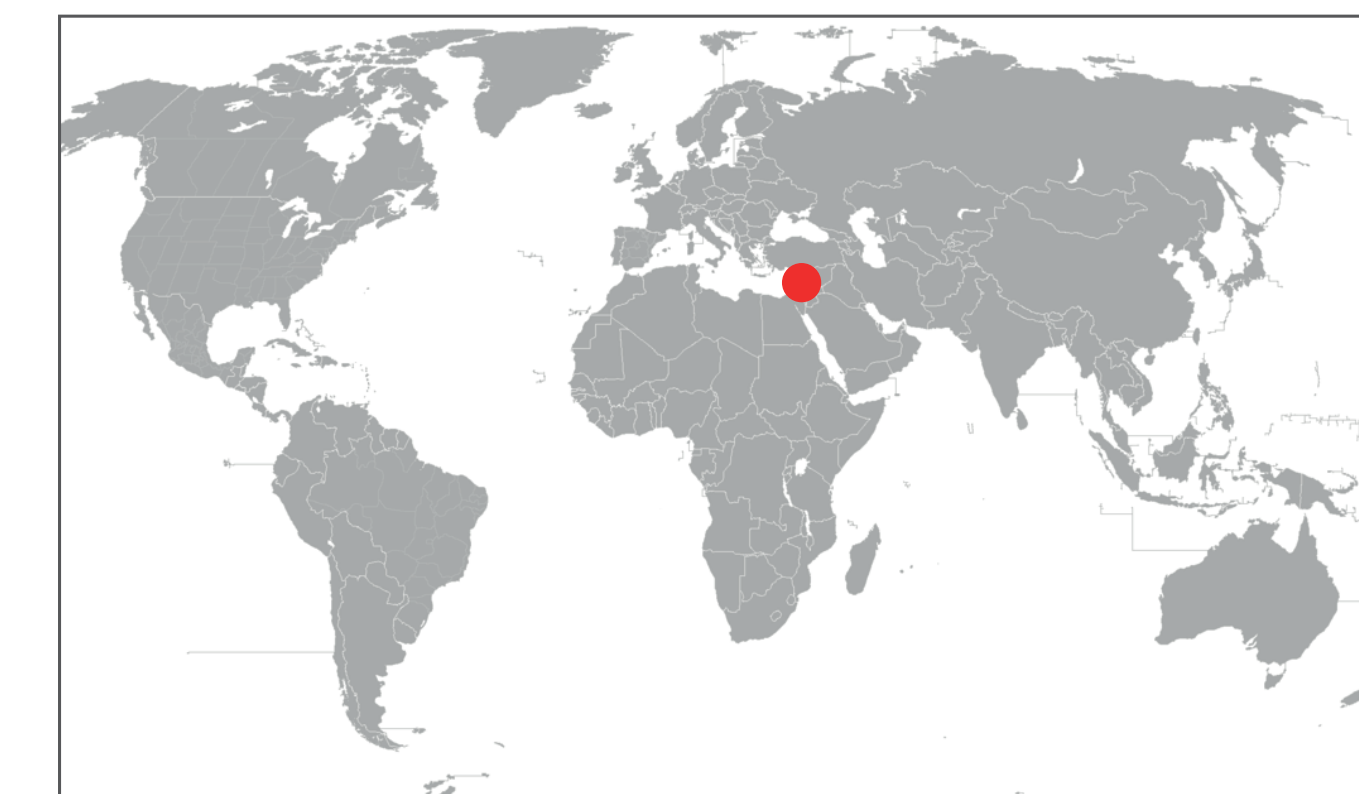
Water Trucks



Wells



Bottled Water



The Lebanese water system: between formal and informal

Water supply is intermittent -- few hours every other day: households can receive as little as 0.065 m³ per day.

IMPACTS



Environmental

Depletion of Resources



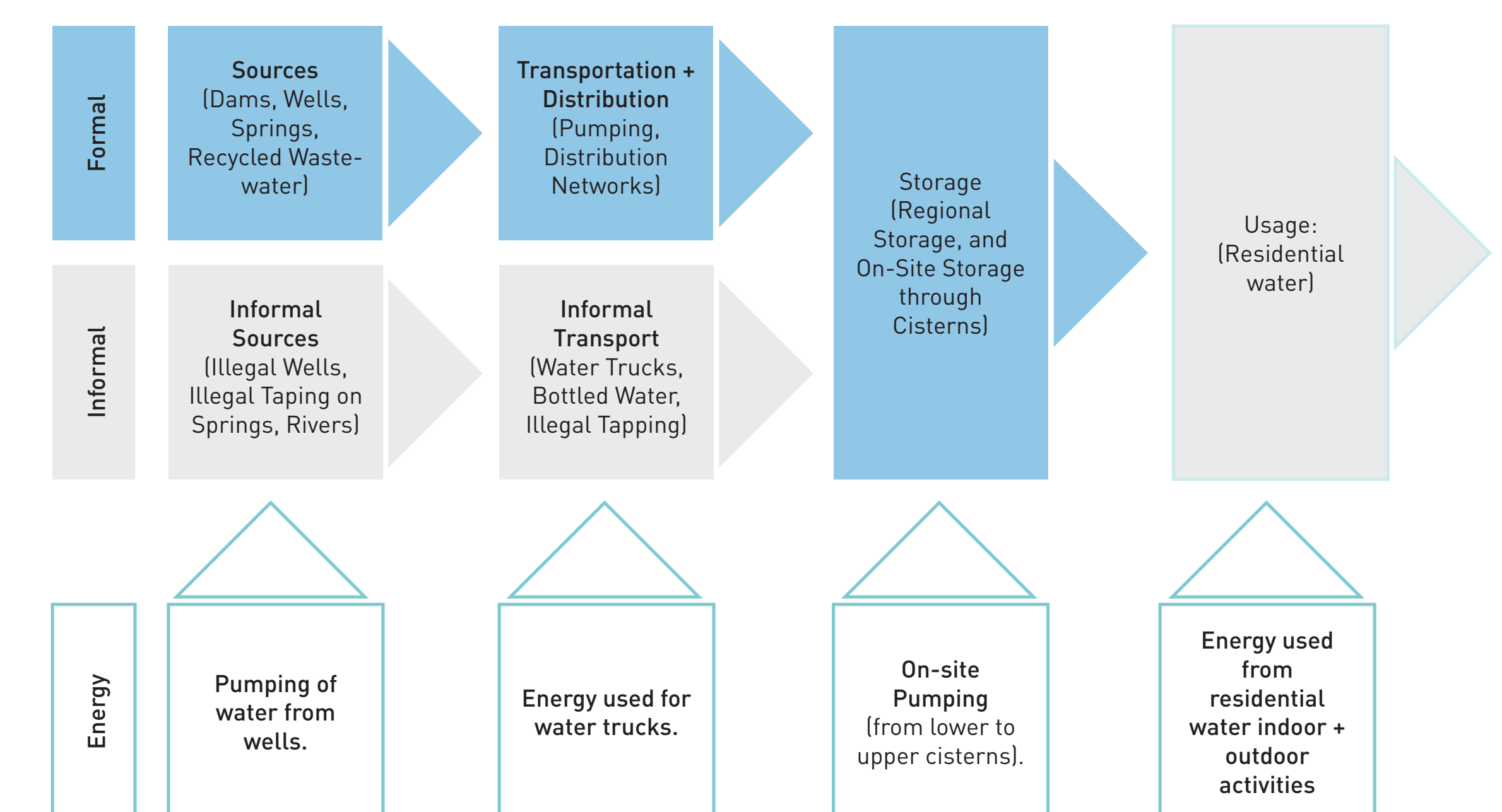
Economic

300% increase in \$



Social

Affordability



INFORMAL WATER-ENERGY NEXUS IMPACTS



Energy from Trucks and on-site Pumps



Diesel Oil consumption and CO₂ Emissions

CONCLUSION

Informality is everywhere!

Daily power outages -> private generator that provides electricity to households.

What about the correlation between informal energy systems and water use?

Further Research

Beirut, the capital, suffers from 3 hours of power outages per day

-> Households' water activities use approximately 12.5% of electricity from private generators

Energy Intensity of Wholesale Water in California

Jon Martindill, Energy Graduate Group, University of California, Davis

ABSTRACT

About two percent of the state's total energy use is used for the conveyance, treatment, and distribution of water (DWR, 2016). Consequently, California's water infrastructure is an emerging target for energy efficiency and greenhouse gas emission reduction efforts. However, allocating energy and GHG reduction dollars to water efficiency programs requires an accurate method for calculating the energy intensity of water, as well as verifiable monitoring of energy and carbon savings. While the UC Davis Center for Water-Energy Efficiency has established a method to verify the energy intensity of individual water systems, extending this methodology to the state's wholesale water supply system is needed to include the upstream embedded energy of water systems throughout the state.

The Wholesale Water Model calculates the energy intensity of water as it passes through pumping stations and generating facilities along the **State Water Project (SWP)**, the **Colorado River Aqueduct (CRA)**, and the **San Diego County Water Authority (SDCWA)** – three of the largest wholesale water conveyance systems in California. The SWP and CRA are the primary sources of supply for the **Metropolitan Water District of Southern California (MWD)**, which is the largest water retailer in the state. This model is the first step towards building a generalized method for calculating the energy intensity of water anywhere in California. The successful implementation of a statewide model may lead to greater investment in water-energy conservation measures.

METHODS

The Wholesale Water Model tracks water flow and energy use or generation through water infrastructure “assets”, which include pumping stations, wells, treatment plants, and generating stations. As water flows through assets, the energy used or generated from each asset is “embedded” in the water. Where data is available, the energy use or generation of each asset is applied directly. No energy or flow data was available for assets in the CRA, however, so a regression model was built that estimates the energy intensity of a pumping station based on its static pumping head (**Figure 1**).

RESULTS

Cumulative energy intensity of the SWP, CRA, MWD, and SDCWA were all calculated (**Figure 2**). Pumping water up an elevation gradient increases the embedded energy of water, though the SWP occasionally recovers some of that energy intensity using generation on downhill slopes (**Figures 3, 4**). The resulting model can be used to estimate the energy intensity of water delivered to water retailers or other customers of these wholesale water agencies.

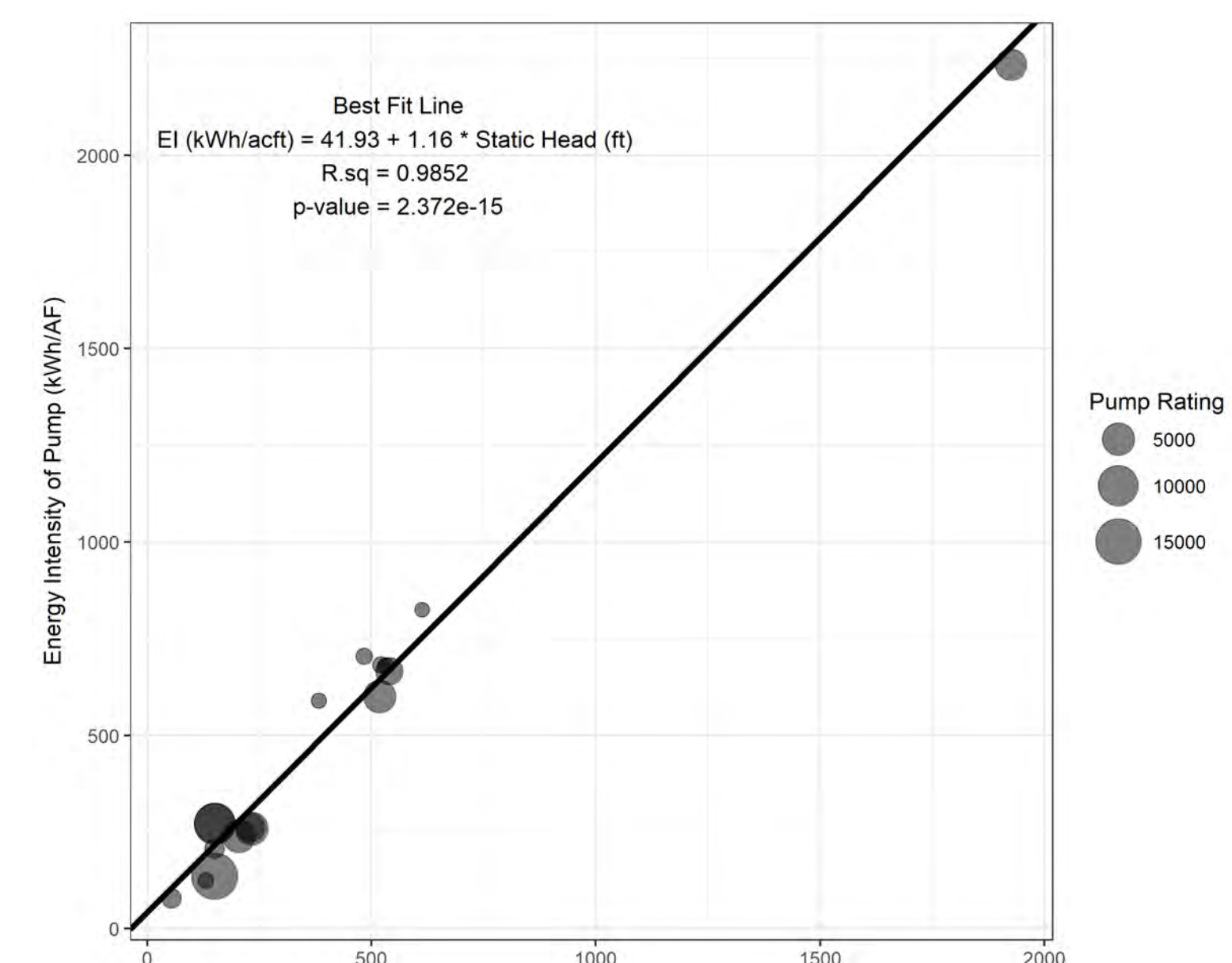


Figure 1. Energy intensity of SWP pumps is strongly predicted by static head

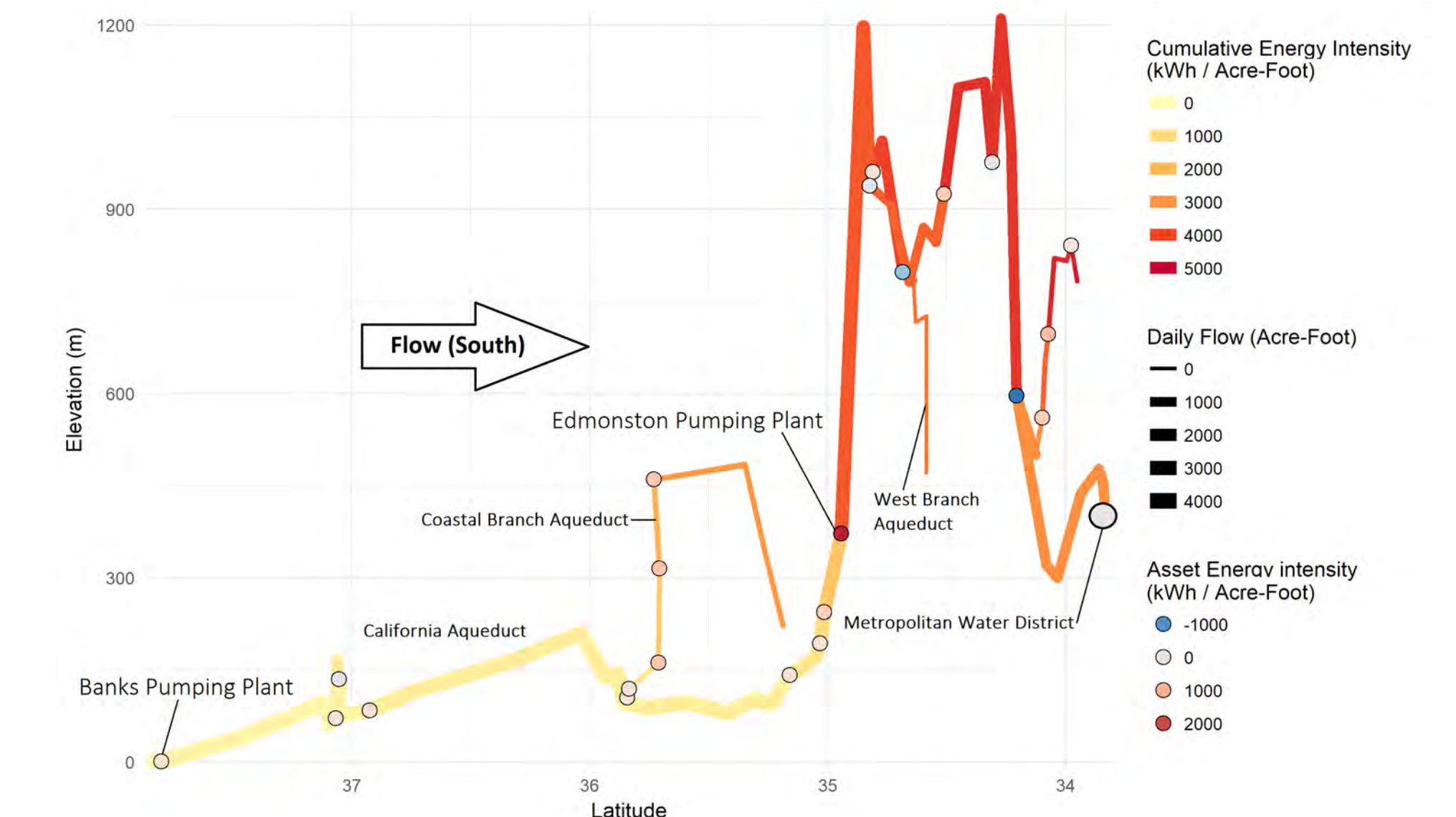


Figure 3. Elevation profile of the California State Water Project



Figure 2. Energy intensity map including SWP, CRA, and SDCWA

CONCLUSION

This model can be used to calculate the energy intensity of water delivered to any water district served by the SWP, CRA, MWD, or the SDCWA. In a potential future where water conservation programs are considered for carbon and energy-reduction measures, the ability to demonstrate the cumulative upstream energy intensity of water systems will be vital. More work is required to continue building and refine the Wholesale Water Model, as well as building specific energy intensity metrics for individual water agencies throughout the state. Also, including energy intensity of water treatment and reclamation will be key in building a true picture of the energy intensity of water in the state.

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California's urban water conservation mandate delivers bonus energy and greenhouse gas savings

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STUDY OVERVIEW

In April 2015, the Governor of California mandated a 25 percent statewide reduction in water consumption (relative to 2013 levels) by the more than 400 urban water utilities in California. The UC Davis Center for Water-Energy Efficiency analyzed the water use data reported by the utilities to the State Water Resources Control Board during the 12-month mandate and assessed the resulting electricity and greenhouse gas (GHG) emissions reductions associated with reduced urban water infrastructure operations.

The results show that the State succeeded in reducing water use by a total of 24.5% relative to the 2013 baseline. The total electricity savings linked to water conservation are approximately 11% greater than the savings achieved by the investor-owned electricity utilities' (IOU) efficiency programs for roughly the same time period, and the GHG savings represent the equivalent of taking ~111,000 cars off the road for a year.

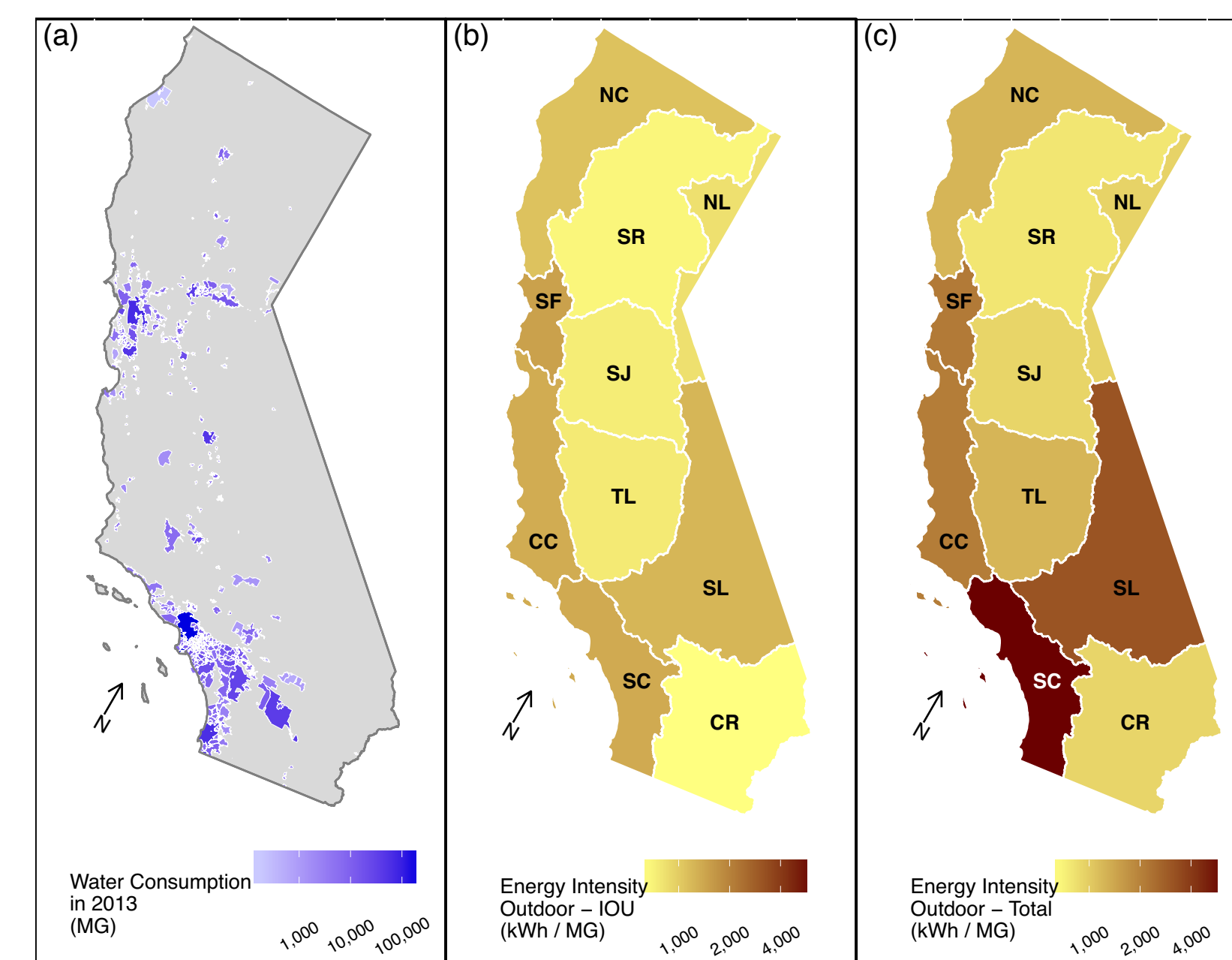


Figure 1. Water consumption by urban water supplier service area (a), and IOU energy intensity (b) and Total energy intensity (c) by California's hydrologic regions.

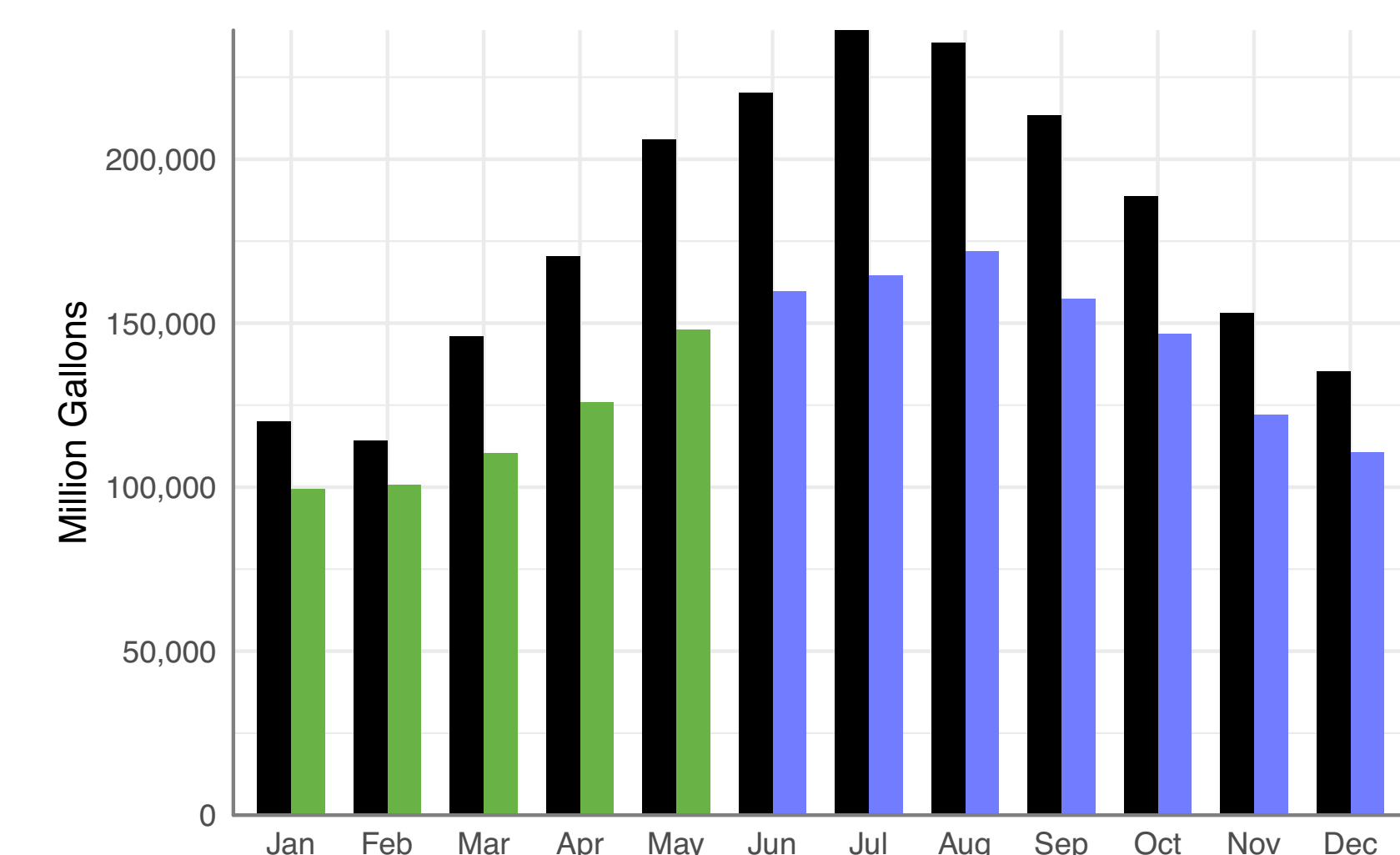


Figure 2. Reported monthly water deliveries (June 2015 - May 2016) relative to 2013 baseline values

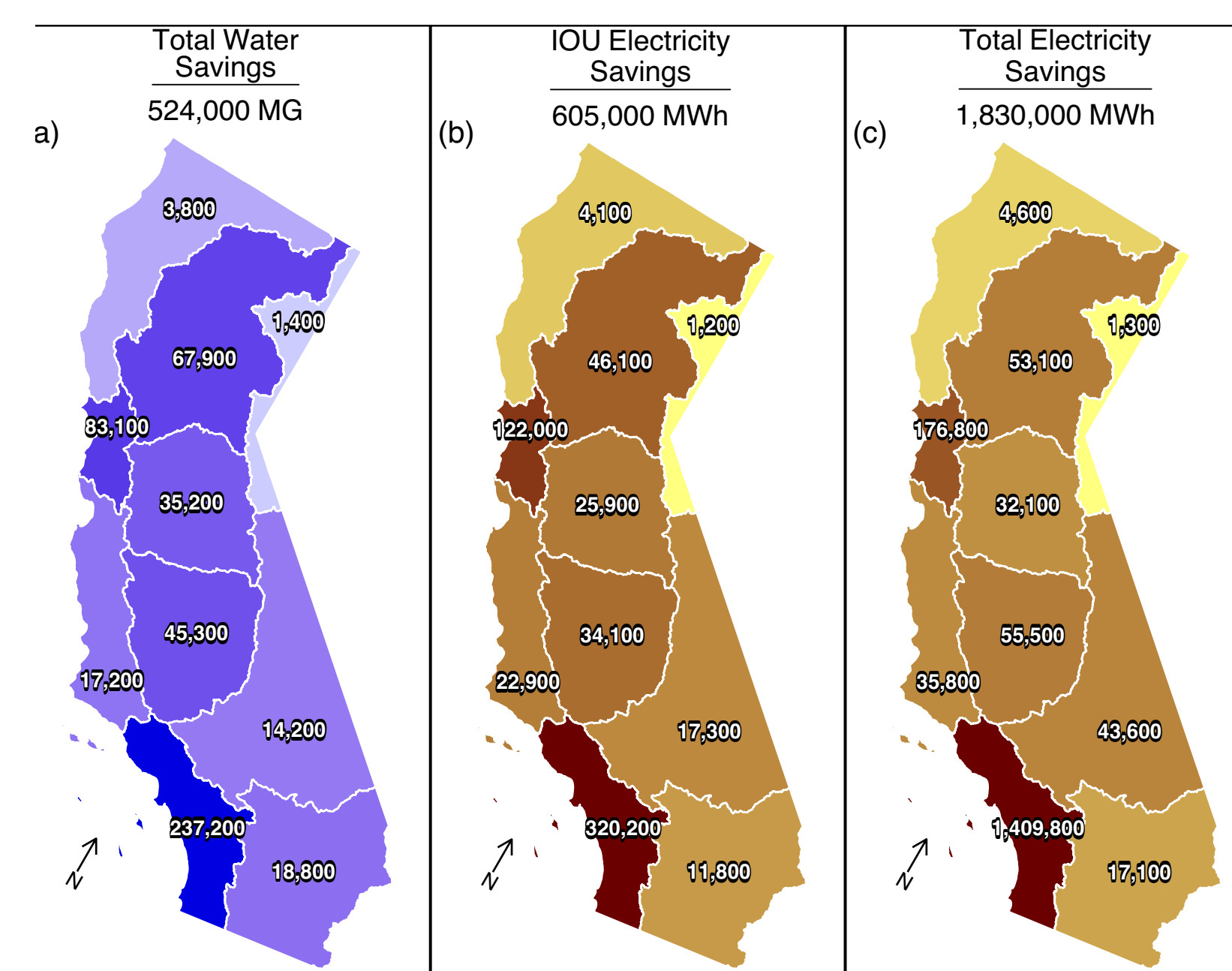


Figure 3. Observed water savings - 24.5% reduction from the baseline (a), estimated IOU electricity savings (b), and estimated total electricity savings (c) achieved over the duration of California's urban water conservation mandate

ENERGY SAVINGS FROM WATER CONSERVATION

Energy savings from reduced water use was estimated utilizing two different energy intensity metrics (the energy required to deliver a unit of water to the end-user) for the water supply portfolios associated with the ten hydrologic regions of California, "Total" and "IOU" (Figure 1, (b) and (c)). **Total energy intensity** refers to the total electricity consumption utilized for water sourcing and delivery, regardless of the electricity generating institution. **IOU energy intensity** refers only to the electricity consumed by the water infrastructure that was generated by an investor-owned utility. This is a critical distinction because of the over \$1 billion available annually for IOU allocated energy efficiency programs (per California Public Utility Commission policy) which is a potential funding source of water-energy conservation programs.

TAKE AWAY

The cost of achieving integrated water-energy-GHG savings through water conservation are shown to be cost competitive to existing programs that specifically target electricity or GHG reductions. These results support including direct water conservation in the portfolio of program and technology options for IOU energy efficiency programs and the GHG Revolving Fund. Furthermore, the results reveal a strong incentive for water and energy utilities to partner on opportunities for combined resource savings at a shared cost; and, for the associated regulatory agencies to support these partnerships through aligned policy measures and targeted funding initiatives.

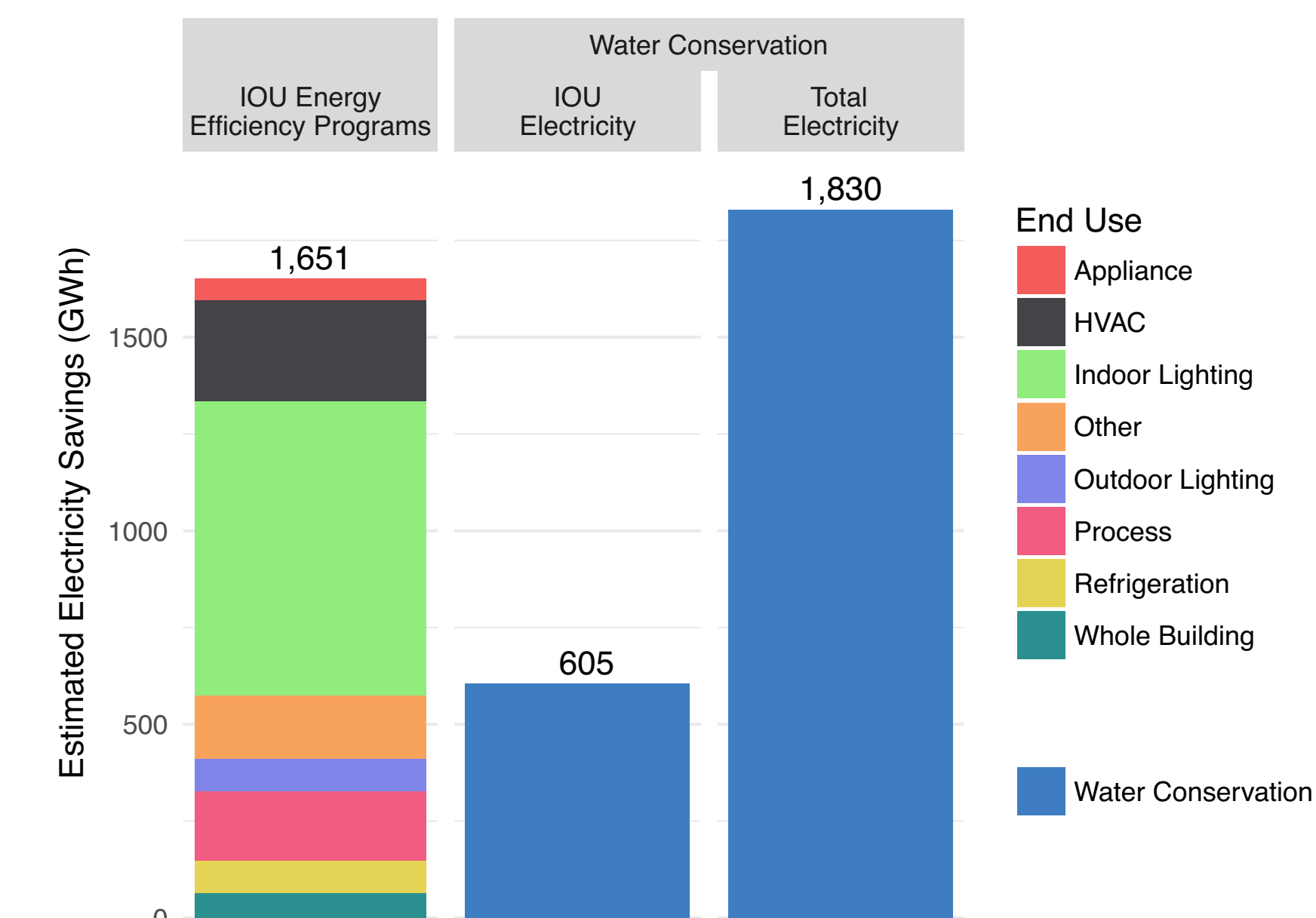


Figure 4. Electricity savings from IOU EE programs (July 2015 - June 2016) by end-use category vs. estimated electricity savings (IOU and total) from statewide water conservation (June 2015 - May 2016)

Table 1. Total GHG Emissions Savings by Hydrologic Region.

Hydrologic Region	MT CO ₂ e Saved
Central Coast	10,210
Colorado River	4,870
North Coast	1,310
North Lahontan	380
Sacramento River	15,510
San Francisco Bay	50,400
San Joaquin	9,160
South Coast	401,790
South Lahontan	12,430
Tulare Lake	15,810

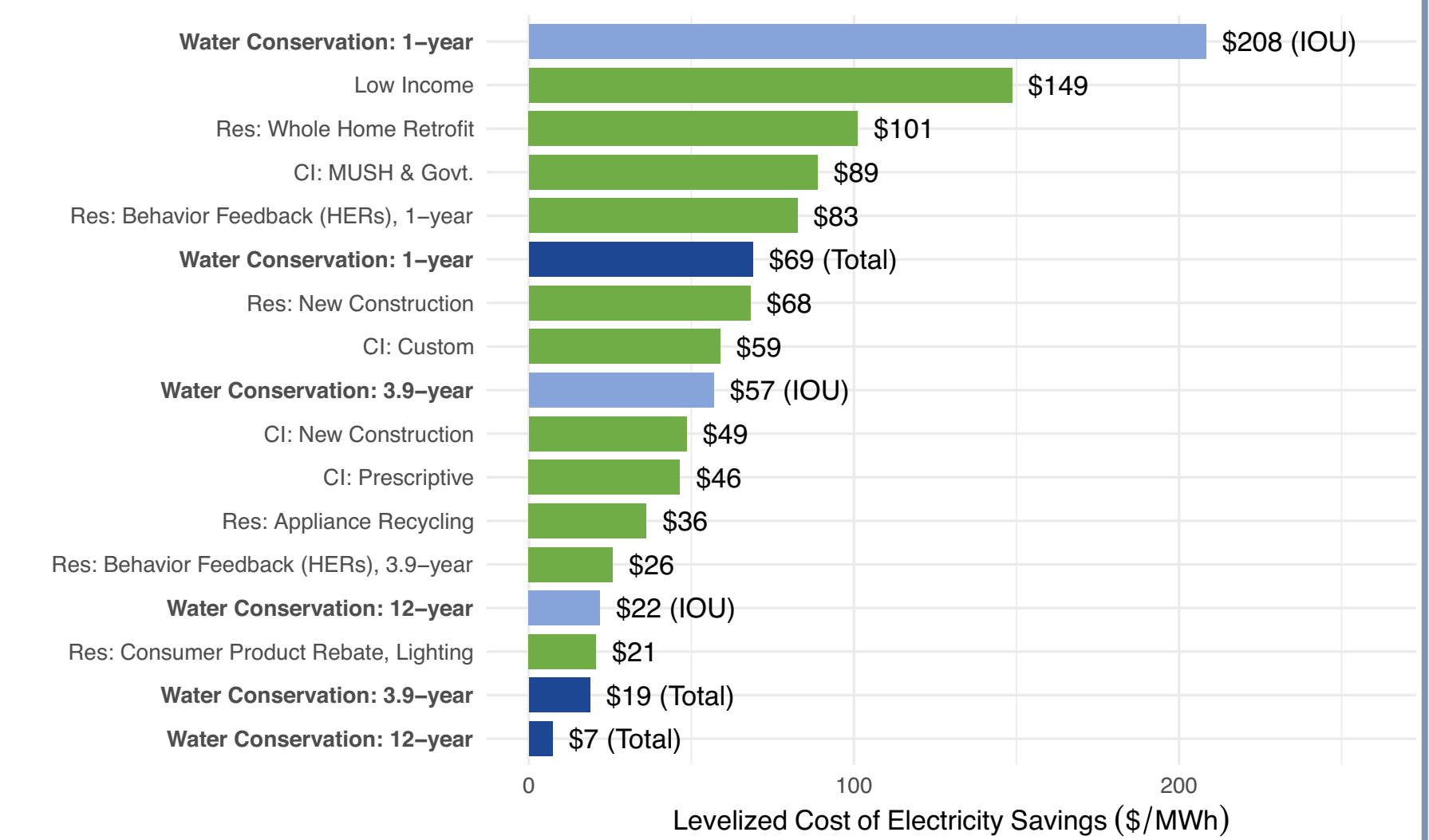


Figure 5. Comparison of the levelized cost of electricity savings achieved through statewide water conservation relative to other energy efficiency programs (adapted from Hoffman et al (2015)). Notes: "Res" = Residential; "CI" = Commercial, Agricultural, and Institutional; "MUSH" = Municipalities, Universities, Schools, and Hospitals; and "HERs" = Home Energy Reports.

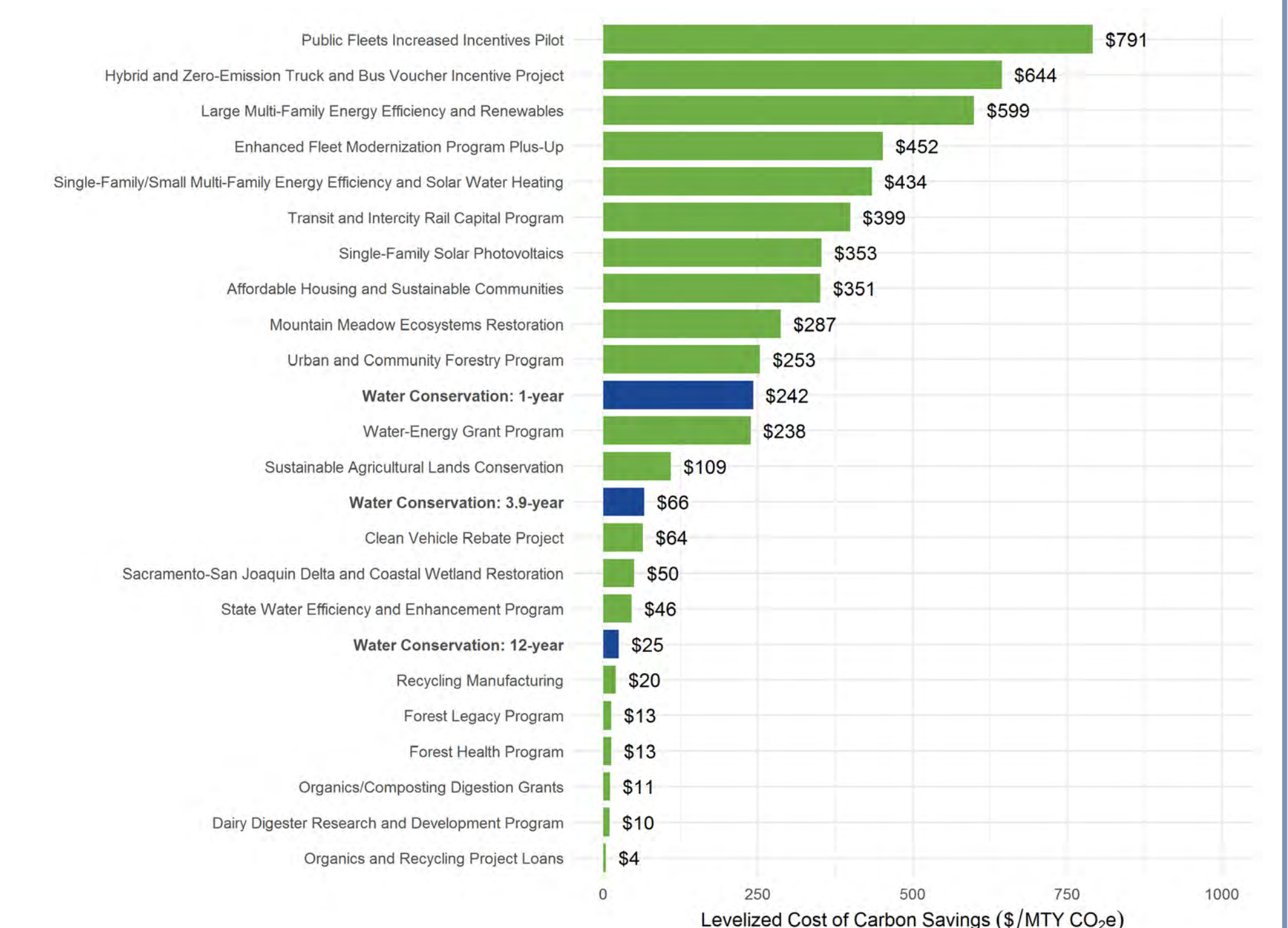


Figure 6. Comparing the levelized cost of saved GHGs savings achieved through statewide water conservation relative to GGRF program investments (CARB (2016a))

REFERENCES

- CARB 2016a Annual Report to the Legislature on Investments of Cap-and-Trade Auction Proceeds - 2016 (Sacramento, CA: California Air Resources Board (CARB))
- Hoffman I M, Schiller S R, Todd A, Billingsley M A, Goldman C A and Schwartz L C 2015 Energy Savings Lifetimes and Persistence: Practices, Issues and Data (Berkeley, CA: Lawrence Berkeley National Lab (LBNL))