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The Energy Implications of Greater Reliance on Direct Potable Reuse Water Recycling in ImportReliant Regions

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The Energy Implications of Greater Reliance on Direct Potable Reuse Water Recycling in Import-Reliant Regions

Evidence from Los Angeles County

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

The Energy Implications of Greater Reliance on Direct Potable Reuse Water Recycling in Import Reliant Regions is the final report for the Optimizing Use of Non-traditional Waters, Drought Proofing the Electricity System and Improving Snowpack Prediction project (300-15-006-03) conducted by The Regents of the University of California, on behalf of the Los Angeles Campus. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's website at www.energy.ca.gov/research/

ABSTRACT

This research explores the energy intensities to implement an advanced water treatment process, specifically for direct potable reuse (DPR) and seeks to inform decision makers on important considerations facing water managers, energy managers, and environmental actors. This study uses the County of Los Angeles as a case study to quantitatively examine the water, energy, and greenhouse gas tradeoffs of utilizing different water supply sources. This project particularly models four different treatment trains which are being tested in California, three of which rely on advanced membrane filtration to achieve pathogen removal. Across these trains, the analysis shows various energy intensities ranging from 497 kWh/AF to 1,374 kWh/AF and estimates that their use could increase energy consumption at wastewater treatment facilities by a factor of 2.3 to 3.3. DPR can refer to two distinct management approaches untreated (raw) and treated water augmentation. The former refers to introducing recycled water directly into a drinking water system distribution network, while the latter requires the water to be treated again before reintroduction to the drinking water supply. We calculate the total energy needed for raw (untreated) water and treated water augmentation strategies and compare these results to existing water supply options like imported water and desalination. The first conclusion of the analysis is that despite the high energy intensity of DPR, raw water augmentation can be relatively energy efficient when compared to imports and desalination as it avoids large uphill pumping energy costs. Treated water augmentation, however, is shown to be as energy intensive as imports to Los Angeles County. The secondary analysis of the report details likely power mixes to be utilized by different water supply sources and, thus, quantifies their expected greenhouse gas intensities. Converse to energy intensity findings, imported water has a very low greenhouse gas intensity due to its primary source being hydroelectric. Extending the analysis to the timeline on which DPR may be implemented (est. 2035), findings show that the disparities in greenhouse gas intensities are greatly diminished. This means that carbon impacts in this sector can be a lower priority during future decision-making if energy providers can achieve their promised emissions reductions.

Keywords: *water, reuse, recycling, potable, water-energy, intensity, desalination, imports, GHG*

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EXECUTIVE SUMMARY

Introduction or Background

As California aims to achieve its ambitious clean energy goals, grid managers, electricity providers, and regulators must consider how to meet electricity demand reliably and affordably. Increases in statewide electricity demand affect the ability of the state to meet existing and future energy needs. It is even harder to do so without triggering expensive electrical transmission and distribution infrastructure upgrades, costs which get passed on to ratepayers. In 2023, wastewater facilities across the state will have the opportunity to develop much needed, yet highly energy intensive, water recycling. This development has important implications for California’s electrical grid as it will change where and how much energy is demanded. Depending on which technologies are adopted by these facilities, the increased demand may result in increased generating needs and upgraded transmission and distribution infrastructure in high impacted areas. It is, therefore, important to understand differences in these new water treatment technologies’ energy impacts.

With an increasingly uncertain climate, the security of California’s long-term water supply is unpredictable. Water recycling, such as wastewater treatment and reuse, enables the state to bolster its supplies by re-utilizing existing water flows to meet demand. Different types of water recycling have been implemented in California since the 1970s, but recent droughts and technological developments have spurred renewed interest in recycling water to potable quality (Potable Reuse) to augment drinking water supplies. For water managers, potable reuse is seen as an important tool in maintaining steady, sustainable water supplies in the face of variable climate. Much of the currently utilized recycled water across the state is non-potable, but Direct Potable Reuse (DPR) is a strategy of emerging interest, where wastewater is reclaimed using advanced technologies and reintroduced to drinking water systems as an additional supply. DPR, however, can be energy-intensive, and implementation could significantly impact the energy grid. Effective decision-making for public and environmental interests will require understanding the tradeoffs and implications of DPR to energy, greenhouse gas, and water management budgets.

The California State Legislature mandates that California’s highest water policy entity, the State Water Resources Control Board (SWRCB), adopt new DPR regulations that describe its allowable implementation. Although currently disallowed, DPR is already an attractive solution in Los Angeles County, where both the City of Los Angeles and the Los Angeles County Sanitation Districts are planning and piloting advanced recycled water treatment facilities that reclaim wastewater to potable quality. Currently, at the forefront of this decision is the choice to allow the implementation of Raw Water Augmentation (RWA) and Treated Water Augmentation (TWA), two distinct strategies under the umbrella of DPR. The former, RWA, is accomplished by treating wastewater to potable quality and returning these flows to the influent (raw water) streams of drinking water treatment plants to be retreated. TWA treats wastewater to potable quality and directly reintroduces this stream into the drinking water distribution system--that is, augmenting water that has already been treated.

Ultimately, the decision on whether and which DPR strategies will be allowed will fall to the SWRCB, and this analysis assesses how these two strategies might differently influence the water and energy sectors. Despite strong water-sector interest in DPR, little guidance or support exists for water agencies to examine the energy impacts of DPR decisions beyond their own operational boundaries, and this report is a starting point to address this information gap. In Southern California, the discussion of DPR takes place alongside other water supply alternatives, such as increased freshwater imports and desalination. Evaluating the impacts of DPR in regions with diverse water supply alternatives, energy intensities, and energy sources requires a comparative analysis of existing water supply strategies to discern the relative benefits of each approach.

While existing research provides a description of the range of water supply and energy use possibilities for the region, the variable implementation strategies being considered by regulatory decision-makers (TWA and RWA) and the diverse treatment processes that are being considered by engineers, have not yet been fully described. When California formalizes DPR regulations in 2023, these strategies and technologies could greatly influence energy impacts to the grid, especially in scenarios where many water agencies begin adoption of DPR concurrently.

To highlight the impact of these future changes, we rely on data collected from government agencies describing existing energy use for wastewater management, and we compare this to data that we have modeled to describe the energy intensity of DPR across the same wastewater treatment facilities in LA County. In addition, we collect data on both the cost and GHG intensities of likely water supply alternatives and describe how those might affect decision making over time.

Project Purpose

With diminishing water availability and a need for new water sources, this research informs the CEC on the potential upcoming surge in disaggregated energy demand while the water sector explores one of its most promising opportunities: water recycling for potable reuse. To achieve this, our analysis collected data from wastewater agencies and engineers to describe trends, emerging technologies, and implementation practices for DPR. This data was paired with quantified energy consumption, greenhouse gas production, and electricity cost data. Similar data collection for alternative water supplies (desalination and freshwater imports) enables us to complete a comparative analysis, which describes the local and net regional energy impacts of DPR adoption in California.

While DPR may be an attractive solution for water managers, its impact will be further reaching than just the water sector, and the magnitude of its impact will be influenced greatly by the decisions of regulators in determining which strategies will be allowable. In part, this study is meant to serve as a tool to give water managers greater visibility on how their supply decisions influence not only their supply but also the wider energy grid and climate. In part, this study is meant to inform decision-makers like the State Water Resources Control Board in creating regulations by providing greater visibility as to the impacts of their decisions. For water ratepayers, these regulatory and water supply decisions are localized within a water system, but for energy ratepayers, these decisions can impact regional upgrade schedules and necessary energy procurement and generation.

Project Approach

The project approach involved three discrete steps and made several assumptions in order to arrive at pertinent and sound results. The first step of the project was to establish a baseline for energy consumption. We accomplished this task using a combination of data from compiled interviews, data requests and publicly available data online. Once the energy consumption baseline was established, we generated an estimate of energy consumption if new water recycling technologies were employed. Then, by synthesizing published engineering reports and academic studies, we could apply a new energy consumption estimate to existing systems, creating a new comparison energy consumption figure. Finally, we compared the baseline energy consumption estimate with the consumption estimate for new technologies.

While this approach is useful, it does have limitations. There is a lack of perfect data because few systems have implemented these approaches, which led us to create a model of energy intensity describing combinations of different water treatment trains. We also made a set of assumptions while conducting the applied analysis, which includes: 1) the broad availability of wastewater streams, which may be otherwise dedicated to existing customers in the short-run or by legal circumstances; 2) simplified conveyance pipeline, pressurization, and engineering estimates; and 3) described uncertainty around waste management for advanced treatment. These assumptions were made in order to produce results that are useful to water managers and state entities. We were also unable to address the performance and efficiency over time of new technologies at the regional level, which would be of interest to regional water managers and entities. However, even with these limitations, we believe in the validity of our approach and the applicability of our findings.

Project Results

This project achieved its goals of identifying the features of an upcoming recycled water policy and how those features might impact the energy grid. Specifically, this report describes likely technological alternatives and how those could affect both local and regional energy services.

Beyond the quantified regional water supply benefits, through comparative analysis, DPR is potentially shown to have net energy benefits when compared to existing water alternatives being considered in the region. This energy benefit can be achieved despite economic and emissions estimates disincentivizing DPR's adoption currently. Our findings explore these economic and emissions incentives to highlight that the former is historically emplaced and unlikely to shift, while the latter is more apparent than real—likely due to greenhouse gas accounting methods. Importantly, the project analyzes whether these emissions incentives remain in 2035 when DPR facilities are being emplaced. The findings show that while disparities are likely to exist, their magnitude in emissions will be greatly reduced if California continues to pursue the Renewable Portfolio Standards.

The analysis in this project should allow for and encourage more aggressive pursuit of water recycling as well as identify potential consequences of pursuing other water sources. The major conclusion of this research is that DPR has a significant potential to impact water sector energy use, but the resultant direction and magnitude of that impact will be variable depending on which DPR strategy is permitted/utilized and where that strategy is implemented.

Knowledge Transfer and Market Adoption

This project provides water and energy utility planners a framework for assessing the energy impacts of DPR's adoption both at the water utility level and also for broader regional analysis. The project demonstrates this functionality through its case study on the City of Los Angeles. The City is currently pursuing the infrastructure upgrades necessary for DPR at the Hyperion Water Reclamation Plant. We utilize the project's framework to consider different energy intensity, distribution strategy, and regional supply scenarios. Our findings guide policy-based decision-making not only on energy effectiveness, but also on engineering and equity discussions on future DPR strategy.

The research team used a method that can be applied to other water-scarce jurisdictions where water imports or desalination are critical parts of their water supply. It allows these jurisdictions to assess the potential of recycled water and how DPR might affect larger-scale energy consumption. As such, this method can be used to create guidelines for DPR that are useful to water and energy utilities in assessing the effectiveness of DPR.

Benefits to California

This research project provides helpful information on recycled water's potential impacts to the energy grid and how those impacts might vary across regions based on their existing water and energy infrastructure. The primary value of DPR to ratepayers is the water security and resilience it provides. Implementing DPR will not necessarily lead to a reduction in costs for ratepayers but will result in a delay in capacity upgrades in some localities. In Los Angeles specifically, DPR will lead to an increase in energy consumption which will lead to increased costs for ratepayers. However, DPR would also lead to a significant reduction in carbon emissions for ratepayers. While this project does not address regional implementation, we believe it lays the framework for a similar analysis in other jurisdictions, which would respectively, help their ratepayers.

CHAPTER 1: Introduction

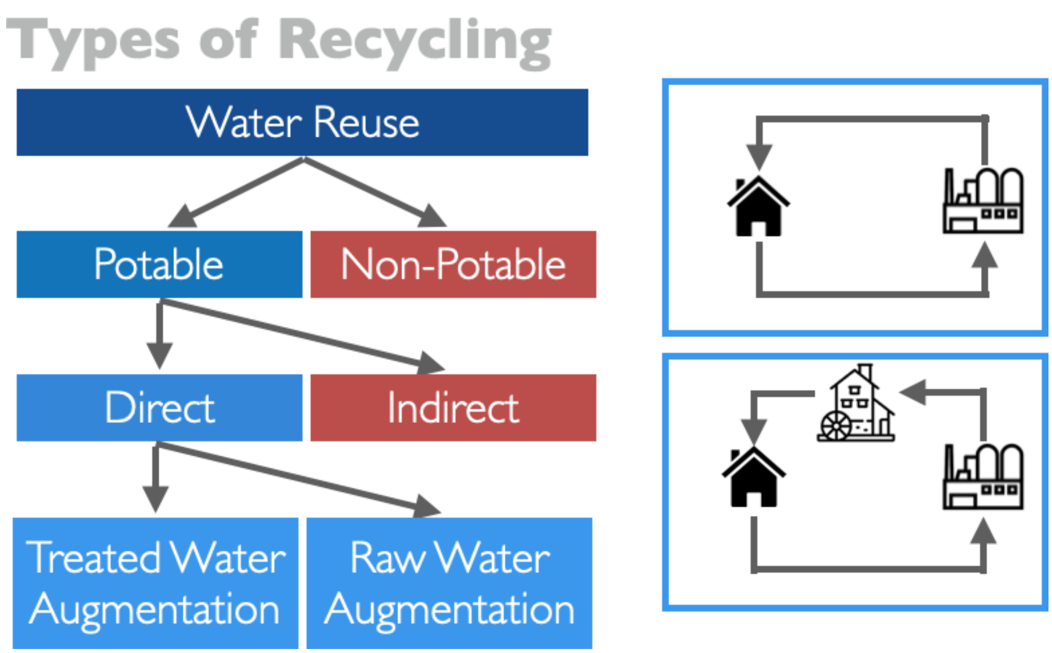
Recycled water production is a rapidly expanding field of interest for water resource managers around the world and is particularly relevant in the water-scarce southwestern United States. In California, recycled water is seen as an important tool in maintaining sustainable water supplies in the face of shifting climate; already more than half of the state's large water providers rely on recycled water for some portion of their water supply portfolio (California Department of Water Resources (DWR), 2015). Much of the currently utilized recycled water across the state is non-potable, but Direct Potable Reuse (DPR) is an emerging strategy of interest. In DPR, wastewater is reclaimed using advanced technologies, and reintroduced to drinking water systems as an additional supply. Especially in Southern California, where crucial imported water supplies are vulnerable to hazards such as earthquakes and droughts, developing a new, local drinking water supply through DPR will be invaluable. However, DPR can be energy intensive. Effective decision-making for public and environmental interests will require understanding the tradeoffs and implications of DPR to water resource managers, energy grids, and regional stakeholders.

In the United States and around the world, DPR has already proved to be a safe, effective solution to water shortages in a handful of communities (Isaacson and Sayed, 1988; du Pisania, 2015; Salveson et al. 2015). However, adoption has been slow due to health concerns (Hartley et al. 2019) and the high price associated with DPR. Despite this, the highest-level water governance entity in California, the California Water Resources Control Board (SWRCB), has increasingly supported its adoption through research, the development of regulations, and legislation (SB 918, SB 322, SB 524, AB 574). In accordance with AB 574, the Board faces a pressing deadline to adopt uniform criteria for DPR by 2023, and this research aims to evaluate its potential impacts to the energy grid.

DPR adoption is already an increasingly attractive solution in Los Angeles County, where both the City of Los Angeles and the Los Angeles County Sanitation Districts are planning and piloting advanced recycled water treatment facilities that reclaim wastewater to potable quality. Advanced Water Treatment (AWT) is the process of treating water to a higher quality, and it can encompass a range of possible technologies in many coordination's called treatment trains. DPR strategies rely on AWT to bring wastewater streams to a potable quality before distribution either to drinking water facilities or into drinking water distribution systems.

The SWRCB and LA County both face challenging decisions in allowing and implementing DPR, which needs to prioritize protecting public health while balancing the dire need for additional water resources to support the state's population and industry. At the forefront of this decision currently is the debate between Raw Water Augmentation (RWA) and Treated Water Augmentation, two distinct strategies under the umbrella of DPR strategies. The former, RWA, is accomplished by treating wastewater to potable quality and returning these flows to the influent (raw water) streams of drinking water treatment plants to be retreated. Prior to augmenting raw water influent to the drinking water facility, this water is potable quality, and this additional treatment is seen as yet another layer of protection to public health and as a means to reduce the stigma against potable water recycling as the flows would be retreated at existing facilities to existing drinking water standards. The latter strategy, TWA, treats wastewater to potable quality and directly reintroduces this stream into the drinking water distribution system--that is, augmenting water that has already been treated. The merits of these different strategies are under consideration by the SWRCB, but regardless, the underlying treatment trains supporting AWT will be the same and major drivers directing DPR's total energy consumption.

Figure 1: Direct Potable Reuse Distinction from Other Forms of Water Recycling showing Treated Water Augmentation (right top) and Raw Water Augmentation Distinctions (right bottom)



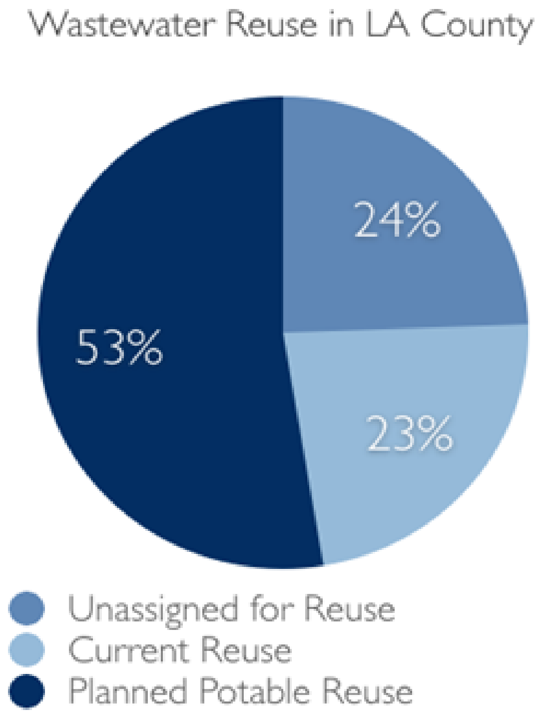
Source: University of California, Los Angeles

Ultimately, the decision of whether to implement DPR and in what form falls to the SWRCB. Several legislative entities are pushing an institution-level interest to have it approved. In 2016, Senator Hertzberg proposed Senate Bill 163 (Hertzberg, 2016), forcing water managers to drastically reduce their discharge of valuable wastewater effluent. In response, Mayor Eric Garcetti announced in early 2019 that the City of LA would recycle all of the wastewater leaving its largest plant, Hyperion, by 2035. In Southern California, where the price of importing water is already high and climbing, public agencies and policy decision makers are especially interested in potable-level water recycling. This interest is because it can replace more costly drinking water supplies, while also addressing challenges such as dependence on external water imports, dwindling local water supplies, salinity management, and the risk of supply security during seismic and climate events. DPR is one of the newest strategies for achieving potable-level water recycling in California. Despite current planning and active consideration of regulations and implementation, little guidance or support exists for water agencies to examine the water and energy impacts of DPR decisions beyond their own operational boundaries.

In Southern California, the discussion of DPR takes place alongside other water supply alternatives, such as increased freshwater imports, enhanced groundwater pumping, desalination, and conservation. Across the state, electricity use for water supply management is approximately 5-8 percent of the total budget, California Public Utilities Commission (CPUC), 2010; California Energy Commission (CEC), 2005). Much of this energy use is attributed to the heavy pumping requirements of imports to Southern California. These imports are, on average, already more energy intensive than Advanced Water Treatment (AWT) (Electric Power Research Institute (EPRI), 2013), implying that a shift to DPR would save the state energy. Studies by Tchobanoglous et al. (2015) and Raucher et al. (2014) hint at this energy conservation and provide economic and energy intensity estimations for the AWT processes. Their quantification of energy intensities serves as a tool to show that potable reuse can be an energy-saving water supply solution, but they do not make any quantification of location specific energy shifts or net energy impacts to a region. Tchobanoglous et al.'s paper concludes by outlining the need for further research comparing sector-wide energy costs of water supply alternatives, especially as DPR regulations are developed and technologies are better refined. Evaluating the impacts of DPR in regions with diverse water supplies, energy intensities, and energy supplies requires a comparative analysis of existing water supply strategies to discern the relative benefits of each strategy.

Recent research by Porse et al. (2020) attends to Tchobanoglous' suggestion to examine the LA region's water-energy nexus by modeling alternative water supply scenarios, their energy intensities, and the end-user decisions. While this work provides an encompassing description of a range of water supply and energy use nexus possibilities for the region and even allows for recycled water use in its model, it does not explicitly consider DPR and the variable implementation strategies that are being considered by regulatory decision-makers. These strategies would define key technologies that could drastically shift energy use expectations for the region and this strongly influences net energy consumption and GHG emissions. Similar research by Sanders (2016) and Fang et al. (2015) studies the City of Los Angeles and examines energy intensities for water supplies in the limited geography of the City of LA, without addressing DPR, AWT, or the wider regional benefits. Sanders performed an analysis of the Los Angeles Department of Water and Power’s (LADWP) future energy needs by quantifying its feasible sources of potable water and their energy intensities. As the City of Los Angeles does not yet engage in DPR, her analysis does not provide any quantified estimates for the strategy. However, she does recognize the potential for DPR to affect large changes in the City of Los Angeles’s water supply, not only because of its lower energy intensity, but also because of its direct drinking water supply benefits which are currently unmet by existing recycled water (Sanders, 2016). Fang et al. (2015) undertakes similar work with a focus on the City of Los Angeles’ existing water’s energy and carbon intensities and concurs that DPR could become increasingly important to the City of Los Angeles as it seeks to diversify its water resources. These studies form a basis for energy intensity quantification of water supplies within Los Angeles County, however, they were developed prior to the discussion around DPR and were not able to address its significance as is needed today. With the limited geographic scope and limited consideration of underlying energy sector features, both of these works were unable to highlight the regional benefits of water-energy tradeoffs as well as the associated greenhouse gas considerations. It is in these two areas that this research differs significantly and will contribute to our understanding.

Figure 2: Existing and Planned Wastewater Reuse in LA County



Source: University of California, Los Angeles

When California formalizes DPR regulations in 2023, many water agencies may concurrently begin adoption of energy intensive AWT, which may result in a steep increase in local energy use. This paper seeks to fill several gaps in the literature by examining this potential energy use increase alongside existing energy consumption for wastewater management. This paper firstly estimates the magnitude of energy shift in the sector and enables the power grid to prepare for such a change. Utilizing our modelled energy use and intensity data, we assess regional and statewide benefits of adopting DPR by quantifying its energy use and intensity compared to existing and potential drinking water supply solutions in Los Angeles. Lastly, our analysis takes a broader perspective on water supply by providing a greenhouse gas (GHG) and economic analysis of the energy intensities associated with these supply alternatives to better inform policy and decision making in accordance with California's clean energy initiatives. To answer these questions, we rely on data collected from government agencies describing existing energy use for wastewater management, and we compare this to data that we have modeled to describe the energy intensity of DPR across the same wastewater treatment facilities in LA County. Finally, we collect data on both the cost and GHG intensities of the energy supporting the water supply alternatives and describe how those might affect decision making over time.

CHAPTER 2: Project Approach

This research first evaluates the energy shifts associated with the application of a range of AWT treatment trains to wastewater treatment facilities in LA County. Secondly, our analysis evaluates the net energy benefits of using these technologies in the state's energy grid. Lastly, given the range of possible DPR energy needs, our research considers the greenhouse gas and electricity cost implications of these alternatives for policy decision making at the state and regional level. The following section describes the data and methods used to develop our results and includes both collected and calculated data for wastewater, direct potable reuse, and water supply alternatives in LA County. We also further describe the data collected to inform our sensitivity analysis covered in our discussion.

We first provide a description of the ongoing energy use for wastewater management as a baseline to understand the magnitude of potential change in energy consumption associated with implementing DPR in LA County. We then quantify the energy used by various AWT trains and use these values to describe the maximum and likely shifts in energy use incurred in treating wastewater flows for DPR. As DPR adoption will shift water supply portfolios, we compare its energy use to those of existing water supply alternatives, which allows us to describe potential net impacts to the wider California energy system. Throughout the paper, we discuss the energy consumption of three types of water systems:

- Wastewater Management Systems--describing current non-potable wastewater system operations.
- DPR Systems--describing the future potential energy use and associated energy implications.
- Water Supply Alternatives Systems--describing common water supply alternatives for LA County, including imported water and desalination.

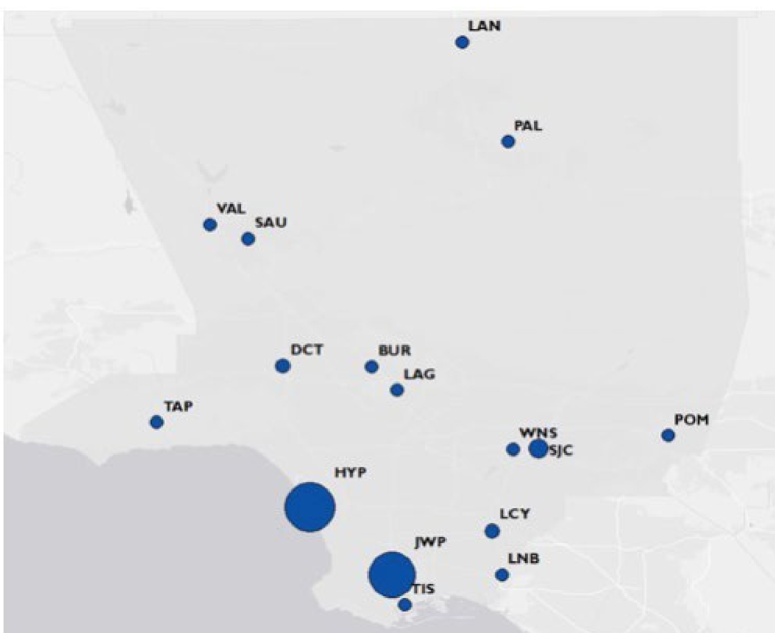
Across each of these systems, energy uses are further distinguished into energy for conveyance, treatment, distribution, and waste management, the most energy intensive aspects of non-residential water management.

2.1 Wastewater Management Systems

To establish a baseline for energy use in wastewater systems, we first calculated the energy intensity and total energy consumption of existing wastewater treatment (WWT) plants that could feasibly upgrade to AWT facilities. WWT plants that collect and have ownership over their wastewater flows, as well as have sufficient flow to make the AWT process viable, were considered for this analysis. Our analysis chose only to consider plants with flows above 5 million gallons per day (MGD) based both on literature claiming that plants treating fewer than 5 million gallons per day (MGD) showed inconsistent energy use characteristics, and expert opinions suggesting that DPR would likely be uneconomical at that scale. For this analysis, we collected relevant data for WWTP in LA County with greater than 5MGD through in-person interviews, public information requests, and reviews of existing literature. Using this information, an energy intensity (kilowatt hours per acre-foot) was calculated for each plant and was applied to their respective current average flows to determine an average annual energy use.

Of the 27 WWT facilities identified in LA County, 16 met the ownership and flow size requirements for the analysis and were surveyed through personal communications and public data collection. These 16 plants represent more than 99% of the raw municipal wastewater collected in LA County and are managed by four major sanitation agencies. Below is a list of the examined facilities showing energy-relevant descriptive information for each plant, such as treatment level, plant flows, and energy usage, as well as information about their plant processes.

Figure 3: Identified Wastewater Treatment Facilities in Los Angeles County



Shows a map of 16 wastewater treatment facilities which manage a majority of Los Angeles County's wastewater flows. Circle size represents each facility's average daily flows ranging from 6 MGD to 260 MGD.

Source: University of California, Los Angeles

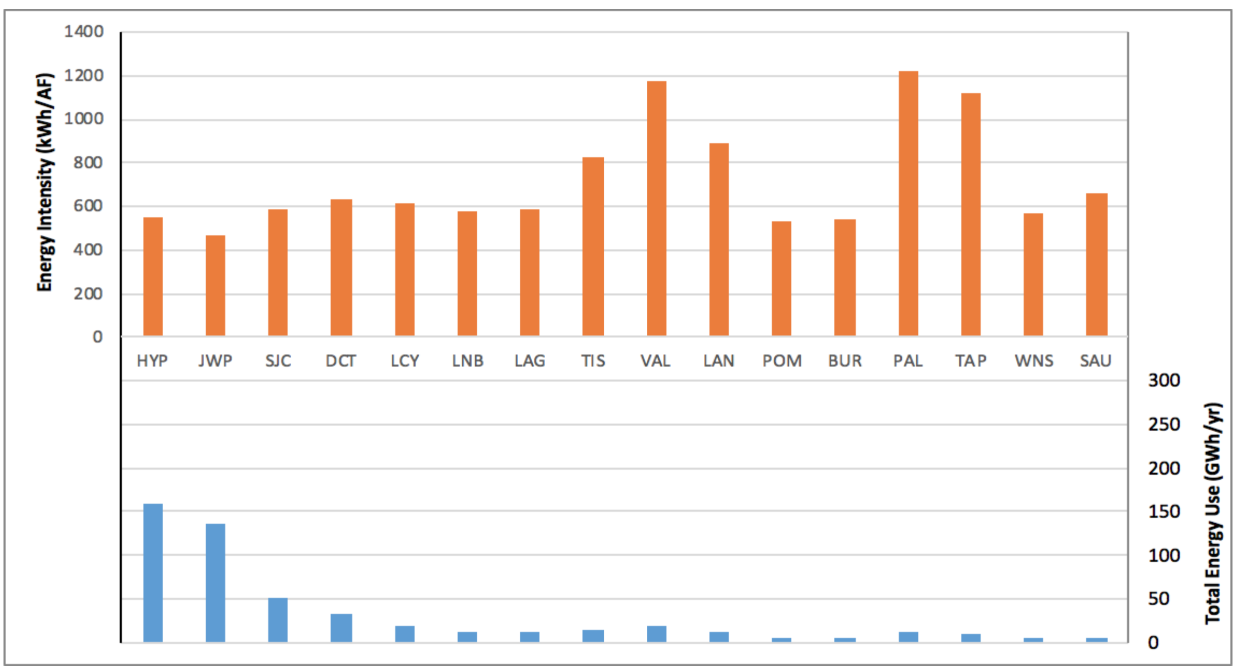
Table 1: Summary of Treatment, Flow, and Energy Data for Wastewater Treatment Facilities in Los Angeles County

Plant Name	Plant ID	Treatment Level	Biological Nutrient Removal	Solid Waste Management	Recycled Water Distribution	Average Daily Flow (MGD)	Energy Intensity (kWh/AF)	Total Energy Usage (GWh/yr)
Hyperion WRP	HYP	Secondary		Yes	Yes	299	549	1,598
Joint Water Pollution Control	JWP	Secondary		Yes		260	465	1,353
San Jose Creek WRP	SJC	Tertiary	Yes		Yes	77	590	509
Tillman WRP	DCT	Tertiary	Yes	Yes		32	634	330
Los Coyotes WRP	LCY	Tertiary	Yes		Yes	27	615	186
Long Beach WRP	LNB	Tertiary	Yes			18	578	117
LAG WRP	LAG	Tertiary	Yes	Yes	Yes	17	584	111
Terminal Island WRP	TIS	Tertiary				16	823	138
Valencia WRP	VAL	Tertiary	Yes			14.6	1,175	192
Lancaster WRP	LAN	Tertiary	Yes	Yes		12.8	891	128
Pomona WRP	BUR	Tertiary	Yes		Yes	9	533	54
Burbank WRP	PAL	Tertiary	Yes		Yes	9	545	55
Palmdale WRP	TAP	Tertiary	Yes	Yes	Yes	8.31	1,223	114
Tapia WRF	POM	Tertiary				7	1,117	88
Whittier Narrows WRP	WNS	Tertiary	Yes		Yes	7	573	45
Saugus WRP	SAU	Tertiary	Yes		Yes	5.7	661	42

Source: University of California, Los Angeles

Our data collection efforts resulted in both unit energy intensity as well as total energy use estimates shown graphically below.

Figure 4: Energy Intensity (kWh/AF) and Use (GWh/yr) for Wastewater Facilities in Los Angeles County



Source: University of California, Los Angeles

The data shows that there is a wide range of energy intensities among plants in LA County, from 464.511kWh/AF to 1222.575 kWh/AF, shown in the upper graph in Figure 1. Energy intensities between 520-670 kWh/AF are common for WWT (Raucher and Tchobanoglous, 2014), and the collected data shows that most of the plants fall within this range. The plants show energy intensity variability in solids waste management technologies, solids loading, and other operations (shown in Table 1). While it is difficult to unequivocally attribute the deviations in energy intensity to these processes, many of the plants which notably deviate from the common range (TIS, VAL, LAN, and PAL) engage in additional solids waste management processes which are not present at other facilities. The remaining plant with a deviant energy intensity (TAP), was identified as having additional recycled water pumping costs of up to 151.407kWh/AF and is also in the process of upgrading the dated components of their facilities.

Figure 1 shows that each plant's contribution to energy use in the wastewater sector is more directly a function of its flows. Notably, the two largest plants (HYP & JWP), which have some of the lowest energy intensities, contribute 58.33% of the total energy use in the sector annually. This aggregated annual energy usage for the LA County wastewater sector is 505.938 GWh/yr. and provides a baseline against which to compare the additional energy load incurred through direct potable reuse strategies.

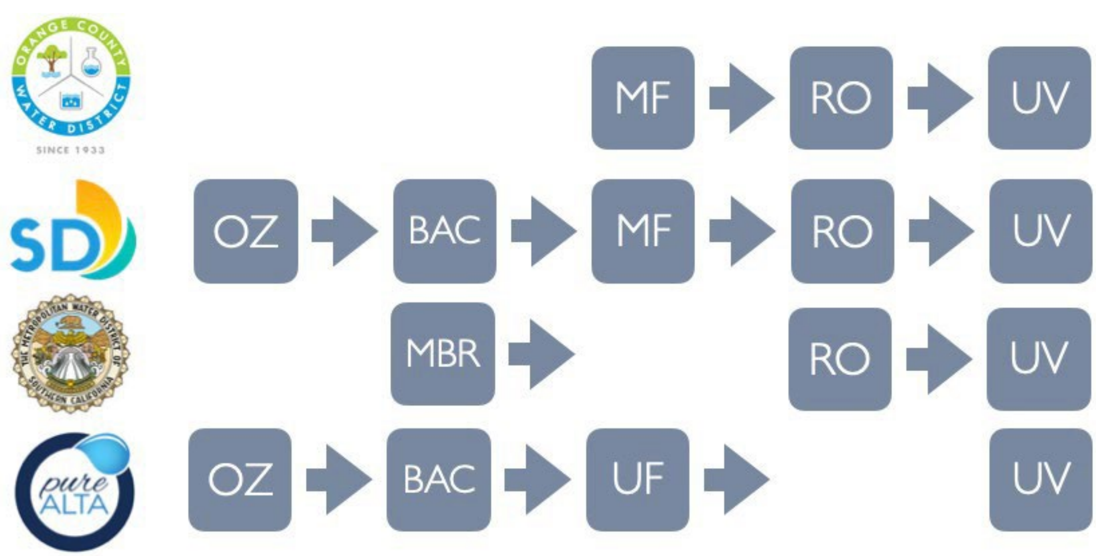
2.2 Direct Potable Reuse Systems

As treatment is consistently one of the most energy intensive components of DPR, this analysis focuses on establishing credible estimates for AWT, while accounting for variation in plant size among our sample. Treatment energy use, however, is not the only consideration when engaging in DPR, and can become secondary to the aggregation of the other energy intensive components like distribution and waste management. These two factors are highly variable and based on site-specific conditions such as land availability, topographic variability, and access to ocean outfall brine disposal lines. For our analysis, covering both raw water and treated water augmentation, we first consider the common components only: conveyance and treatment. In a later analysis, we then address the energy use incurred through site-specific conditions (distribution and waste management) for both strategies using a breakeven analysis method (See section 2.4).

We used information from our primary data collection and in-person interviews to establish assumptions for the conveyance of wastewater to new AWT facilities. Interviewees explained that primarily due to the high land cost and energy needs for pumping, AWT facilities are unlikely to be sited far from WWT facilities or on new premises. They further explained that AWT technology's relatively small footprint and modular layout would enable it to be sited at many existing facilities without much difficulty. Taking these findings together, we assume that AWT facilities can be built on the same site as WWT facilities. This makes conveyance energy costs effectively zero and simplifies the factors in this first component of our analysis of DPR systems to treatment only.

For AWT, there are many combinations of unit processes that can produce potable water for DPR, dependent on influent quality and contaminants at the onset of the process. Without site specific chemical data across facilities in LA County, this research focuses on modeling a range of likely treatment trains that are established or currently being considered for implementation among California water utilities. These include those of Orange County Water District's Groundwater Replenishment Water System (OCWD), San Diego's Pure Water Project (SDPW), Metropolitan Water District of southern California's Regional Recycled Water Program (MWD), and the City of Almonte Spring's pureALTA project (ALTA). These treatment trains include a range of technologies as well as influent types with the OCWD, MWD, and ALTA trains receiving (or planning to receive) secondary treated wastewater effluent, while the SDPW train receives tertiary treated wastewater effluent. The unit processes for the selected trains are shown in summary below.

Figure 5: Overview of Advanced Water Treatment Trains Considered in this Analysis



The above treatment trains are referred to in short throughout the text as OWCD, SDPW, MWD, and pureALTA respectively.

Source: University of California, Los Angeles

Where:

MF- Microfiltration

RO- Reverse Osmosis

UV- Ultraviolet Irradiation and Advanced Oxidative Processes

OZ- Ozonation

BAC- Biologically Activated Carbon

MBR- Membrane Bioreactor

UF- Ultrafiltration

2.2.1 Advanced Water Treatment Energy Intensity Estimation

To define the energy intensity of the AWT trains being considered in this report, observed treatment train data provided through a pilot study and the literature were prioritized. In cases where this data was not available, we estimated unit process energy intensity using the literature values derived from operations and maintenance (O&M) cost estimates provided by Plumlee et al. (2014). This strategy was undertaken for the SDPW and MWD trains using the true data of the OCWD treatment train as a basis.

SSSSSSSS EEEEEEEEEEEE IIEEIIEEEEIIIIIIEE (EEII) = OOOOSSSS EEII + OOOOOOEEEE SSEEOOccEEIIII EEII + BBBBOO SSEEOOccEEIIII EEII

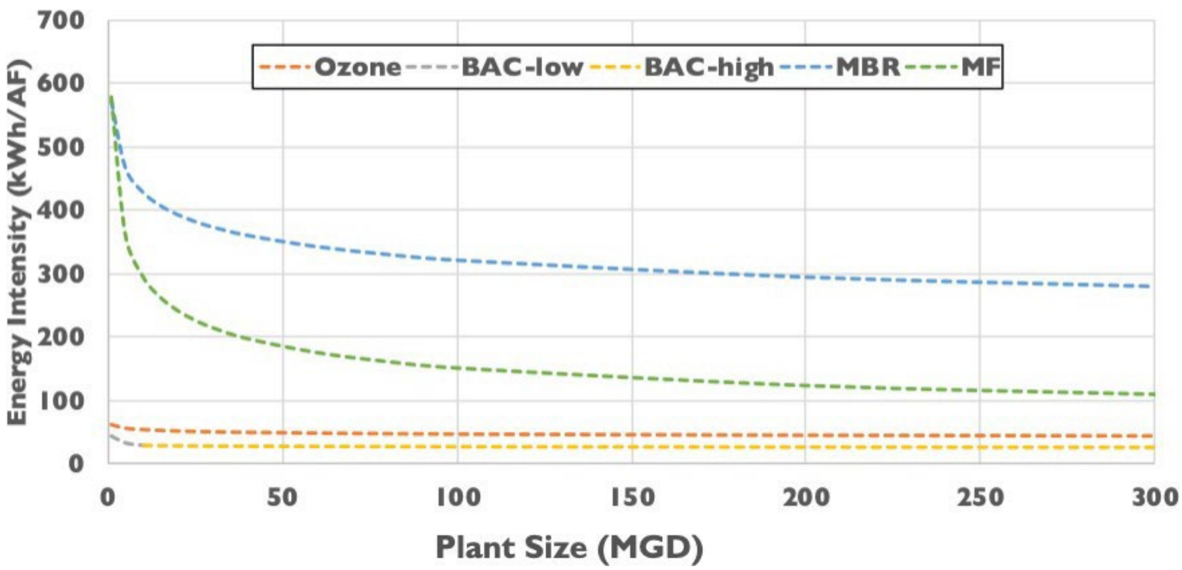
MMSSSS EEEEEEEEEEEE IIEEIIEEEEIIIIIIEE (EEII) = OOOOSSSS EEII − MMMM SSEEOOccEEIIII EEII + MMBBMM SSEEOOccEEIIII EEII

Observed data for the OCWD train was derived from Tchobanoglous et al. (2015) and observed data for the ALTA train was provided by its pilot study operators (Kumar et al., 2017).

The effect of economies of scale was accounted for in AWT estimates through the development of energy intensity curves for each relevant process, and for the OCWD train as a whole. These curves allow for the calculation of expected energy intensity for any treatment process, in accordance with their plant size. Each of the unit processes, as well as OCWD's train curves, are defined using a power curve: $y = ax^b$. As described by Plumlee et al. (2014) and confirmed using EPRI's Municipal Wastewater Energy Calculation Tool (2013), using a power curve accurately reflects how energy intensity changes with plant size.

For each relevant unit process, we adapted Plumlee's (2014) O&M curves using a log-log transformation. This process was predicated on the assumption that the developed energy curve would have the same shape as Plumlee's, as shown by an identical gradient. Given a defined gradient and an estimation for an existing southern California water plant (San Jose Creek Water Reclamation Plant: Gerrity et. al (2013)), the general form of the curve was estimated and is shown and described below.

Figure 6: Estimated Energy Intensity Curves for Each Unit Process



Due to the difference in magnitude of the estimated energy intensity curve for the entire OCWD treatment train, it is not displayed on this graph. Data used in the development of these estimates.

Source: University of California, Los Angeles

Table 2: Values for Estimated Energy Intensity Curves Using a Power Form

Train/unit process	a	b	Primary Sources
OCWD Train	1432.3	-0.073	Tchobanoglous et al. (2015)
MF	577.503	-0.291	Plumlee et al. (2014); Gerrity et. al (2013)
MBR	574.12	-0.126	Tchobanoglous et al. (2015); Bertanza et al. (2017)
OZ	61.813	-0.052	Plumlee et al. (2014); Gerrity et. al (2013); Margot et al. (2013); Lee et al. (2010)
BAC <10 MGD	45.164	-0.160	Plumlee et al. (2014); Gerrity et. al (2013)
BAC > 10 MGD	33.946	-0.036	Plumlee et al. (2014); Gerrity et. al (2013)

Source: University of California, Los Angeles

Importantly, while benefits for economies of scale were applied to most plant sizes (5MGD-70MGD), those beyond this range for which there was true field data (HYP and JWP at 260MGD) were not afforded greater economies of scale. This was done to avoid overestimating energy savings due to increasing economies of scale. In keeping with this practice, energy estimations for the 5MGD ALTA treatment train were not adjusted for economies of scale and instead applied uniformly to all plants. Because this pilot data is derived from a 5MGD plant, there is an expectation that any larger implementation will see benefits of economies of scale and thus have a reduced energy intensity.

For the development of these values from the calculated curves, note that with the exception of the ozone curve, all other unit process O&M curves are expected to contain labor and maintenance costs. These non-electrical costs factor into the shape of the curve but are unable to be distinctly isolated from energy operations costs. We have accepted this error in the analysis as an improvement over a linear or uniform assumption, which generally showed a lower R2 value when compared to the power function.

2.2.2 Advanced Treated Water Pressurization Energy Intensity Estimation

In addition to treatment, and regardless of uphill pumping requirements, any DPR implementation would require off-site water conveyance to pressurized water mains. The required re-pressurization could use a significant amount of energy. We, therefore, have included it within our primary analysis assuming conveyance to an ideally pressurized system at 70psi as described in the literature by Xu et al. (2014).

To determine the energy requirement for this pressurization, we use the following equation:

$$\mathit{EEEEEEEEEEEE\ IIEEIIEEEEIIIIIIEE}_{\mathit{pppppppppp,xx}}$$
$$= \mathit{SSIIIIIIEEIIDDDDIIIIOOEE\ SSEEIIIIEESS\ SSEEEEIIIIDDEEEE} \times \mathit{OOOOEECCEEEEIIIIOOEE\ MMFFccIIOOEE}$$
$$\times \mathit{EEEEEEEEEEEE\ IIEEIIEEEEIIIIIIEE\ EEEEDDIICCFFEEEEEEII\ ffOOEE\ LLIIffII} \times \mathit{SSDDSSPP\ EEffffIIccIIEEEEccEE}$$

Where the distribution system pressure is 70psi, conversion factor is 2.31 ft/psi, lift energy is 1.02kWh/AF, and a pump efficiency of 85% is assumed. This results in a uniform requirement for pressurization energy of 222kWh/AF.

2.2.3 Aggregated Energy Intensity Estimates

The project arrived at the following energy intensity estimates by aggregating treatment and pressurization energy estimations described in the previous sections (2.2.1 and 2.2.2). These numbers will form the basis of our analysis and will be used in our overarching analysis comparing DPR strategies with water supply alternatives. The following table contains energy intensity estimates for the four alternative AWT trains identified (OCWD, SDPW, MWD, ALTA). The product of these energy intensity estimates, and each plant's specific flows results in the energy use estimates which describe total energy use for LA County.

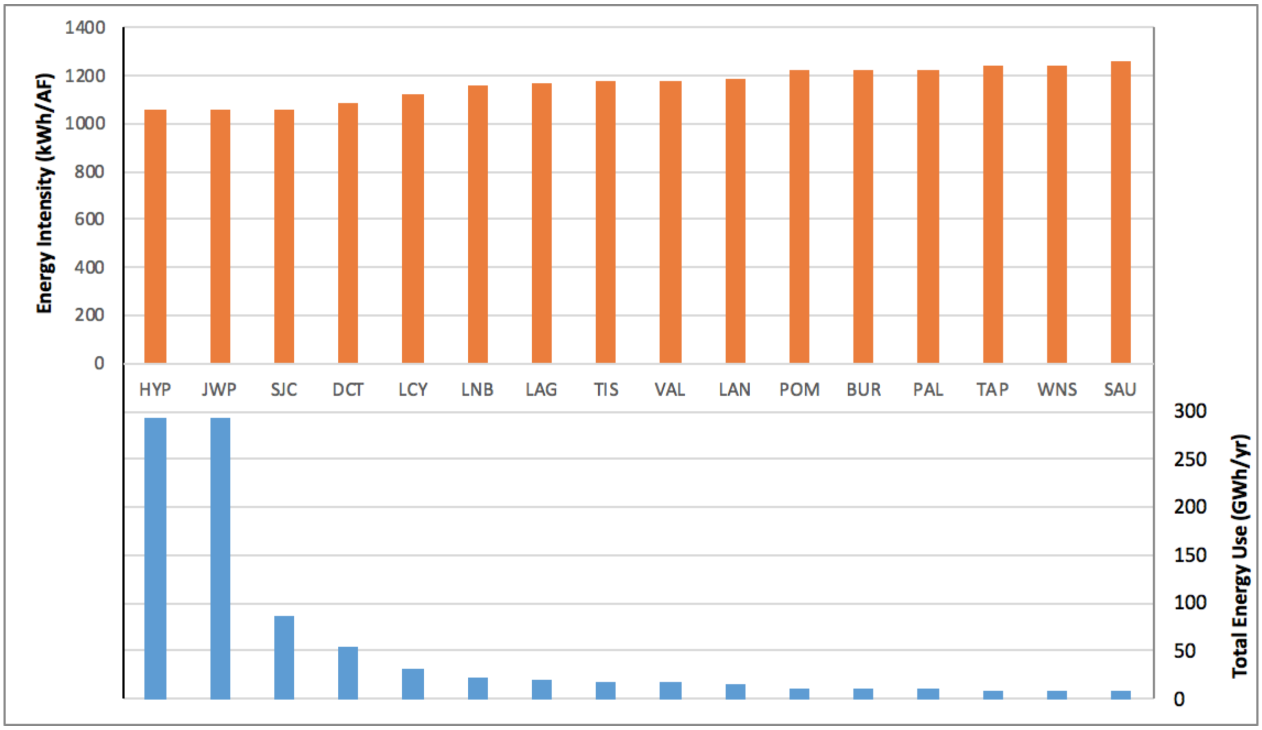
Table 3: Energy Intensities and Use for the Alternative AWT Trains

Plant Name	Plant ID	Average Daily Flow (MGD)	AWT EI OCWD (kWh/AF)	AWT EI SDPW (kWh/AF)	AWT EI MWD (kWh/AF)	AWT EI ALTA (kWh/AF)	Energy Use by OCWD AWT (GWh/yr)	Energy Use by SDPW AWT (GWh/yr)	Energy Use by MWD AWT (GWh/yr)	Energy Use by ALTA AWT (GWh/yr)
Hyperion WRP	HYP	299	1,059	1,134	1,199	497	293.00	313.83	331.60	137.52
Joint Water Pollution Control	JWP	260	1,059	1,134	1,199	497	293.00	313.83	331.60	137.52
San Jose Creek WRP	SJC	77	1,043	1,121	1,193	497	86.77	93.19	99.09	40.73
Tillman WRP	DCT	32	1,082	1,162	1,247	497	53.55	57.52	61.71	24.60
Los Coyotes WRP	LCY	27	1,126	1,208	1,284	497	32.35	34.71	36.88	14.28
Long Beach WRP	LNB	18	1,160	1,244	1,310	497	22.22	23.82	25.09	9.52
LAG WRP	LAG	17	1,165	1,249	1,313	497	21.07	22.59	23.76	8.99
Terminal Island WRP	TIS	16	1,175	1,260	1,321	497	18.76	20.11	21.08	7.93
Valencia WRP	VAL	14.6	1,178	1,262	1,323	497	18.30	19.61	20.55	7.72
Lancaster WRP	LAN	12.8	1,189	1,274	1,330	497	16.20	17.36	18.12	6.77
Pomona WRP	BUR	9	1,220	1,307	1,351	497	11.68	12.51	12.94	4.76
Burbank WRP	PAL	9	1,220	1,307	1,351	497	11.68	12.51	12.94	4.76
Palmdale WRP	TAP	8.31	1,227	1,314	1,355	497	10.85	11.62	11.98	4.40
Tapia WRF	POM	7	1,243	1,331	1,364	497	9.26	9.91	10.16	3.70
Whittier Narrows WRP	WNS	7	1,243	1,331	1,364	497	9.26	9.91	10.16	3.70
Saugus WRP	SAU	5.7	1,261	1,350	1,374	497	7.65	8.19	8.34	3.01

Source: University of California, Los Angeles

The energy intensity data shows small decreases in efficiency with decreasing plant size (economies of scale) across the sample. As an example, we look at the energy intensity and total energy consumption for each WWTP in LA County if the OCWD fat train were applied to each plant, shown graphically below.

Figure 7: Increased Energy Intensity and Use Applying OCWD AWT Train



Across the alternative treatment trains, the potential energy use in LA County incurred by the adoption of AWT ranges from 419.930GWh/yr. (ALTA) to 1035.983 GWh/yr. (MWD).

Source: University of California, Los Angeles

2.3 Water Supply Alternatives Systems

Our analysis compares the energy intensity of ATRW water to alternative water supplies which would likely be displaced: imports from either the Colorado River or State Water Project, or Desalination. The LA County-specific energy intensity values for these imports are provided by the 2015 CPUC report on California's water supplies. Estimates describing the energy intensity of water imports are adjusted to represent the entire imports sector by accounting for conveyance, treatment, distribution, and waste management (88 percent, 1 percent, 11 percent, and ~0%respectively) using EPRI (2013) information on proportional energy use. While EPRI did not specifically include waste management estimates, the energy intensity of this process for drinking water plants is expected to be minimal compared to that of extraction and conveyance energy use for Southern California water imports.

AWT can be expected to displace these alternatives either through immediate replacement of supplies, or through delaying the need for additional supplies. To quantify the benefit of this displacement, we apply the energy intensity of each water supply alternative to the volume of water expected to be displaced. This volume is calculated assuming that all wastewater flows are used to produce advanced treated water with a 5 percent and 15 percent water loss through WWT and AWT respectively. With overall energy needs for providing each water supply alternative alongside ATRW's energy costs, we are able to comparatively define a range of net energy impacts to the region's electrical grid. These impacts include where and how much energy is demanded, both of which have implications for the electrical grid.

This section uses data from the literature to describe the energy intensity estimates for three commonly considered water supply alternatives in Southern California: Colorado River Water Imports, State Water Project Imports, and Desalination. These energy intensities are then multiplied by the maximum volume of water potentially produced through advanced water treatment, to describe the energy shift incurred by the adoption of a DPR strategy. The difference between the energy use for AWT and these water supply alternatives is calculated as the potential net energy benefit to the state of California.

Table 4: Energy intensity Estimates for Common Drinking Water Supply Alternatives Already in Use in Southern California

Alternative Water Supply Type	Energy Intensity (kWh/AF)
Interbasin Transfer from SWP	3652.273
Colorado River Transfers	2840.909
Desalination	3910.212

Source: University of California, Los Angeles

Table 5: Potential Advanced Treated Water Production at Each Facility and Corresponding Energy Use for Equivalent Water Supply Alternative

Plant Name	Plant ID	Maximum Potential ATW Production (AFY)	Energy Use to Provide This Volume of Water from a Water Supply Alternative (GWh/yr)		
			Colorado River Aqueduct	State Water Project	Desalination
Hyperion WRP	HYP	235,174.205	668.109	858.920	919.581
Joint Water Pollution Control Plant	JWP	235,174.205	668.109	858.920	919.581
San Jose Creek WRP	SJC	69,647.745	197.863	254.373	272.337
Tillman WRP	DCT	42,060.002	119.489	153.615	164.464
Los Coyotes WRP	LCY	24,421.937	69.381	89.196	95.495
Long Beach WRP	LNB	16,281.291	46.254	59.464	63.663
LAG WRP	LAG	15,376.775	43.684	56.160	60.126
Terminal Island WRP	TIS	13,567.743	38.545	49.553	53.053
Valencia WRP	VAL	13,205.936	37.517	48.232	51.638
Lancaster WRP	LAN	11,577.807	32.891	42.285	45.272
Pomona WRP	BUR	8,140.646	23.127	29.732	31.832
Burbank WRP	PAL	8,140.646	23.127	29.732	31.832
Palmdale WRP	TAP	7,516.529	21.354	27.452	29.391
Tapia WRF	POM	6,331.613	17.988	23.125	24.758
Whittier Narrows WRP	WNS	6,331.613	17.988	23.125	24.758
Saugus WRP	SAU	5,155.742	14.647	18.830	20.160

Source: University of California, Los Angeles

From this calculation, the maximum potential advanced treated water production for LA County is estimated to be 718,104.436 acre-feet per year, assuming current average daily wastewater flows. Providing this volume of water through the water imports sector (Colorado River Aqueduct and the State Water Project) would incur between 2,040.069 and 2,622.713 GWh of electricity usage per year, while providing the same volume through desalination would instead incur 2,807.941 GWh/yr. of electricity usage.

2.4 Sensitivity Analysis

In the primary analysis of this research we describe minimum and maximum energy demand scenarios under a given set of broad assumptions meant to be conservative for planning. We have identified these assumptions (See Section 3.4 Sensitivity Analysis) and recognize that the true result of adopting DRP is variable based on these factors as well as time. Despite confidence in our scenarios, we also describe alternative assumptions for each of the above and the impact of such changes relative to our primary scenarios. In addition to our maximum and minimum energy demand scenarios, we also describe a short-term "likely" scenario which describes planned AWT as of mid-2019.

Data informing alternatives for our sensitivity analysis was derived from personal communications with operators and experts as well as literature accepted values primarily from Tchobanoglous et al. (2014).

The results of the sensitivity analysis are described in Section 3.4.

2.5 Further Considerations

The net energy effects to the region and state are dependent on the DPR strategy adopted compared to the water supply alternative offset, as well as water distribution and waste management strategies employed. The following data analysis informs our discussion on how the net energy benefit calculations can guide decision making on recycled water distribution and waste management, as well as be influenced by energy-intrinsic factors like greenhouse gas emissions and economic cost.

2.5.1 Energy Availability for Recycled Water Distribution and Waste Management

The net energy impacts previously described for the regional grid are only fully captured in a DPR strategy with minimal distribution and waste management energy costs. These non-treatment components can be widely variable in their energy use depending on site-specific factors. Without the capability to recreate each facility's considerations, including water quality objectives, land availability, topographic variability, and access to ocean outfall brine disposal lines, this analysis cannot directly estimate a facility's energy use for these non-treatment processes, and so no independent datasets were used to perform this analysis. Instead, we use the described regional energy impacts to calculate the maximum energy intensity that these processes can have while still capturing a net energy benefit to the state. This value is meant to serve as a guideline in DPR planning and to encourage adoption of strategies which will support the state in developing new water supply solutions while also realizing net energy savings.

2.5.2 Greenhouse Gases

A core component of California's decision making revolves around greenhouse gas implications and with each supply alternative having a unique emissions portfolio we might expect this consideration to dictate water supply decision-making. Without a clear, region-specific understanding of how DPR might shift emissions, we moved to assess the energy supplies providing for the water supply alternatives under consideration in this analysis. We use estimates provided by the Los Angeles Department of Water and Power (LADWP) and Metropolitan Water District (MWD) (Mika et al., 2018) to describe emissions profiles for the supply alternatives considered both in 2015 and 2035. For our analysis, we examine GHG emissions in 2015 and in 2035, the latter of which more accurately describes the likely impact of a DPR strategy once built and implemented.

In order to estimate the emission factors of different Los Angeles County Energy providers, we use a weighted average of energy source emission factors based on each energy provider's energy mix. First, we assembled the 2014 and 2017 Energy Mix reports for Los Angeles Department of Water and Power (LADWP), Southern California Edison (SCE), Pasadena Water and Power, Burbank Power and Water, Glendale Power and Water, City of Azusa, City of Cerritos, and the City of Industry. These energy mix profiles come from the California Energy Commission (California Energy Commission 2017). The energy mixes report the percentage of energy generated from different sources for each Los Angeles County energy provider. Emission factors data came from the IPCC for renewable energy sources (Edenhofer et al., 2011), the California Air Resources Board for unspecified power sources (California Air Resources Board 2015), and the Los Angeles City Report for all other power sources (Mika, et al. 2018).

We also estimated the 2035 power mixes using the following methods. We interpolated renewable percentages between the level in 2017 (California Energy Commission, 2018) and the renewables target for 2036 (City of Los Angeles 2019) to estimate that 78 percent of the power mix will come from renewables in 2035 for LADWP. We then scale renewables proportionally from 2017 levels to meet that new target (i.e. biomass was 5 percent/30 percent in 2017, so it is 16 percent/78 percent renewables in 2035). We assume no coal will be in the power mix in 2035, as it will be phased out in 2025. Nuclear and hydropower are held constant as a share of the total power mix. First, we assume that energy provided by nuclear power remains constant as the operating licenses for the nuclear generating station from which LADWP procures its nuclear power do not expire until the mid-2040s (LADWP 2017). Second, hydropower generation is held constant due to data paucity–its generation is generally dependent on rainfall, which cannot be predicted in 2035. 'Other' power is assumed to be 0 percent, as it was in 2014 and 2017. Natural gas and unspecified are scaled to the remainder based on their share of the energy portfolio in 2017.

The next step was to multiply those percentages by an emissions factor for each type of energy source. These emissions factors were sourced from the Los Angeles City report. The Los Angeles City Report used methods provided by the Climate Registry (TCR), which standardizes emissions for specific power sources with the exception of renewable energy sources. The emissions factors for renewable energy sources were sourced from the Intergovernmental Panel on Climate Change (IPCC) and the emissions factors for nuclear energy was sourced from the World Nuclear Association (WNA). Multiplying these emissions factors by the energy mix percentage produces a weighted emissions factor (MTCO2e/MWh) for each Los Angeles County Energy provider.

However, we believe that the LA City Report's emission estimate for coal and natural gas were lower than they should be, as they are significantly lower than IPCC's emissions factors for coal and natural gas. To remedy this, we duplicated the previously described method using fuel source emissions factors sourced exclusively from IPCC. These factors were multiplied by the 2014, 2017 and 2035 power mixes for the CRA, SWP and LADWP.

Emissions profiles for imported water supplies were calculated similarly by quantifying emissions related to the energy sources powering these imports. The energy used for both the State Water Project (SWP) and the Colorado River Aqueduct (CRA) were found in Metropolitan Water District (MWD) reports, and they were comprised of a mix hydropower, purchased grid power, and directly provided power from power plants (Metropolitan Water District 2014) (Metropolitan Water District 2017). We used this data to construct an energy and emissions profile for water imports. We assigned the IPCC's "large hydroelectric" emissions factor to hydropower plants within the State Water Project and the Colorado River Aqueduct. Energy purchases were assigned the emissions factor calculated (using the above method) for that energy provider. Energy provided directly from power plants were assigned an average of their reported energy sources (e.g. 50 percent coal and 50 percent natural gas for the Reid Power Plant in Nevada). These emissions factors were weighted proportionally for each imported water supply to produce an aggregated emissions intensity for each imported water supply.

This method, however, is only apt for describing 2014 emissions as it does not project future power mixes for each imported water supply. In order to produce 2035 estimates for these two entities, we employed a scaling method based on the 2014 mixes and the expected future power mixes described by the City of LA's energy portfolio and MWD's anticipated emissions reductions.

Table 6: 2014 and 2035 Expected Emissions for Water Management by Supply Alternative

	Original 2014 Numbers ($MTCO_2e/yr$) (a)	Projected Typical 2035 Numbers ($MTCO_2e/yr$) (b)	Scaling Value Multiplier
SWP	338,442	63,679	0.188
CRA	61,715	48,624	0.788
LADWP	221484	48,491	0.216

Table 6: Scaling Value is calculated as (a)/(b).

Source: University of California, Los Angeles

First, we calculated the MTCO2e/AF by dividing the total emissions by the 2035 water supply rate as reported in the Los Angeles City Report. We then divided the 2035 water supply rate (MTCO2e/AF) by the 2014 water supply rate. The result is the percentage of the 2014 water supply rate remains in the 2035 water supply emission rate, or the 2035 percentage remaining. Emissions factors were then multiplied by high, typical, and low energy consumption numbers to produce the MTCO2e/year for SWP and CRA in 2035.

2.5.3 Cost of Electricity

The cost of commercial electricity in urban Los Angeles ranges from 11.81 to 20.01c/kWh (U.S. Energy Information Administration State Electricity Profiles). A shift in water supply to a local DPR strategy may incur differential costs to providing water through imports simply due to the associated change in energy provider. Our analysis therefore also collects data that describes the cost of electricity associated with each water supply alternatives considered to assist in decision making.

The next step was to develop a method for estimating the energy cost for this sample water recycling plant. We focused on Southern California Edison (SCE) and Los Angeles Department of Water and Power (LADWP) as energy providers. A single pay schedule was selected for each provider. For SCE, this was TOU-8 and for LADWP, this was the A3 pay schedule. TOU-8 was selected for SCE because it is a commercial rate for plants operating at a capacity similar to most water recycling plants. A3 was selected for LADWP because it is a commercial rate for plants with a capacity of over 30kW and less than 10 MW. These pay schedules show the price on weekends and weekday by month and time of day. We then created daily average prices for weekdays and weekends by averaging the price across 24 hours. An overall daily average was developed by then by averaging 2 weekend day prices with 5 weekday prices. This overall average cost was then multiplied by the typical energy use, low energy use and high energy use estimates to generate overall cost estimates for SWP, CRA, Recycling Water and Desalination.

For the water importers, the total cost of energy was provided by a Metropolitan Water District report, Bulletin 132-11. These costs were then divided by the amount of energy provided, resulting in a cost per kWh.

CHAPTER 3: Project Results

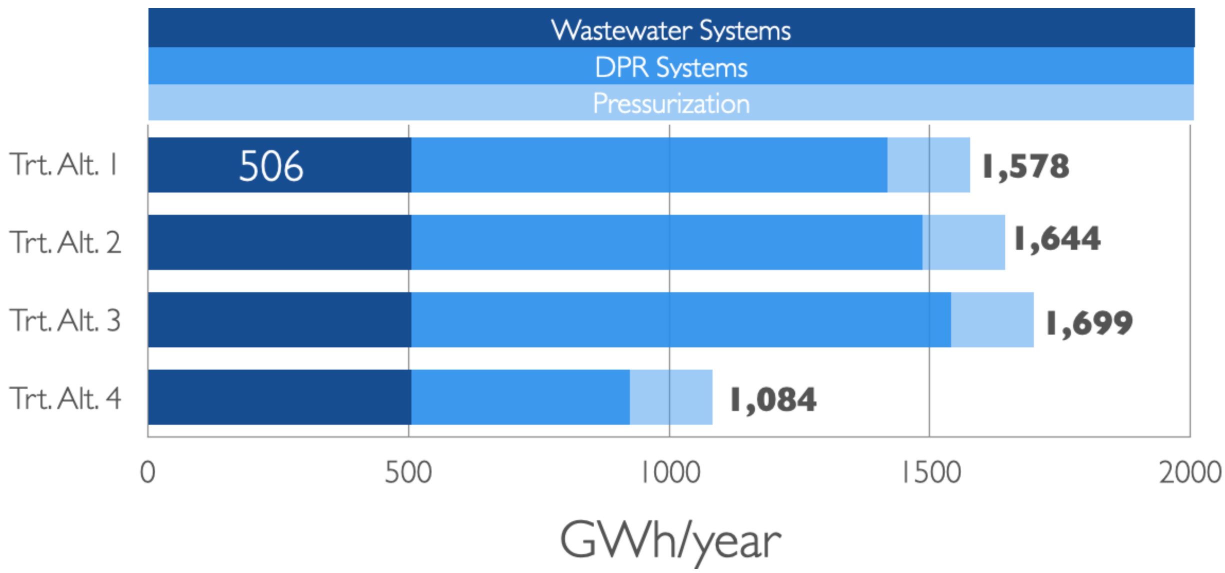
Using the collected and calculated data from previous sections, we analyze the change in energy use that occurs when shifting some of LA County's water supply provision to a DPR strategy. We then examine this shift in the wider context of California's water-energy supply portfolio and alternatives. Lastly, we address the significance of our findings and provide guidance on the previously unquantified energy components in DPR systems by using a breakeven analysis.

Our study finds that at baseline, full DPR adoption could increase energy use in the LA County's wastewater sector from anywhere between 2.1 to 3.3 times current levels. This increase in local energy use is accompanied by a potential water supply benefit of roughly 718,000 acre-feet (AF) per year—enough to meet the needs of almost 3 million southern California households. This increase, however, represents a shift in where energy is demanded. The comparative analysis of water supply alternatives demonstrates that DPR can provide relative net energy benefits to the state of more than 2300 GWh/yr, a savings of 0.8% of its statewide electricity budget. The subsequent analysis of the electricity cost suggests that economic incentives are inefficiently levied to incentivize DPR adoption compared to water imports. Notably, DPR will be a comparably GHG-intensive to low emissions imported water by 2035, though not in 2015—highlighting the importance of considering the temporal impacts of California's aggressive renewable portfolio standards on long-term decision making. Given the uncertainty in regulations, implementation strategy, and construction costs, these results show only a fraction of the possibilities for DPR in LA County and are intended to function as a framework or model to inform both policy decision makers as well as engineers on their future decisions in realizing the most appropriate DPR for the region.

3.1 Shifting Energy Load Associated with DPR

For the 16 wastewater facilities examined, the data shows that the plants have an existing annual energy need of 505.938 GWh/yr. If all possible waters from these plants were directed to a DPR strategy, the treatment processes required are expected to add between 419.930GWh/yr. and 1035.983 GWh/yr. to the existing load, depending on the treatment train used (Figure 3). This increased load, from 505.938 GWh/yr. to between 925.868 GWh/yr. and 1541.921 GWh/yr. represents a 1.830 to 3.048 factor energy use increase in the sector.

Figure 8: Potential Energy Use Incurred Through the Addition of AWT Trains For DPR



Source: University of California, Los Angele

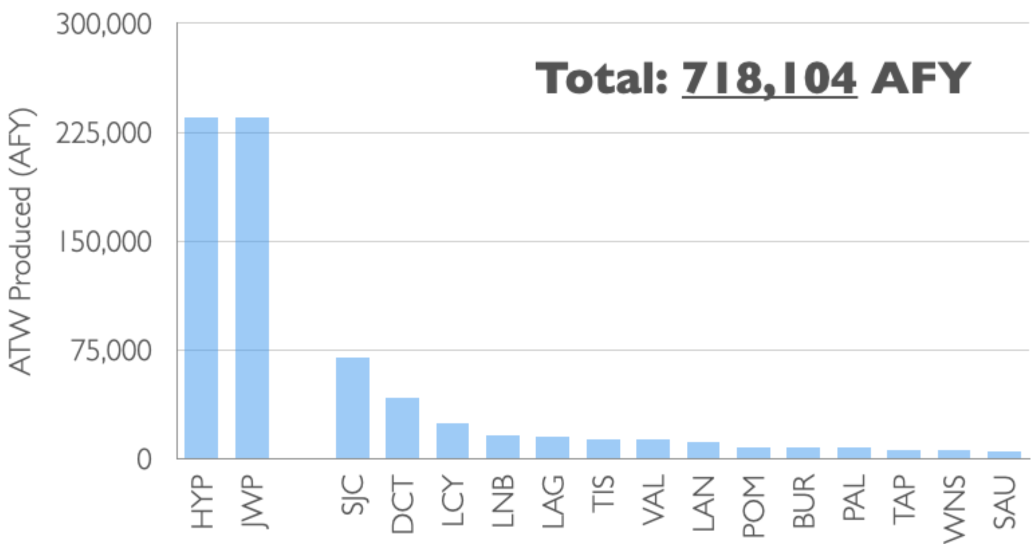
3.2 Local Water Supply Benefits

With the assumption that all flows from WWT are diverted to AWT for DPR, with 5 percent and 15 percent water losses respectively, the maximum potential potable water production for LA County is 718,104 AF/yr. In total, this represents 56.563 percent of the 2015 demand of LA County's largest water agencies (UWMP, 2015), with most of the flow produced at the largest plants, HYP and JWP, each providing 18.524 percent (37.048 percent total). With increased residential water conservation in recent years, which is expected to last into the future, wastewater flows are not expected to increase drastically. Thus, this quantification provides a maximum limit for AWT in the county. The major benefit from this water source is that it would be local and potentially more reliable than hydrologically derived water, considering the future climate uncertainty in the region. Beyond this, DPR will displace the need for other potable water sources, relieving some of the reliance on costly imports and the challenges associated with it.

For the short-term outlook at 2020, Raucher and Tchobanoglous (2014) estimate that roughly 60 percent of wastewater flows are available for DPR in the Los Angeles Water Resources Control Board Region. Considering this, our estimate for maximum ATRW production for 2020 is 430,862.662 AF, with an associated energy use range of between 603.235 GWh and 1,432.806 GWh.

Capturing this maximum flow may be ambitious in the short term due to the existing water supply agreements which agencies face (non-potable recycled water sales, groundwater recharge agreements, and seawater barrier defense wells). As water scarcity increases in the long-term, it will become more of an imperative to divert wastewater flows to this high value, potable water use.

Figure 9: Maximum Potential Water Recaptured for DPR using AWT



Source: University of California, Los Angeles

3.3 Statewide Energy Impacts

Given the potential potable water supply available through DPR, we are able to compare the energy burden to the grid in providing the same volume of water through the previously identified water supply alternatives for Southern California. As the additional energy load incurred by DPR treatment is uniformly lower than that of providing new water supplies from the alternatives, this analysis finds that shifting to DPR would provide net energy savings to the state. The table below shows the magnitude of the net energy savings for each alternative treatment train considering that the water produced would reduce the need for water from any existing or future water supply alternatives.

Table 7: Matrix Showing Net Statewide Energy Benefits Expected When Shifting to AWT from Imported and Desalinated Water Supply Alternatives

Net Statewide Energy Savings Range (GWh/yr)				
	MWD	SDPW	OCWD	ALTA
Desal	1,614.016	1,668.756	1,734.389	2,228.764
SWP	1,428.789	1,483.529	1,549.162	2,043.536
CRA	846.145	900.885	966.518	1,460.893

Source: University of California, Los Angeles

This data shows that the relative statewide energy benefit of DPR compared to other potable water supply strategies ranges from 1004.087 GWh/yr. to 2388.011 GWh/yr. depending on the treatment train used and the water supply alternative displaced. According to Silverman's (2007) estimates, the benefit captured from only a change in LA County's operations, is enough energy to power up to 398,002 California households annually.

As expected, the greatest energy benefit is seen when using the least energy intensive treatment train (ALTA) to displace the most energy intensive water supply alternative (desalination). The net savings would represent a 0.344 percent to 0.818 percent reduction of the state's total 2017 electricity usage, which is particularly significant recognizing that between only 5.1-7.7 percent of the state's electricity is attributed to water and wastewater management (CEC, 2017; CPUC, 2015, 2010, 2005). Within this context, the 1004.087 GWh/yr. to 2388.011 GWh/yr savings translates to a reduction of between 4.471 percent and 16.033 percent of all of the state's electricity for non-end use water operations.

The relatively large net energy benefits seen when using the ALTA train as compared to the alternatives come as a result of ALTA, not including a reverse osmosis unit process. In California, this approach is being met with skepticism as reverse osmosis is considered to be the most protective of public health through its significant removal of contaminants. However, in cases which may not need this additional removal, excluding the reverse osmosis unit process from the treatment train can provide attractive benefits in greatly reducing energy demand, but more importantly for water managers: without a reverse osmosis process, AWT would not produce a brine concentrate waste stream. Challenges with brine management are further addressed in section 3.5.1.

3.4 Sensitivity Analysis

In the sensitivity analysis for this research, we identified six key assumptions which allow us to reach the described conclusions.

All existing wastewater flows entering reclamation facilities are utilized for AWT

Wastewater flows exist and operate independently from one another.

- During WWT, 5 percent of flows are lost or used.
- During WWT, 15 percent of flows are lost or used.
- Large plants are not afforded economies of scale above the available field data limitations.
- ATW will be pressurized to 80psi for distribution.

We are confident in the assumptions that we have chosen, however we recognize that these may not capture the entire range of possibilities and that adjustments in these assumptions could result in results of different magnitudes. Based on our review of the assumptions identified, we find that most of the alternatives independently result in relatively small magnitude shifts of less than ±10 percent (up to 8 percent increase in net energy savings at the state level and as much as a 5 percent decrease). Table 6 summarizes how adjustments in our key assumptions affect statewide energy impacts. The assumptions which may most shift our results are those guided by water agency decisions: allocating wastewater flows to recycling, and decisions based on inter-dependency of flows between wastewater treatment plants.

For the analysis considering maximum potential energy use, we assumed that wastewater treatment plants would eventually move towards assigning all of their flows to the highest quality of water use available. This scenario is likely true from a long-term perspective where growing water scarcity in California will continue to drive full-scale AWT even in advance of desalination. In the short-term however, agencies may have agreements to serve portions of the wastewater flows to existing customers for non-DPR uses, effectively reducing the volume of water available for DPR. To identify a more likely short-term scenario, we have collected publicly available information for our modeled facilities detailing any of their planned AWT. Notably, the two largest facilities (HYP and JWP) in our study do expect to reclaim some portion of their flows within the next 20 years, meaning a large proportion of energy use will be realized.

The latter assumption concerning the interdependency of wastewater treatment plant flows assumes that flows to wastewater facilities are independent of one another, meaning that any facility can recycle its influent water without reducing the availability of wastewater to other treatment plants. This can be true in LA County, however under current operational practices, wastewater flows are highly interdependent and coordinated through joint management of networks of reclamation facilities. Our analysis does not attempt to model this complex interdependency, but recognizes that in the short term, one facility's choice to engage in AWT may significantly affect a downstream facility's AWT capacity. In the long term, even with a joint, networked system of reclamation facilities, each can maximize its recycling potential and achieve an equilibrium steady state which would be theoretically identical to our scenario results.

Table 8: Key Assumptions, Alternatives, And Potential Impacts to Primary Results

	Key Assumption	Reasonable Alternative	Impact to Primary Scenario's Statewide Energy Impacts
1	All existing wastewater flows entering reclamation facilities are utilized for AWT	Given prior commitments in the short term a lesser proportion of water is available for AWT. An average between two large projects in Los Angeles suggests that this value may be closer to 72.5% (LADWP-77%, MWD- 68%)	Decrease in short-term net energy savings. Long-term energy impacts unaffected.
2	Wastewater flows exist and operate independently from one another	In reality, many LA County facilities interconnectedly direct flows. AWT recycling at one will affect flow other facilities. No effort has been made to model this complex interdependency in this analysis.	Potentially significant decrease in net energy savings among plants that are jointly coordinated.
3	During WWT, 5% of flows are lost or used.	Described values from operators range from 4-10%.	Variable. Changes in net energy savings ranging from an increase of 1% and a decrease of up to 5%.
4	During WWT, 15% of flows are lost.	Described values from operators and experts range from 10-20%.	Variable. Changes in net energy savings ranging from an increase of

			5% and a decrease of up to 5%.
5	Large plants are not afforded economies of scale above the available field data limitations.	Assuming the same gradient as for modeled plants, enable economies of scale across plants of all sizes.	Potential increase in energy savings of between 2-8%.
6	ATW will be pressurized to 80psi for distribution.	A wide range exists for distribution systems with ideals described between 60-80psi. Minimum recommended pressure is as low as 35 psi with few systems assigning maximum limitations. A survey of systems shows a true range of pressures as low as 20psi, routinely above 100psi, and as high as 300psi.	Variable. Reasonably expected changes (35-100psi modelled) in net energy savings range from an increase of up to 8% and a decrease of up to 7%.

Source: University of California, Los Angeles

3.5 Further Considerations

3.5.1 Energy Availability for Recycled Water Distribution and Waste Management

A plant's site-specific conditions can significantly impact the overall energy intensity of its recycled water operations. Therefore, this section attempts to address these factors by using the previously calculated net energy savings to develop guidelines for energy operations in the yet unquantified components of the sector. These energy values describe the range of energy intensities for non-treatment operations within which the state would still see net energy benefits.

Table 9: Matrix Showing Maximum Energy Intensities for Non-treatment Operations within which Statewide Energy Benefits Are Still Accrued

Breakeven Analysis showing Remaining Energy Capacity kWh/AF				
	MWD	SDPW	OCWD	ALTA
Desal	1,814.94	1,876.50	1,950.30	2,506.22
SWP	1,606.66	1,668.21	1,742.01	2,297.93
CRA	951.48	1,013.03	1,086.84	1,642.76

Source: University of California, Los Angeles

This breakeven analysis estimates that the energy per unit of raw wastewater treated ranges from 1,129.084 kWh/AF to 2,685.290 kWh/AF, depending on the treatment train used and alternative displaced.

To provide energy benefits to the state, the energy intensities for both distribution and waste management would need to fall below the relevant "breakeven value" for the specific DPR strategy being considered. A system's ability to remain within these bounds is highly dependent on site-specific considerations and will particularly rely on a system's topography.

For distribution in a DPR strategy, this energy represents pumping of between 1,102.621 to 2,622.354 ft of dynamic head. While this amount may be reasonable for distributing water to existing drinking water main lines for treated water augmentation, it may not provide a feasible range for large scale DPR via raw water augmentation. For the two largest WWT plants in LA County (HYP and JWP), pumping water to their nearest drinking water facilities (Los Angeles Aqueduct Filtration Plant and the Robert B Diemer Plant, respectively) would require roughly 1087.1ft and 781 ft of static head pumping respectively; a significant portion of the breakeven value, even when not accounting for significant friction loss considerations across the horizontal distances needed to move this water. This rough calculation implies that for these major plants, a raw water augmentation DPR strategy may be far from viable if considering pumping only to existing drinking water treatment plants.

For the waste management component, the energy effective range would be primarily utilized for disposal of brine concentrate. In the instances where facilities have access to existing ocean outfall brine disposal lines, this energy intensity will be relatively low compared to those pumping from inland facilities to the coast, or those doing deep well injection to non-potable subsurface waters. A simple energy estimation based on OCWD's operations (Raucher and Tchobanoglous, 2014) estimates that the energy effective range would translate to between 830.209 and 1974.478 ft of dynamic head for brine conveyance—shorter than that of the distribution dynamic head due to the increased brine density over potable water. With this limited dynamic head range, distant inland plants would be limited in their capacity to convey brine while still providing net energy benefits to the state. It is significant to note here that all energy effective estimations fall short of the energy intensity for zero liquid discharge brine management alternative at 3420-5030 kWh/AF (Raucher and Tchobanoglous, 2014, Voutchokov, 2013).

In the case of treated water augmentation using the ALTA treatment train there are exceptional considerations. For treated water augmentation, the distribution of water to the nearest drinking water main is likely minimal allowing for more flexibility in energy intensity for waste management. With the ALTA train, the process does not produce any brine to be managed, which allows for larger variation in the energy intensity for distribution. A treated water augmentation DPR strategy using an ALTA train would provide the greatest net energy benefits to the state by avoiding high distribution and brine management energy costs.

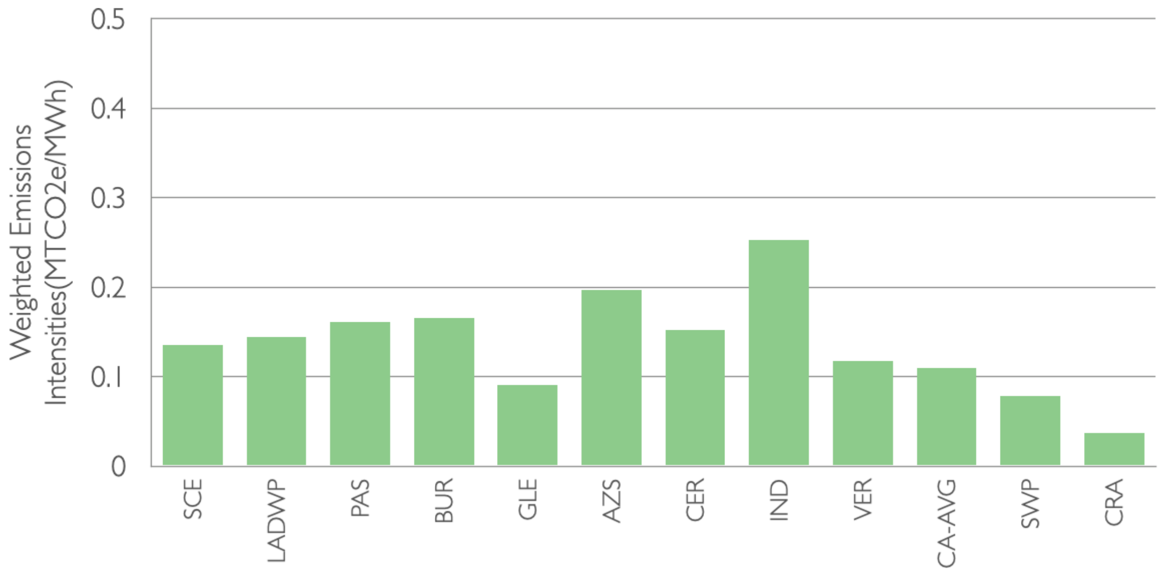
Quantifying the aspects of DPR that are highly site-specific is challenging, and while our breakeven analysis attempts to address and guide the energy impacts of distribution and waste management, this research was unable to capture the granular level decisions about unit processes.

An example of this would be that AWT for DPR strategies may require further biological nutrient removal, which can increase energy intensity, while also making redundant some existing components of the existing WWT train. Despite these uncertainties, our conservative approach suggests that if DPR is pursued in California, it can still result in significant energy savings at the state level.

3.5.2 Greenhouse Gases

This analysis shows a range of emissions contributed through the provision of different water supplies to LA County. To estimate this amount, we specifically examine the roughly 718,000 AF that can be provided through AWT and compare the provision of the same volume of water through import and desalination alternatives. Depending on the energy provider and power mix for each treatment facility, the total emissions contribution will be variable and to examine the extent of this, we demonstrate the range of emissions factors by energy providers in LA County.

Figure 10: Emissions Intensities for LA County Energy Providers



Source: University of California, Los Angeles

To develop comparable estimate for emissions, we assumed that TWA, RWA, and DSL were most likely to be developed in the City of Los Angeles and thus used LADWP's emissions factor (0.144 MTCO2e/MWh) to examine the relative emissions impacts. We chose this value as a conservative intermediary between the high (0.253MTCO2e/MWh) and low (0.091MTCO2e/MWh) emissions intensities found across the county. For imported water, the SWP and CRA specific emissions values were used.

Figure 11: Emissions Contributed by the Provision of Recycled and Alternative Waters in LA County using 2014 (left) and 2035 (right) Emissions Estimates

Source: University of California, Los Angeles

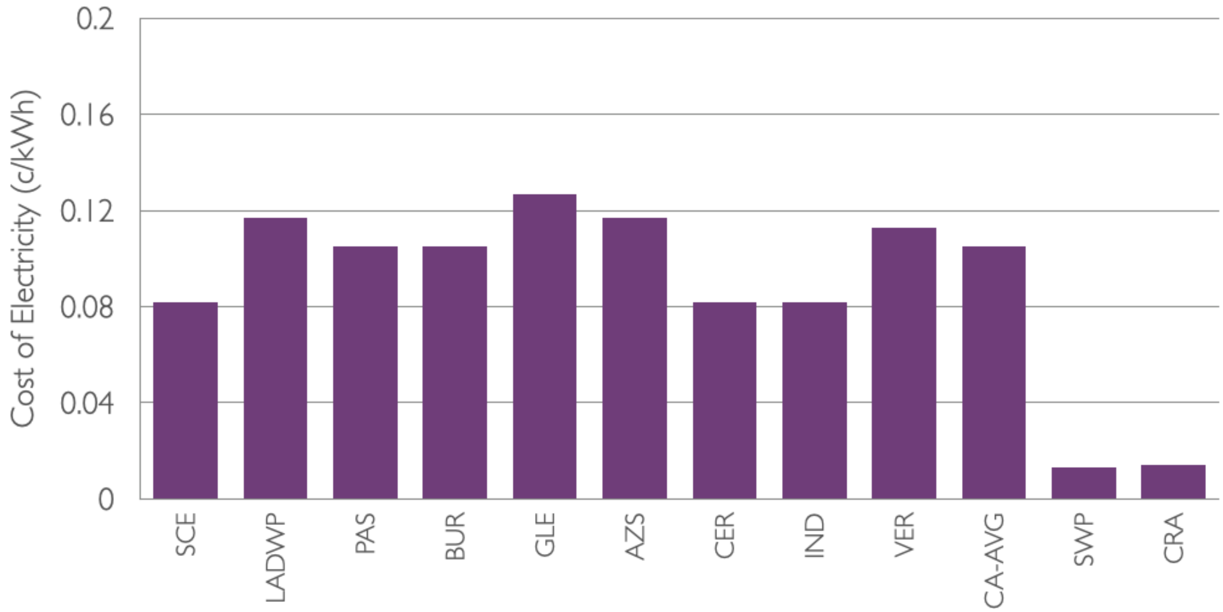
These results show that desalination has the highest annual emissions factor with RWA closely following. TWA shows a far reduced emissions factor compared to RWA. The CRA and SWP emissions factors are the lowest, despite having some of the highest energy intensities. This confounding result is due to these supplies heavily utilizing low-emission energy, in particular large hydro power from agreements with the California Department of Water Resources and Hoover Dam. With this in mind, if today's water supply decisions are being driven by climate and emissions outcomes, these values suggest that Southern California might elect to utilize greater water imports in the future to keep emissions low. However, when we compare these total emissions values between 2014 and 2035, TWA appears to have a comparably low carbon footprint to imports, though RWA is still higher. Importantly, all the projected emissions for 2035 are comparable to the lowest emissions in 2014, suggesting that the emissions profiles of water supplies will be a topic of diminishing importance into the future.

Our GHG analysis emphasizes that importance of energy providers meeting their aggressive emissions reduction goals in their energy portfolios to enable local resiliency through water supply decisions. The vast difference between the 2014 and 2035 emissions intensity for each water supply alternative demonstrates the importance of considering the emissions conditions for future implementation when making decisions. These findings also suggest that as California's energy portfolio becomes increasingly cleaner, water supply alternatives will be more similar from an environmental standpoint, indicating that their cost and energy use will play a more important role in future supply decisions.

3.5.3 Cost of Electricity

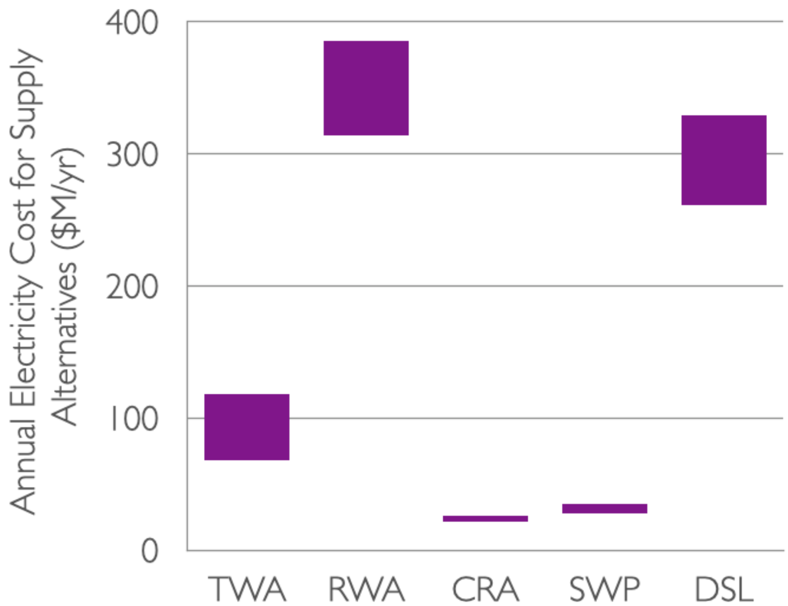
Our analysis of the economic cost of electricity shows that all local energy providers have a higher cost relative to imports due to the longstanding agreements that importers hold in purchasing hydropower from the California Department of Water Resources and the U.S. Federal Bureau of Reclamation (Hoover Dam). While we acknowledge that the final cost of water is not dictated solely by electricity cost, the magnitude of this finding demonstrates that there may be a need to address the affordability of recycled water as these energy costs will ultimately be passed to ratepayers.

Figure 12: Current Industrial User Energy Rates for Each Provider in LA County



Source: University of California, Los Angeles

Figure 13: Additional Regional Electricity Cost per Year by Water Supply Alternative



Source: University of California, Los Angeles

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

This research provides a framework for both water utilities and regional energy planners to consider the impacts of DPR adoption on the wider water-energy nexus in Los Angeles County, and this section describes a case study example developed for the City of Los Angeles informing energy and water supply tradeoffs for the recycled water expansion of the Hyperion Water Reclamation Plant.

This methodology demonstrated in this example can be applied to other water-scarce regions reliant on imports or desalination to determine their recycled water potential and the larger scale energy effects of DPR strategies. It can also be used to create regionally-specific guidelines for the highly variable distribution and waste management components of DPR. These guidelines are useful for operational stakeholders like water and energy utilities who can use these standards to assess whether DPR will be an energy effective solution for their local and regional system, or to inform their future infrastructure and load planning.

Hyperion NEXT Project

The Hyperion NEXT project is a joint response by the City of Los Angeles' Department of Water and Power and the City's Sanitation Department to the ambitious proclamation that it will recycle 100 percent of its ocean-bound wastewater effluent by 2035. The Hyperion Water Reclamation Facility is located on the coast of the Pacific Ocean in the City of Los Angeles. One of the challenges that the project faces is determining which recycled water strategy might be most beneficial given the potential large uphill pumping required to provide the City with its own recycled water. The remainder of this section outlines how our analysis was applied to this scenario to present some of the energy relevant tradeoffs for this project across different strategies.

The primary strategies under consideration for DPR using Hyperion's water are RWA strategies which require uphill pumping to one of two facilities: the Los Angeles Aqueduct filtration plant (LAA) located toward the northern extent of the city's boundary and the Glendale Headworks Reservoir (HWR). These facilities are at 493 and 1,163 ft of elevation, respectively, but are separated from the Hyperion facility by small mountain ranges.

Case Study Approach

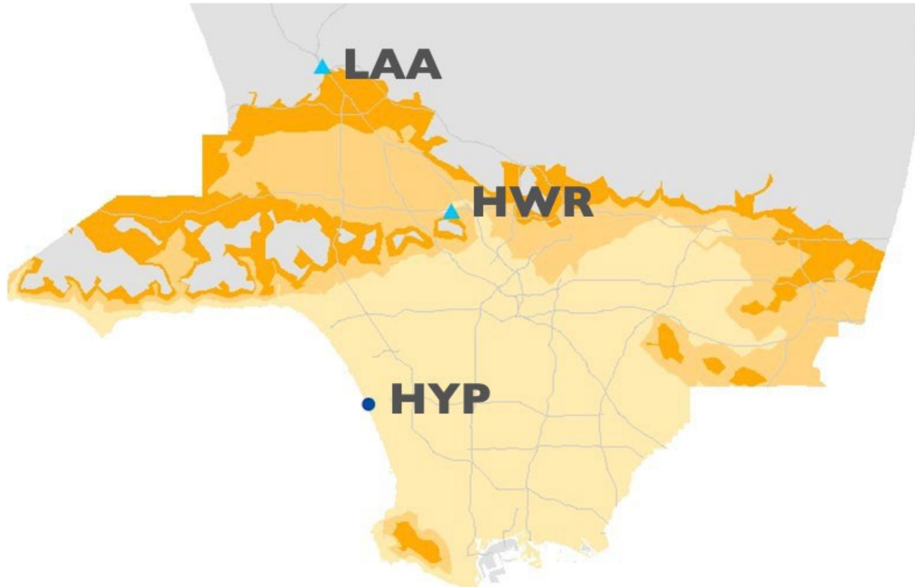
To quantify which strategy might be most effective for the City, this case study first specifically examines the Hyperion Water Reclamation Plant's energy usage, available water flows, and the City's likely water supply alternatives. We then compare the energy use required to treat the available flows for DPR to the energy use required to provide common water supply alternatives in the region. The net energy difference between these represents the energy benefit for TWA but does not capture the uphill pumping required for RWA. Through an understanding of the energy required to lift water we can use the net energy savings calculations for each supply alternative to determine how much lift we might be able to apply to Hyperion's recycled water flow before a strategy becomes net energy neutral relative to existing water supply alternatives.

The following results show the pumping extents available for planned Hyperion recycled water flows assuming Hyperion's installation of the MWD treatment train (Treatment Train 3). To show the extent of possibilities the results displayed in this section compare the energy use of Hyperion's DPR strategy to providing imported water through the CRA (low range) and through desalination (high range). As the project has not yet settled on construction paths for pipelines our analysis primarily estimates energy use for lift, but not friction or efficiency losses. To account for these losses, we describe a range of pumping extents representing scenarios with additional high and intermediate losses by estimating an energy use increase in the strategy of 3 and 2 times, respectively. Our analysis does not specifically account for pumping over the intermediary mountain ranges and assumes full energy recapture through in-conduit hydro turbines. Actual in-conduit hydro energy recapture efficiencies are expected to be ~90% (Casini, 2015)

Case Study Results

The net energy available for pumping while making the project energy neutral is the smallest when using AWT to offset CRA imports. This map shows that under these conditions Hyperion's recycled water cannot be pumped uphill to the LAA without incurring net additional energy consumption to the state.

Figure 14: Allowable Pumping Extents for DPR When Displacing Supply Alternatives with AWT and Providing Net Statewide Energy Benefits



Source: University of California, Los Angeles

Each colored area represents a pumping extent for net-neutral energy use when displacing a supply alternative with AWT. Dark Orange- Desalination. Medium Orange- SWP Imports, Light Orange- CRA Imports.

The net energy available for pumping while making the project energy neutral is the largest when using DPR to offset desalination. This map shows that even under these best-case scenarios, Hyperion water cannot be pumped uphill to the LAA plant and provide net energy benefits to the state. Under the intermediate scenario, Hyperion water can be pumped to the HWR, and under the worst case (highest loss) scenario the available recycled water can’t be provided to either facility.

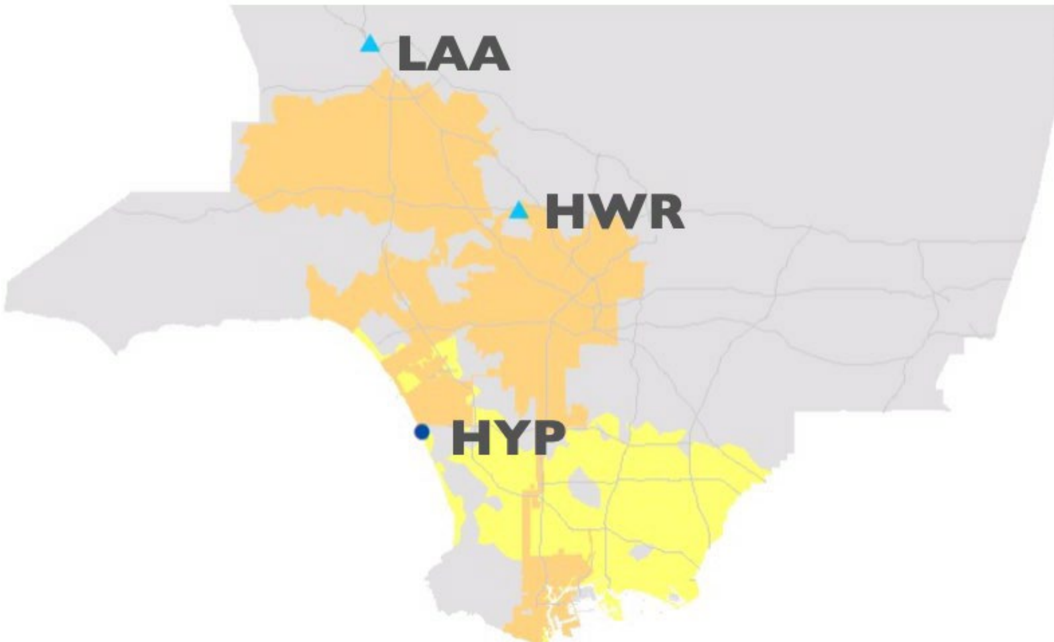
Regional Policy and Joint Decision Making

Given these circumstances if LADWP is bound to using a RWA strategy, the state will not see any net energy benefits. There are some alternatives to our primary case study scenario which might enable this project to realize energy benefits to the state. Firstly, the possibility that using a less energy intensive treatment train could be applied, for example the ALTA train (TT4). Secondly, whether there is the possibility to supply Hyperion’s recycled water not just to the LAA for the city’s use, but if it could provide water to a wider, nearby area. And thirdly, building off the last point, there may be opportunity for joint management and access to a drinking water facility beyond the city’s limits. We address these points in the following paragraphs.

Applying a treatment train like TT4 will be challenging for many California water systems given existing contamination and salts in our water supplies. However, if a technology or treatment train were to be found to be sufficiently protective of public health, net energy efficiency gains would increase significantly, resulting in more flexibility for additional energy uses like waste management or an increased pumping extent. Feedback gathered during this case study process suggests that this alternative is unlikely to come to fruition due to lack of technological maturity and an unproven record of success in protecting public health.

The second possibility to ensure net energy efficiency benefits to the state while maintaining the anticipated required treatment levels is to use the recycled water closer to Hyperion. This possibility isn't within the city's vision as the communities closest to the Hyperion facility do not largely belong to the City and do not demand a sufficient amount of water to utilize all of Hyperion's output. Implementing a strategy that overcomes these would require joint policy and bureaucratic leadership to move beyond the existing legal limitations preventing the city from serving water beyond its stated boundaries. Additionally, if RWA were still required, there would be a need for joint management and conveyance to a drinking water treatment facility in the lower LA basin.

Figure 15: City of Los Angeles Service Area Required to Meet Consumptive Use for Project NEXT Compared to Closer Local Consumers



Source: University of California, Los Angeles

A further consideration for energy management in the sector should be biogas, which is currently an underutilized resource following recent air quality regulations and inter-agency operational limitations. At some WWTP facilities, on-site electricity production from biogas created as a byproduct of water treatment processes can already be in excess of its energy consumption. SB 1383 stands to further increase biogas production. On-site biogas electricity generation could be a solution to meet the shift to local energy demand from the potential growth of DPR using local energy.

CHAPTER 5: Conclusions

In conclusion, this research shows that while DPR would increase local energy usage in LA County, it can also provide significant statewide energy benefits. The magnitude of these benefits will be dependent on which AWT treatment train is selected and the type of water supply being displaced. Most importantly however, the type of DPR strategy (RWA or TWA) will determine the water sector's impacts on the energy grid, and this decision will be greatly influenced by SWRCB and DDW policy decisions expected in 2023. A decision to solely allow RWA, will greatly diminish the chances of reducing the state's net energy demand. Regardless, through both RWA and TWA strategies, energy demand in LA County will increase locally, having potential externalities of increasing the cost of both water and energy to customers, as well as shifting the region's carbon footprint.

In our analysis we have made conservative assumptions throughout our calculations describing the AWT trains and thus energy use estimates are likely overstated, and the net energy savings are understated. The calculated benefit to the state's electricity budget for the water sector (California Energy Commission, 2006) is a reduction of between 4.471 percent and 16.033 percent. Evidence for this reduction is demonstrated in this analysis while only accounting for wastewater flows for less than half of Southern California's population, suggesting that if this analysis were to be expanded, the state would see yet larger energy savings.

As a local water supply strategy, DPR is shown to be able to produce up to 56.563 percent of LA County's water demand, which would provide significant regional resiliency benefits, while also helping to meet the sustainability and reliability goals of individual water stakeholders in the county. These volumes of water could roughly double the state's 2015 recycled water use (DWR, 2017), bringing the state closer to its wider DWR goal of 1.5 million AF by 2020. Even if supplying 56.563 percent of the County's water using recycled supplies may be a distant future, 37.048 percent can be captured from the top two plants alone, both of which are already considering AWT adoption. At a regional scale, an analysis further considering the indirect benefits of recycling and joint wastewater management would highlight the value of making regionally focused water supply decisions such as increased recycling.

Similarly, a more granular examination of site-specific, non-treatment operational factors like solid waste management, biogas generation and use, solar energy capture, and existing recycled water operations, would enable a more holistic examination of the wastewater sector beyond the embedded energies within the water products only. This knowledge, alongside daily load profiles for water recycling, would provide insight into how load shifting of energy intensive AWT processes might be used to support the grid or minimize greenhouse gas emissions. Expanding this research to a broader geography, especially within Southern California, will provide a greater understanding of the potential net statewide energy benefits of DPR. Furthermore, with appropriately detailed energy intensity information on existing water supply alternatives, a mapping tool could identify priority areas for developing DPR— those that would provide greater net energy benefits to the state.

CHAPTER 6: Benefits to Ratepayers

As California's water sector shifts towards using more DPR in water-stressed areas, advanced water treatment processes will drastically increase local energy consumption. Depending on the extent of DPR adoption and reduced reliance on energy-intensive alternative supplies, the impact to the local energy grid--and thus ratepayers--will be variable. For example, localities implementing DPR to replace or reduce energy-intensive imported water supplies stand to contribute to a net reduction in the state's energy demand, however, a locality implementing DPR to avoid groundwater pumping stands to show the opposite. It is important to recognize these juxtaposed outcomes as it shows that DPR may not be the least energy intensive solution for all water systems, and it will be the decisions of disparate water systems that will determine the net energy outcomes of this advancement.

The value of DPR adoption for ratepayers is taken predominantly through water supply resilience and security. However, there are both direct and indirect benefits influenced through the energy sector, but these are dependent on a ratepayer's location. In geographies expecting DPR adoption local infrastructure like substation and transmission lines will likely necessitate capital upgrades to accommodate the roughly tripling in energy needs from wastewater treatment facilities. These costs will be distributed and borne by ratepayers in their electricity bills. Conversely, reduced reliance on energy-intensive water supply alternatives like imported water will reduce the need for existing infrastructure capacity in geographies which currently provide energy for pumping. This reduced need isn't a cost reduction in itself but will result in the delayed need for capacity upgrades in those areas.

Our analysis specifically shows that with the adoption of DPR in Los Angeles County, local energy consumption will rise, and we expect that this will translate into increased capital upgrades and thus costs for local ratepayers, regardless of their electricity provider. In addition to these direct costs, our analysis also notes that costs for electricity provision locally are already higher than those costs identified for imported water, which may result in a compounded increase of costs to water ratepayers. Our GHG analysis additionally suggests that there are indirect carbon emissions benefits to reducing reliance on imported water supplies, which may be of value to California ratepayers more generally.

GLOSSARY OR LIST OF ACRONYMS

Acronym	Definition
AF	Acre-Feet
ALTA	PureALTA Project (Direct Potable Reuse Recycling Project)
AWT	Advanced Water Treatment
ATW	Advanced Treated Water
BAC	Biologically Activated Carbon
CRA	Colorado River Aqueduct
DPR	Direct Potable Reuse
DSL	Desalination
EI	Energy Intensity
FAT	Full Advanced Treatment
RO	Reverse Osmosis
MBR	Membrane Bioreactor
MF	Microfiltration
MGD	Million Gallons per Day
MWD	Metropolitan Water District of Southern California
OCWD	Orange County Water District
OZ	Ozone
SDPW	San Diego Pure Water (Direct Potable Reuse Recycling Project)
SWP	State Water Project (California Aqueduct)
UF	Ultrafiltration
UV	Ultraviolet Irradiation
WWT	Wastewater Treatment

GHG	Greenhouse Gases
GWh	Gigawatt Hour
KWh	Kilowatt Hour

REFERENCES

Bertanza, G., Canato, M., Laera, G., Vaccari, M., Svanstrom, M., Heimersson, S. 2017. A Comparative techno-economic-environmental assessment of full-scale CAS vs MBR technologies. The Membrane Bioreactor Site. https://www.thembrsite.com/features/a-comparative-techno-economic-environmental-assessment-of-full-scale-classical-activated-sludge-vs-membrane-bioreactor-technologies/

California Air Resource Board. 2013. Dat Requirements and Calculation Methods for Electric Power Entities. California Code of Regulations §95111(b)(1). Page 97.

California Energy Commission. 2017a. Annual Power Content Labels for 2017: Los Angeles Department of Water and Power. California Energy Commission. Accessed October 2019. https://www.energy.ca.gov/files/annual-power-content-labels-2017

California Energy Commission. 2017b. Annual Power Content Labels for 2017: Southern California Edison. California Energy Commission. Accessed October 2019. https://www.energy.ca.gov/files/annual-power-content-labels-2017

Casini, M. 2015. Harvesting Energy from In-pipe Hydro Systems at Urban and Building Scale. International Journal of Smart Grid and Clean Energy.

City of Los Angeles. 2019. L.A.'s Green New Deal: Sustainable City pLAn. City of Los Angeles Report. https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf

du Pisani, P.L. 2006. Direct reclamation of potable water at Windhoek's Goreangab reclamation plant. Desalination Volume 188, Issues 1–3, 5 February 2006, Pages 79-88. https://doi.org/10.1016/j.desal.2005.04.104

Edenhofer, O., Pichs-Madruga, R., Sokona, Y, Seyboth, K, Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schloemer, S., von Stechow, C. 2011. Renewable Energy Sources and Climate Change Mitigation. International Panel on Climate Change Special Report.

Fang, AJ., Newell, JP., Cousins, JJ. 2015. The Energy and emissions footprint of water supply for southern California. Environmental Research Letters. Volume 10, Number 11.

GEI Consultants/Navigant Consulting, Inc. 2010. Embedded Energy in Water Studies. Study 1: Statewide and Regional Water-Energy Relationship. California Public Utilities Commission: Energy Division.

Gerrity, D., Pecson, B., Trussell, RS., Trussell, R. 2013. Potable Reuse Treatment Trains throughout the World. Journal of Water Supply: Research and Technology-AQUA. 62(6):321-338. DOI: 10.2166/aqua.2013.041

Hartley, K., Tortajada, C., Biswas, AK. 2019. A formal model concerning policy strategies to build public acceptance of potable water reuse. Journal of Environmental Management. Volume 250, 15 November 2019, 109505. https://doi.org/10.1016/j.jenvman.2019.109505

Hertzberg, R. Wiener, S. 2016 (edited 2019). California Senate Bill 332. California Senate.

Isaacson, M., Sayed, AR. 1988. Health Aspects of the use of recycled water in Windhoek, SWA/Namibia 1974-1983. Diarrhoeal diseases and consumption of reclaimed water. South African Medical Journal = Suid-afrikaanse Tydskrif vir Geneeskunde. 73(10):596- 599

Klein, G., Krebs, M., Hall, V., O'Brien, T., Blevins, B. 2005. California's Water-Energy Relationship: Final Staff Report. California Energy Commission.

Kumar, PS., Salveson, A., Ammerman, DK., Steinle-Darling, E. 2017. Innovative Potable Water Purification without RO- Direct Potable Reuse Demonstration Pilot in Central Florida. Proceedings of the Water Environment Federation. Volume 12: 2340-2347.http://dx.doi.org/10.2175/193864717822152455

Lee, CO., Howe, KJ., Thomson, BM. 2010. Ozone and Biofiltration as an Alternative to Reverse Osmosis for Removing PPCPs and EDCs from Wastewater. University of New Mexico Report for New Mexico Environment Department. http://www.unm.edu/~howe/UNM%20Howe%20Final%20PPCP%20Ozone-Biofiltration%20Report.pdf

Los Angeles Department of Water of Power. 2015. 2015 Urban Water Management Plan. http://www.ladwp.com/uwmp

Los Angeles Department of Water and Power. 2017. Power Strategic Long-Term Resources Plan. Los Angeles Department of Water and Power Report. Page F-7.

California Energy Commission. California 2004. Statewide Residential Appliance Study. California Energy Commission Report.

Margot, J., Kienle, C., Magnet, A., Weil, A., Rossi, L., de Alencastro, LF., Abegglen, C., Thonney, D., Chevre, N., Scharer, M., Barry, DA. 2013. Science of The Total Environment. Volume 461-462, Pages 480-498. https://doi.org/10.1016/j.scitotenv.2013.05.034

Mika, K., Gallow, E., Porse, E., Hogue, T., Pincetl, S., Gold, M. 2018. LA Sustainable Water Project: Los Angeles City-Wide Overview. UCLA Sustainable LA Grand Challenge Report. Retrieved from: https://escholarship.org/uc/item/4tp3x8g4

Pabi, S., Amaranth, A., Goldstein, R., Reekie, L. 2013. Electricity Use and Management in the Municipal Water Supply and Wastewater Industries. Water Research Foundation, Electric Power Research Institute Joint Report.

Plumlee, MH., Stanford, BD., Debroux, JF., Hopkins, DC., Snyder, SA. 2014. Cost of Advanced Treatment in Water Reclamation. Ozone: Science and Engineering.

Porse, E., Mika, KB., Escriba-Bou, A., Fournier, ED., Sanders, KT., Spang, E., Stokes-Draut, J., Federico, F., Gold, M., Pincetl, S. 2020. Energy Use for Urban Water Management by Utilities and Households in Los Angeles. Environmental Research Communications. Volume 2, Number 1.

Raucher, R., Tchobanoglous, G.2014. The Opportunity and Economics of Direct Potable Reuse, WateReuse Research Foundation Report.

Salveson, A.; Steinle-Darling, E.; Trussell, S.; Trussell, B.; McPherson, L. Guidelines for Engineered Storage for Direct Potable Reuse. WateReuse Research Foundation: Alexandria, VA, 2015.

Sanders, K. 2016. The energy trade-offs of adapting to a water-scarce future: case study of Los Angeles. International Journal of Water Resources Development. https://doi.org/10.1080/07900627.2015.1095079

Tchobanoglous, G., Cotruvo, J., Crook, J., McDonald, E., Olivieri, A., Salveson, A., Trussell, RS. 2015. Framework for Direct Potable Reuse Report. Water Resuse Foundation, American Water Works Association, Water Environment Federation, National Water Research Institute.

Voutchkov, N. 2013. Seawater Desalination—Costs and Technology Trends. Encyclopedia of Membrane Science and Technology. https://doi.org/10.1002/9781118522318.emst115

Xu, M., Uang, J., Hughes, DM., Lechevallier, MW. 2014. Survey of Pressure Management in Water Distribution Systems. Journal of American Water Works Association. Volume 106, Issue 11.