Energy Efficient Flight Conveyor Dishwashers

ET Project Number: ET16PGE1971

Project Manager: **Jeff Beresini**
Pacific Gas and Electric Company

Prepared By: **Michael Slater   Amin Delagah   Angelo Karas   Rodney Davis**
Fisher Nickel, a division of Frontier Energy, Inc.
12949 Alcosta Blvd., Suite 101
San Ramon, CA, 94583

Issued: **April 14, 2017**

Pacific Gas and Electric Company®

ACKNOWLEDGEMENTS

LEGAL NOTICE

This report was prepared for Pacific Gas and Electric Company for use by its employees and agents. Neither Pacific Gas and Electric Company nor any of its employees and agents:

(1) makes any written or oral warranty, expressed or implied, including, but not limited to those concerning merchantability or fitness for a particular purpose;

(2) assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, process, method, or policy contained herein; or

(3) represents that its use would not infringe any privately owned rights, including, but not limited to, patents, trademarks, or copyrights.

ABBREVIATIONS AND ACRONYMS

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Section of the International Association for Testing Materials
BE	Booster Efficiency
EE	Energy Efficiency
EI	Energy Index
ES1	ENERGY STAR 1.0 Commercial Dishwasher Specifications
ES2	ENERGY STAR 2.0 Commercial Dishwasher Specifications
ET	Emerging Technologies
ETCC	Emerging Technologies Coordinating Council
EUI	Energy Use Index
FN	Fisher Nickel
FSTC	PG&E Food Service Technology Center
HCF	Hundred Cubic Feet
hR	Hour Rinse
HX	Heat Exchanger, Heat Exchange
IEEE	Institute of Electrical and Electronics Engineers
kW	Kilowatt
kWh	Kilowatt-hour
ORE	Overall Rinse Efficiency
PG&E	Pacific Gas and Electric Company
uW	Unit Width of Conveyor Belt

FIGURES

TABLES

EQUATIONS

APPENDICES

CONTENTS

EXECUTIVE SUMMARY

This project measured the water and energy consumption of two flight-conveyor dishmachines in order to evaluate the difference between the prior generation best-in-class and new generation best-in-class water and energy efficient dishmachines. Both machines are "energy efficient" machines as defined by the ENERGY STAR® Recognition Program. Each machine integrated exhaust-air heat recovery systems and other features that elevated each unit to the highest level of energy efficiency amongst machines on the market at time of installation.

PROJECT GOAL

The goal of this project was to meter water and energy use to better understand the performance characteristics of first generation ENERGY STAR 1.0 (ES1) flight conveyor dishwashers with added exhaust-air heat recovery system with present generation ENERGY STAR 2.0 (ES2) units that incorporate advanced heat recovery systems, lower rinse water flow rates and new innovative features. The study evaluated the impact on performance and energy/water consumption associated with machines with new technologies such as internal submetering, advanced machine diagnostics, mechanical tank filtering and a sophisticated operating control scheme.

PROJECT DESCRIPTION

This study monitored two dishmachines at Gate Gourmet SFO, a catering service for commercial airlines. The units include an ES1 Hobart FT900D 2BD Advansys with two large blower dryers and an ES2 Meiko M-iQ B-L94 V8 N24 P8 4BD with four small blower dryers. The data analysis portion of this study was expanded to compare a third electric flight conveyor dishwashers, an ES2 Hobart FT1000ER BD with one blower dryer at the Facebook campus. These machines represent a sample of "energy efficient" machines, and consume hot water, cold water, chemicals and electricity. The Hobart FT900 was the most efficient machine in its class around 2010. The Hobart FT1000 is a ES2 machine, and the Meiko M-iQ is the current best-in-class ES2 machine. The water and electricity use of each machine was measured with submetering equipment and boiler gas use estimated in order to stratify the impact of multiple new technologies. Data from each machine was recorded for one month and normalized for per hour of rinse and useful conveyor width.

Dishmachines generally use water for three different purposes: to fill and top-off their wash tanks, to rinse dishes with sanitizing water and for special maintenance functions such as auto-clean and auto-delime. All three machines had exhaust heat recovery systems, which saves energy by capturing effluent heat and using it to preheat incoming cold water for its eventual use as sanitizing rinse water. The Hobart FT1000 and the Meiko M-iQ have improved water filtration technologies and sensors to gauge how soiled the wash tank water is. This saves hot water and energy by decreasing the number of times the tanks need to be drained and then refilled. The Meiko unit also has internal submetering and advanced system diagnostics, which allows for easier machine maintenance and leads to substantial cost savings by communicating machine malfunctions that lead to waste and potential failures.

RESULTS/DATA ANALYSIS

This study found that the Meiko machine significantly outperformed either Hobart machine. Key energy and water use results were normalized to a per hour rinse basis in order to make a better apples-to-apples comparison between the two Gate Gourmet dishmachines. Because they consumed hot water, they also consumed gas at the building's boiler. These results were used to estimate the utility operating costs of each machine.

TABLE 1. WATER AND ENERGY USE PER HOUR OF RINSE ANALYSIS

	Rinse Time (h/d)	Water Use per Hour Rinse (gal/hR)	Electricity Use per Hour Rinse (kWh/hR)	Domestic Boiler Gas Use per Hour Rinse (therm/hR)	Total Energy per hour Rinse (therm/hR)
Hobart FT900 Advansys 2BD	14.9	223	138.2	2.1	6.8
Hobart FT1000 ER BD	7.0	265	132.8	1.5	6.1
Meiko B-L94 V8 N24 P8 4BD	15.6	143	97.6	0.6	3.9

The Meiko unit saved at least 36% water and 37% energy over both Hobart units (Table 1). The data was also additionally normalized for the throughput of each machine based on useful belt width. This normalization yielded at least 52% water savings and 56% energy savings. It's also important to note that the Hobart machines used water and energy at roughly the same rate, which generally means that the technological differences between the two machines had very little impact on their overall utility cost. It is important to note that the FT1000 was monitored in a more demanding dishroom and for roughly half the hours, so the results would be improved slightly if it had been tested at Gate Gourmet.

Researchers noticed that the Hobart machines were dumping and refilling their tanks much more frequently than the Meiko unit. The dump and fill operation is highly energy and water intensive because it consumes hundreds of gallons of hot water in a short period of time. The Meiko used more water to top-off its tanks in between dump and fills. This feature points to a major operating difference between the different tank soil level control schemes. The Meiko's active tank filtering system used about 800 gallons less of hot water per day than the Hobarts' automatic soil removal system, and was clearly the better technology.

Another major finding is that the Meiko's exhaust heat recovery system outperformed the Hobart's. Researchers tracked the heat exchanger's water inlet and outlet temperatures on the Meiko unit and the Hobart FT900, and also separately measured the inlet hot and cold water flow rates. The Meiko used primarily cold water for its rinse, only sipping hot water during periods when it needed to heat up its heat exchanger after being off for a long period of time. There was a constant flow rate of about 1.5 gpm flowing through the Meiko heat exchanger. By contrast, the FT900 used primarily hot water for its rinse, and only sent a very small volume of cold water through its heat exchanger. The Meiko's heat exchanger almost completely replaced the water heater for its rinse operation, whereas the Hobart's heat exchanger did close to zero useful work, most likely due to fouling of the heat exchanger.

The normalized energy and water use for each machine was calculated by averaging the rinse use between both units to 15.25 hours per day. The annual savings in Table 2

associated by upgrading to the best-in-class dishwasher is 591 HCF, 226,000 kWh, and 8,340 therms. This results in an annual utility cost savings potential of $58,303 for each older unit replaced with a best-in-class unit and makes the business case for the early retirement of the older machines at Gate Gourmet.

TABLE 2. NORMALIZED ANNUAL WATER AND ENERGY USE AND UTILITY COST ANALYSIS					
	Normalized Rinse Time (h/d)	Water Use (HCF/y)	Electricity Use (kWh/y)	Estimated Domestic Boiler Gas Use (therms/y)	Total Utility Cost
Hobart FT900 Advansys 2BD	15.3	1,659	769,516	11,651	$176,443
Meiko B-L94 V8 N24 P8 4BD	15.3	1,068	543,591	3,311	$118,140
Savings		591	225,925	8,340	$58,303

PROJECT RECOMMENDATIONS

More research is needed in the area of flight conveyor dishwashers. This study was unable to evaluate the energy and water savings of the GreenEye function of the Meiko unit because of the operating characteristics of the site. Monitoring of this technology in a typical cafeteria setting is needed. Additionally, Hobart has released a heat-pump driven flight conveyor dishwasher recently, and this unit needs to be evaluated in the field. This additional research combined with the existing studies would support a new tier of energy efficient dishwashers known as best-in-class. This is needed because the combined water and energy savings potential of best-in-class dishwashers over ES2 dishwashers is roughly 50%.

It is important to leverage the findings in the complementing market characterization study to fully evaluate the value of the best-in-class unit versus baseline and efficient tiered flight dishmachines for water and power utilities. Regarding utility incentives to support market transformation, the existing practice is to provide custom incentives by large energy utilties and by most larger water utilities. There is an opportunity for both water and power utilities to save on processing costs by working together to offer joint-utility incentives for the replacement of older units.

A turn-key third-party program to meter older units and either retro-commission them for immediate savings or make the business case and replace the existing machines would be an excellent approach with diverse array of commercial, institutional and industrial facilities with commercial kitchens that are unaware of the utilty cost of their dishmachines. By using a regional based embedded energy (in water) calculator, this third party program would also document embedded energy savings potential and realize savings with each retrocommissioning or replacement project. Providing additional incentives for machines that integrate sub-metering equipment and advanced diagnostics to easily allow the facility to continuously monitor the machine and diagnose problems would generate long term savings. Many machines are using more water and energy than is necessary after even short times in the field, and recommissioning these malfunctioning machines will show significant savings and will be more financially attainable for operators than early retirement of younger machines.

INTRODUCTION

Dishmachines are important workhorses in any commercial foodservice operation. While it is theoretically possible to have staff wash all soiled wares manually, it is an infeasible option for most operations because it would be extremely time and cost prohibitive. Dishmachines are a convenient solution to this labor bottleneck because they can keep the operation moving.

Warewashing is an inherently water and energy intensive process. For a dish to go from totally soiled to clean and ready to be used again, a few things need to happen. First, solid and stuck-on debris must be removed in some kind of manual pre-wash operation. In commercial foodservice, this is often done by a combination of dry-scrapping, the process of manually scraping off solid debris, and using a pre-rinse spray nozzle to shoot a high-pressure stream of water at stuck-on food. The dish is then placed in a dishwasher, where it is washed and rinsed, and then dried and sorted for the next use. The wash cycle in a dishwasher uses warm (~150°F) water to remove any stuck-on debris that was not addressed by the pre-wash operation. It is an almost universal practice for operations like Gate Gourmet with larger machines to bypass the pre-rinse sprayer step of the typical manual pre-wash operation with automated pre-wash and wash cycle(s) in the dishmachine. Because the pre-rinse operation happens in the machine, flight conveyor dishwashers typically handle more heavily soiled wares than other dishwashers. This has a huge impact on their overall water and energy use because it controls how often these machines dump and refill their tanks to get rid of soiled tank water. Following the wash cycle, the dish then gets rinsed with a powered rinse spray and the last step is to be sanitized with rinse water. The dishes can be sanitized either by a warm (~140°F) chemical sanitizer solution or by water heated to above 180°F. The two different sanitization schemes classify dishwashers into two types: low temperature and high temperature machines. Flight-conveyor dishwashers by the nature of its high volume production are setup for high-temperature sanitation. Dishes are then dried, which can be done by the dishwasher if it has a blower-dryer. Multiple blower dryers are used especially for fast pace catering operations and/or to help dry plastic wares. To keep clean water in the wash tanks, the dishwasher has to periodically dump and refill its tanks, which is a water and energy intensive process. The rinse is also highly intensive, and is especially energy intensive in high temperature machines because dishwashers typically use a booster heater to achieve the sanitizing rinse temperature.

Hobart, the largest manufacturers of commercial dishwashers in the United States, has been addressing the problem of rinse water use by manipulating the rinse spray pattern and droplet size with its OptiRinse system since 2004. The product literature of the day boasted that OptiRinse could cut rinse water use in half compared to then-standard dishmachines. OptiRinse and the addition of a Dual Rinse feature reduced rinse water use from the first FT900 machines at 3.0 gpm to the fourth iteration at 1.5 gpm. Advansys has been the new standard for Hobart's line of commercial dishmachines since 2010. The most important technological advancement with the Advansys line was the addition of exhaust-side heat recovery, which saves some energy by recycling waste heat into the rinse function. Hobart with the newer generation FT1000 has added an 'Automatic Soil Removal System' in advance of the dishwasher tanks in order to lessen the frequency of energy and water intensive tank dump and fill operations by removing the food debris before it reaches them.

Meiko, the largest dishwasher manufacturer in Europe, released its M-iQ line of dishmachines in 2014, and with it released a number of new technologies to save energy and water. Meiko introduced an active mechanical tank filtration system, a more advanced

Pacific Gas and
Electric Company®

4

exhaust heat recovery system, an optimized rinse spray pattern, and a self-submetering and diagnostics system. The active tank filter uses an optical sensor to control a pump which sends water through a filter during normal operation. The filter is then cleaned during tank dump/fill operation, greatly reducing the required number of dump and fills. The heat recovery module's performance is augmented by a more advanced path for the waste steam-laden air. The optimized rinse spray pattern boasts 30% improved cleaning power and 100% more cleaning efficiency than the current standard efficiency machines. The self-submetering and diagnostics system saves on repair costs by alerting the operator when it's time for maintenance. Since poorly maintained dishmachines are known to consume significantly more water and energy than properly-operating machines, this feature also leads to savings. Meiko also introduced their 'GreenEye' technology, which uses an internal optical sensor to spatially sense where the batch of dishes have been loaded, and can shut off sections of the conveyor in order to save energy during slower periods. The technology also alerts the operator during slower periods to load only a limited vertical section of the conveyor, thus shutting off portions of the conveyor belt and associated wash and rinse functions in the cavity. This study did not factor in any savings from the 'GreenEye' because the site was so consistently busy that operators were unable to run the machine at less than full capacity.

Unfortunately, one of the major barriers to a market-wide adoption of these new energy saving technologies is the relatively high price point and extremely long lifespan of existing commercial dishmachines. Flight conveyor dishwashers can cost up to a quarter of a million dollars to purchase, install and commission, and large commercial foodservice operations typically have tight margins and small budgets for new equipment. One of the major motivations for this study is to provide a business case for early retirement of even ENERGY STAR qualified machines with best-in-class equipment for foodservice operators.

This assessment is bound to the field monitoring of two flight conveyor machines at the same high-volume facility. These machines were chosen because they have nearly identical operating conditions, so the comparison of measured data is a fair comparison of the design, commissioning, and maintenance of these machines. This is desirable because the market segment which would use flight conveyor dishmachines has highly variable operating conditions, but is categorically affected by design, commissioning and maintenance.

BACKGROUND

Large food service facilities may need to wash hundreds or thousands of patrons' worth of dishes in as little as an hour. Mechanical dishwashers have existed since the turn of the 20th century, and have since evolved from hand-cranked wooden tubs into relatively complex machines with multiple functions and capabilities. Commercial dishwashers have been available since 1926, and dishwashers with a conveyor belt have been in production since the 1950's. The advantage to machines with conveyor belts is that they can wash a large number of dishes in a small amount of time, on the order of thousands of wares per hour. This allows large commercial foodservice facilities such as cafeterias, catering operations and hotels save valuable time and labor. These machines have become so fast that the true dish throughput of these facilities is bound by how quickly staff can load wares into the machine. This would not be the case with smaller commercial dishmachines, such as door-type dishwashers which typically have throughputs on the order of hundreds of dishes per hour. The two most important new technologies evaluated in this study are exhaust heat recovery systems and the method of tank filtration employed by each machine. These were

the most important because they had the biggest impact on the energy use on each machine. Other technologies evaluated were optimized rinse spray heads and advanced metering and diagnostic systems.

The dishmachines monitored were at the Gate Gourmet catering facility at SFO. This facility stocks departing airplanes with meals and concessions, and also handles the refuse and soiled wares from all arriving airplanes. Thus, the dishroom at Gate Gourmet runs for 24 hours a day. There are five dishmachines at Gate Gourmet – one Meiko M-iQ and four Hobart FT900Ds. One of the dishmachines is set up to handle cups and mugs. The remaining wares are split up amongst the machines according to whether the wares are from a domestic flight or an international flight. Because more international flights serve meals than domestic flights, there is a larger volume of international wares than domestic wares. The two machines selected for monitoring were the Meiko M-iQ, which washes domestic wares, and one of the Hobarts which handles international wares. The site has onsite maintenance staff which service the machines daily. It is evident from the data profiles that there are several times per day that each machine is shut off, presumably for maintenance and/or staff breaks. This study is especially valuable to the site because Gate Gourmet has locations around the world and insight into the operation of various machines can greatly help them revise their procurement, maintenance and operating practices.

#1 Hobart FT900D BD Advansys Domestic and International Cups and Mugs

#2 Meiko B-L94 V8 4BD Domestic Mixed Ware

#3 Hobart FT900D BD 20% Domestic and 80% International Mixed Ware

#4 Hobart FT900D BD Advansys International Mixed Ware

#5 Hobart FT900D BD International Mixed Ware

FIGURE 1. GATE GOURMET SFO DISHROOM

Figure 1 shows the interior of the SFO dishroom, which ultimately runs at full capacity close to 24 hours per day, only shutting down machines completely in order to complete necessary maintenance. The two machines (circled in red) were chosen for this study because they had similar loads, both in terms of what kinds of wares were going through the machine and in terms of how long each machine operated per day. This allows for an apples-to-apples comparison between the two machines. The wares going through the machine were 50% ceramic, 40% plastic, and 10% miscellaneous stainless steel. The most common dishes washed were small ceramic plates and plastic trays. Miscellaneous wares

included utensils, tongs, and coffee/tea carafes Cups were mostly glassware, either stemless or stemmed.

FIGURE 2. LOADING A FLIGHT MACHINE

Figure 2 shows some of the wares getting placed in the Meiko M-iQ machine and shows how these machines typically get loaded. The majority of wares loaded on the belt utilize special racks for easy sorting, cleaning and transport. A conveyor belt with small plastic fingers is loaded at one end of the machine and then pushes wares into the dishwasher.

EMERGING TECHNOLOGY/PRODUCT

Both of the dishmachines monitored are considered in-flight catering flight conveyor dishwashers. The Meiko has a second tank heater and a total of four small dryers and blowers, as opposed to normal flight conveyor models, which have one of each. The Hobart base unit has an optional large heater and blower dryer, but the one in this study was outfitted with two. These are designed to accommodate especially heavy loads, plastic wares and huge numbers of wares going through each machine that have to be quickly turned around and redeployed for another departing flight.

The Hobart FT900 electric flight-type dishwasher at Gate Gourmet was the baseline for an energy efficient unit for this study. This machine was chosen because it was the best-in-class unit of the previous generation of flight conveyor dishwashers. This unit is still much more efficient than "conventional" units because it employs numerous energy-saving technologies.

Figure 3 is a schematic of how heat recovery works and displays some sample operating temperatures for each leg of the rinse water loop. Rinse sanitizing water must reach a final temperature of at least 180°F for high-temperature machines in order to successfully meet health codes. Conventional machines take hot water in around 140°F and send this water through a booster heater which uses energy to heat the water to its final rinse temperature. When this rinse water is used in the machine, a large volume of steam is produced, which is

conventionally a large load on the building's ventilation system. Exhaust heat recovery machines take cold supply water and the waste steam as two phases to a heat exchanger. The heat from the condensed steam heats the cold water to a temperature (usually between 110°F and 140°F) that is managed by an oversized booster heater. Booster heaters are designed to have a maximum temperature rise. In order to ensure that the booster heater always produces >180°F water, exhaust heat recovery machines switch its booster heater inlet water between the heat exchanger outlet water and the inlet hot water from the building's water heater. When the machine has just been started for the day or after an extended time off, the hot water from the building is called for when the heat exchanger is too cold to generate the needed temperature rise for the booster heater to work properly. By consuming less hot water than conventional dishmachines, exhaust heat exchange takes a load off of the building's water heater. Both the Hobart FT900 and the Meiko M-iQ have exhaust heat recovery systems, and the inlet and outlet temperatures to the heat exchanger were monitored in order to evaluate how effective each heat exchanger was in capturing steam and preheating cold water.
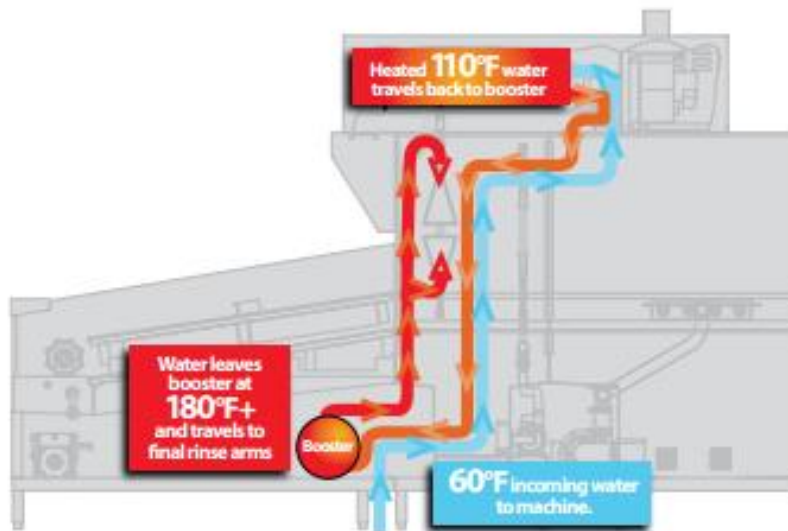
FIGURE 3. EXHAUST HEAT RECOVERY SCHEMATIC (PHOTO CREDIT: CHAMPION INDUSTRIES)

The Hobart FT900 monitored at Gate Gourmet did not have an automatic soil removal system which was developed for the FT1000 unit. The system removes soil from wares prior to the pre-wash section of the machine, and deposits the soil in a strainer basket. The soil is pumped out to a larger depository basket (Figure 4) on regular intervals in order to keep water in the pre wash tank much cleaner. Staff must remove and empty the depository basket every few hours in order to keep this system working. The automatic soil removal system lessens the frequency of tank fills, which saves wash detergent and energy at the building water heater. The tanks typically run at higher operating temperatures than the building water heater, so tank fills also place an energy load on the tank heaters to compensate for this temperature difference.

The Hobart also had an opti-rinse system, which uses an optimized spray pattern in order to use a lower rinse flow rate and less rinse water. Conventional units use over 3 gpm for their rinse flow rates, whereas the Hobart FT900 is rated at 2.2 gpm. This is particularly salient because the ENERGY STAR rating for dishwashers is based primarily on the final rinse flow rate.

FIGURE 4. HOBART AUTOMATIC SOIL REMOVAL SYSTEM

The Meiko M-iQ electric flight-type conveyor dishwasher has numerous technological advancements which yield significant energy and water savings. Because both machines are electric, none of these technologies are fuel-switching. Like the Hobart, the M-iQ has exhaust heat recovery, a soil removal system, and rinse spray pattern optimization. The main differences in these technologies are that the Meiko has a different design for each technology. The M-iQ also has a self-submetering and diagnostics system and GreenEye, which allows the operator to shut off portions of the conveyor belt.

The Meiko's heat exchanger (Figure 5) uses primarily cold water for its rinse. It routes all of its steam through its larger heat exchanger, which allows for a much larger volume of cold water to be pre-heated, dramatically reducing the machine's dependence on hot water for its rinse. While not evaluated, this technology also improves the thermal comfort of the dishroom by removing moisture and heat from the dishwasher's exhaust air.

FIGURE 5. MEIKO M-iQ AIR CONCEPT (PHOTO CREDIT: MEIKO)

Pacific Gas and Electric Company®

The M-iQ active tank filtering system (Figure 6) removes soil from tank water differently than the Hobarts' Automatic Soil Removal System. Instead of removing soil prior to the prewash tank by water spray, the Meiko constantly runs its filter at a much smaller flow rate in order to continuously remove soil. In this way, the water in each tank stays much cleaner, further reducing the need to dump and refill tanks.
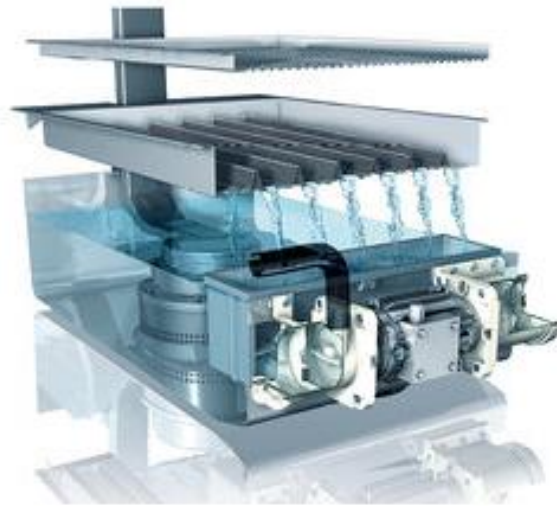
FIGURE 6. MEIKO M-IQ ACTIVE TANK FILTER (PHOTO CREDIT: MEIKO)

The Meiko also has an advanced user interface which is tied to some internal submetering and self-diagnostics. Its internal submetering allows the machine to ensure that it's operating to its specifications, and its self-diagnostics system can alert the user that something's not operating correctly. This helps the user properly maintain the machine, which reduces the incidence of total operating failures, costly repairs, and the replacement of major parts.

With these improvements in technology, the Meiko is a much more efficient machine than the Hobart. It should also have a longer life due to its advanced internal diagnostics. Since each machine is limited in its productivity by the speed at which the operator can load the machine, there are no productivity differences between the machines.

There are some significant market barriers for each tier of efficiency. Flight type dishmachines are designed to have extremely long lives on the order of decades. They are also fairly expensive – the total cost to purchase, install and commission a flight type dishmachine is between $100,000 to $250,000. It is difficult for some operators to make a case for early retirement of old machines because even if the savings potential yields short payback periods and large ROIs, some operators can't afford the initial capital costs. Meiko best-in-class machine has additional barriers to market in the United States because Hobart, Stero, Insinger and Champion and other manufacturers are entrenched in the foodservice market here with their ENERGY STAR machines. One paper, most designers and purchasers are comparing only the rinse flow rate and idle rates (published by ENERGY STAR) of machines along with installed cost and maintenance services. Many of Meiko's efficiency improvements along with best-in-class units from German designed Hobart machines, and

models from Electrolux and Winterhalter have penetrated the European market to a much greater degree than in the US.

ASSESSMENT OBJECTIVES

The main objective of this project is to showcase the water and energy savings potential associated with switching an energy efficient dishmachine with a best-in-class dishmachine. In order to do that, each of the previously listed technological differences was monitored. The difference in utility cost between the two machines monitored could remove some barriers to market entry. The results from this study include a utility cost analysis which shows a simple payback time based on the measured energy and water consumption at each machine. The difference in energy consumption between the two machines and the fact that the Hobart dishwasher heat recovery system was barely functioning will also serve to justify a utility-funded retro-commissioning program and/or an early retirement incentive program.

TECHNOLOGY/PRODUCT EVALUATION

An apples-to-apples field comparison is the only fair way to compare two dishmachines for a number of reasons. The ENERGY STAR test and the ASTM test for flight type dishwashers both fail to tell the whole operating story. The lab tests are essentially designed to test the average final rinse flow rate by washing already clean dishes. This doesn't take into account anything about the tank fill and top off characteristics, nor does it consider the machine's ability to actually get dishes clean at the manufacturer's specified operating rinse pressure and at the maximum conveyor belt speed. The first point is particularly salient because this study showed that the difference between how the tank filters worked had a large impact on the overall energy consumption of the machines. It is also generally observed that many older machines that rely on pressure reducing valves operate at a higher rinse pressure than the manufacturer specifies due to problems with commissioning, cleaning performance and maintenance. This field comparison takes commissioning and maintenance problems into consideration for a more complete view of the energy and water consumption of a dishmachine.

Gate Gourmet has on-site maintenance staff and maintenance contracts with both Hobart and Meiko. The two machines that were monitored were chosen because they handled essentially the same type and volume of wares. This assessment is very close to a true apples-to-apples comparison because the operating conditions of each machine and the load placed through each machine were similar. Because idle losses on each machine are so low this assessment represents a best-case-scenario in terms of operating efficiency. Additionally, because maintenance is such a priority at this site, the machines in this assessment are assumed to be operating at the manufacturers' specifications, as this is a best-case-maintenance-scenario. This site is in the PG&E service territory.

The assessment was carried out by Fisher Nickel (FN). FN has been managing PG&E's Food Service Technology Center since 1987. The FSTC is a fuel-neutral testing facility for benchmarking the energy performance of equipment used in commercial kitchens. Recently, FN completed two reports, the first is entitled "*Conveyor Dishwasher Performance Field Evaluation Report*" (Delagah 2015). The second is, "Results from 20 Rack Conveyor

Dishwasher Monitoring Projects" (Delagah et al. 2017).

TECHNICAL APPROACH/TEST METHODOLOGY

The two dishwashers monitored at Gate Gourmet were on the same hot water system and were fed by the same set of boilers. This site in particular was selected because it is running so many dishmachines simultaneously. It was preferable to gather data with two machines running in parallel on the same hot water system because any changes to this system (i.e. an adjustment of water heater outlet temperature) would affect both machines. Because the machines were continuously monitored by the assessor, any instrumentation problems or extraneous factors could be identified and controlled for before they caused any issues with reportable data.

TEST PLAN

Testing these two machines simultaneously is a fair comparison. The load through each machine is roughly the same daily volume of mixed wares, and the hours of operation for each machine were similar. The load was 50% ceramic wares (mostly small plates,) 40% plastic wares (mostly trays,) and 10% miscellaneous stainless steel serving utensils, tongs and carafes based on staff interviews. Testing in parallel also eliminates seasonal variations in a number of scenarios including the level of staff training and machine maintenance, variations in the hot water delivery system, and the cold water inlet temperature. Because the maintenance schedule for each machine is similarly rigorous, each machine was assumed to be operating as close to the manufacturer's specification as is possible in the field. To compare these machines to dishmachines at other facilities with different operating specifications, the most important results (e.g. the daily water and energy consumption) were normalized to a per-hour-rinse basis and useful belt width as well as measured speed of the conveyor. This level of analysis is useful for a general order-of-magnitude comparison.

Energy consumed by electric dishmachines comes from two sources: electricity and hot water generated by the water heater. Electricity is used to power each machines' electrical components, such as water pumps, conveyor belt, tank heaters, the booster heater and blower dryer heater and fan motor. Each machine had multiple separate electric meters in order to separate the incremental energy usage of each major component. The Hobart machine had 4 electric meters; one for each of its two blower dryers, one for its booster heater, and one for the remaining electrical components. The Meiko had 2 electric meters, one for its booster heater and one for the remaining electrical components. The Meiko was also outfitted with on/off sensors on its four blower dryers and its tank heaters, and researchers were able to use this data to see the energy use from each component. The energy consumed by burning natural gas at the boiler to produce the machine's hot water was estimated. The volume and temperature of hot water consumed was measured, as well as the temperature of the cold water to the facility. It was assumed that the domestic hot water boilers had an operating efficiency of 70% and that hot water lost an average of 10°F in the line between the water heater and each machine.

A major benefit to having the same load going through each machine is that the difference in energy and water consumption is tantamount to the difference in machine efficiency. The performance of each component technology was evaluated. To evaluate the exhaust heat recovery performance, the cold and hot water flow rates and the process inlet and outlet

temperatures to the heat exchanger are sufficient, as this is enough information to assess how much energy the heat exchanger can impart to the rinse. The performance of the tank filtering systems directly affects both the frequency with which the tanks have to dump and fill and the total volume of water consumed by each machine's fill and top-off water. The effectiveness of the Meiko's internal instrumentation was evaluated with a number of on/off sensors, placed on each of its 3 rinse arm solenoids, the rinse pump, the heaters, the blower dryers, the machine status, and the conveyor motor. Because the amount of time each machine spends rinsing is such a crucial measurement, an on/off sensor was placed on each machine's rinse pump.

Each machine was monitored from December of 2016 to January of 2017 at a rate of one sample per 5 seconds. Data was downloaded remotely roughly once per week. This monitoring period was sufficient because the operating conditions were the same for each machine and don't change significantly seasonally.

The accepted lab methodology for commercial dishwashers is documented by ASTM 1920-15. Field monitoring is much more appropriate for this project because the lab test fails to account for real loading conditions, operator error, commissioning and maintenance problems, and ultimately yields an incomplete picture of a commercial dishmachine's real water and energy use and performance under full load.

INSTRUMENTATION PLAN

A list of all variables monitored, the expected range of measurement, and sensors selected for the measurement is available in Appendix A. Temperatures were measured as per ANSI/ASHRAE 41.1 Standard for Temperature Measurement. Electric energy was monitored as per IEEE 1159, Recommended Practice for Monitoring Electric Power Quality. Data was collected into two DataTaker DT80 Series 3 data loggers at a rate of one sample per five seconds, and stored as a .csv file in the logger's internal memory. The proper accuracy, sensitivity and functioning of all instrumentation and data loggers were validated in a lab prior to initiating data collection. Thermocouples were not validated prior to installation because they were made onsite, but they were validated against a handheld temperature sensor onsite before data collection began. A summary of each sensor's technical specifications are included for quick reference in Appendix B.

RESULTS

DISHWASHER OPERATING PROFILES

The first step in the results was to graph each collected sample against time and to do a simple visual analysis. This level of analysis allowed researchers to determine if all of the instrumentation continued to work correctly, and also allowed researchers to determine some simple operating patterns of each machine. Most importantly, the visual analysis allowed researchers to distinguish between tank fills, tank top-offs, rinse cycles, clean cycles, and other sources of water use. The Hobart operating profile for a 5 hour snapshot is shown in Figure 7.
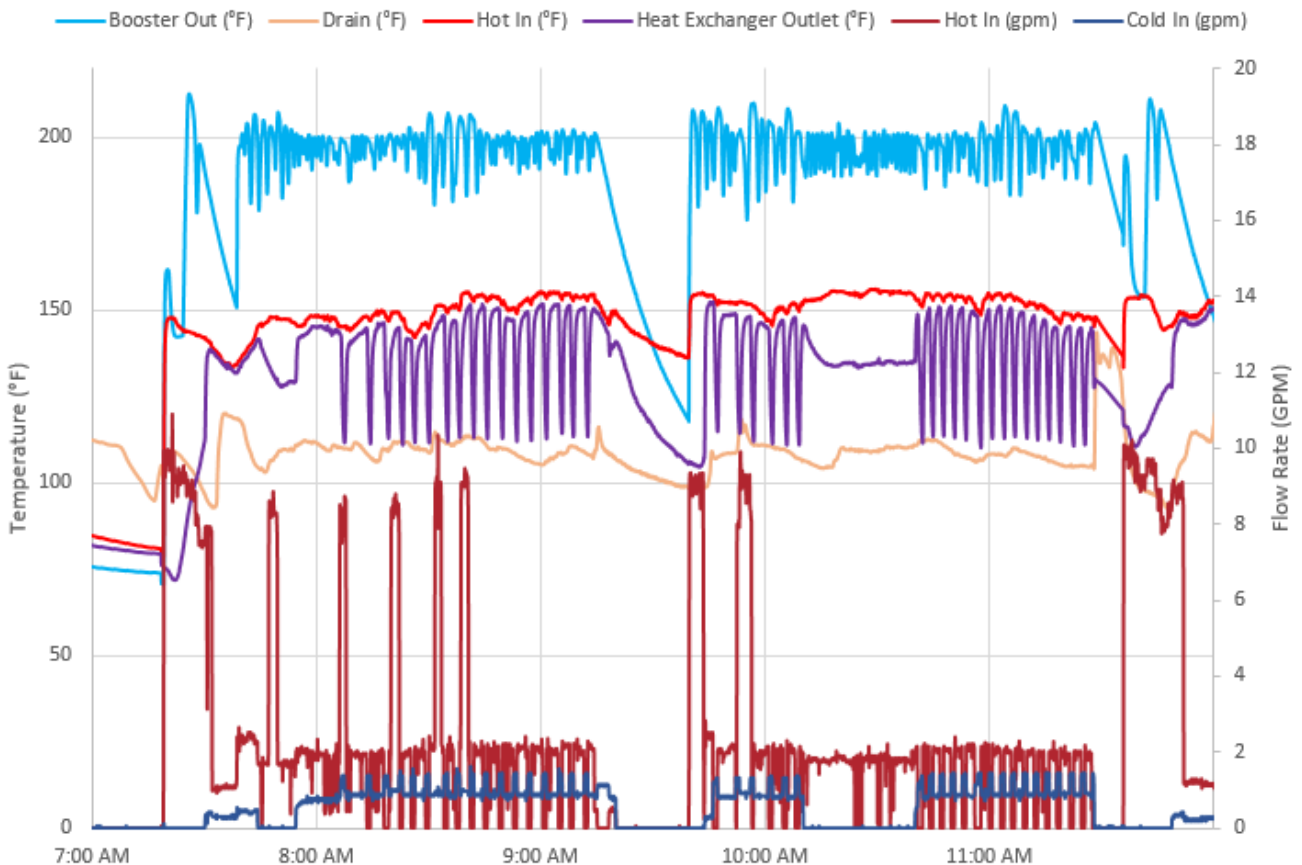
FIGURE 7. HOBART OPERATING PROFILE

Tank fills are generally characterized by sustained levels of high (>8gpm) hot water flow rates, shown on the graph in magenta. The Hobart machine clearly filled at 7:30 AM and around 11:30 AM. Because the FT900 has three tanks, it is possible for each tank to dump and fill independently. This explains the period around 10:35 AM; one tank (as opposed to all three tanks) dumped and filled after a period of no water use. It is important to note that there were three dump and fill events in 5 hours of operation. The other periods of high hot water flow rates are tank top-offs, sometimes referred to as maintenance water. As the dishwasher goes through its normal operation, tank water is lost for a number of reasons, but most commonly, the tank filtration system consumes some water while trying to keep the tanks clean. The maintenance fills are necessary to keep the tanks from running dry.

The other water uses are for the rinse and for tank tempering. The lower (~2 gpm) hot water flow rate is definitely for the rinse. Rinsing also uses cold water, which flows through the heat exchanger before going to the booster heater. The small peaks above the ~1 gpm constant flow are the cold water contribution to the rinse. These sips correlate with the large dips in the heat exchanger outlet temperature (shown in purple.) The heat exchanger has about a 30 degree temperature swing, which indicates that it is able to heat those small sips of cold water up to about 120°F and uses hot water for the rinse the rest of the time. This means that the Hobart machine is using an overwhelming majority of hot water for its rinse. The booster outlet temperature is the final rinse temperature. During the rinse cycle, this

temperature never dips below 180°F, meaning the machine successfully passes that part of the health department specifications. The other use of cold water is its tank tempering and running the scrapper. The sum of these flow rates is around 1 gpm. The tempering water is necessary because water cannot go down the drain at temperatures greater than 140°F.

The heat exchanger outlet temperature is oscillating between 120°F and 150°F during the rinse cycles, and these oscillations happen at the same time of each of the cold water flow rate spikes. This is characteristic of a heat exchanger that is performing poorly. There is a hot water bypass to the heat exchanger, where the booster can draw from the building's water heater as opposed to the heat exchanger itself. The control scheme has the booster heater draw from the hot water supply whenever the heat exchanger temperature drops below 120°F and draws from the heat exchanger otherwise. The heat exchanger is unable to keep up with the rinse demand, and therefore can only handle short sips of cold water. Because of this, the machine has to draw most of its rinse water from the building's water heater, which has substantial energy consequences.

The Meiko had a very different operating profile (Figure 8) than the Hobart. There's a period of very high hot water use from 9:00 to about 9:30 AM. The first part of this is a tank fill, characterized by a long steady period of a high hot water inlet flow rate. When the hot water and cold water flow rates start varying around 9:20 AM, this is actually the machine trying to heat up its heat exchanger by consuming hot water. After this period, the machine tops off with frequent sips of hot water and begins its rinse cycle. This rinse cycle is characterized by a very steady cold water flow rate at 1.56 gpm and a fairly constant heat exchanger outlet temperature of about 135°F. The Meiko is primarily using cold water for its rinse because its heat exchanger is able to preheat the inlet cold water to a temperature which the booster heater can handle. It is again important to note that the final rinse temperature never dips below 180°F during the rinse cycle. The rinse cycle stops at 11:00 AM, characterized by the cold water flow rate dropping to zero and the rinse temperature beginning to fall. During this time, there is no water flowing for the rinse, so the drop in temperature is just the rinse arm equilibrating with the ambient temperature.

It is worth noting that the Meiko uses top-off water between 11:00 AM and 11:30 AM, when the machine is not rinsing. According to the manufacturer, this is not a feature of standard operation and points to a problem where the machine is somehow losing water while it isn't running. From an interview with operators at Gate Gourmet, researchers learned that one of the most common maintenance tasks done at the site was to snake out the drain. It is likely that this top-off issue is caused by food debris stuck in the drain valve, which keeps the drain valve slightly open. Researchers observed this problem intermittently, which suggests that the issue is not a leak or a bad o-ring. If the pattern were observed continuously, a leak would be a more likely diagnosis. It was also noted from the operators' interview that the machine flashes a warning error that it is using too much maintenance water and directs the operator to check the drain valve. Currently, the machine does not cease its operation to force the operator to resolve maintenance water issues, so the operator generally ignores this warning to continue washing wares.
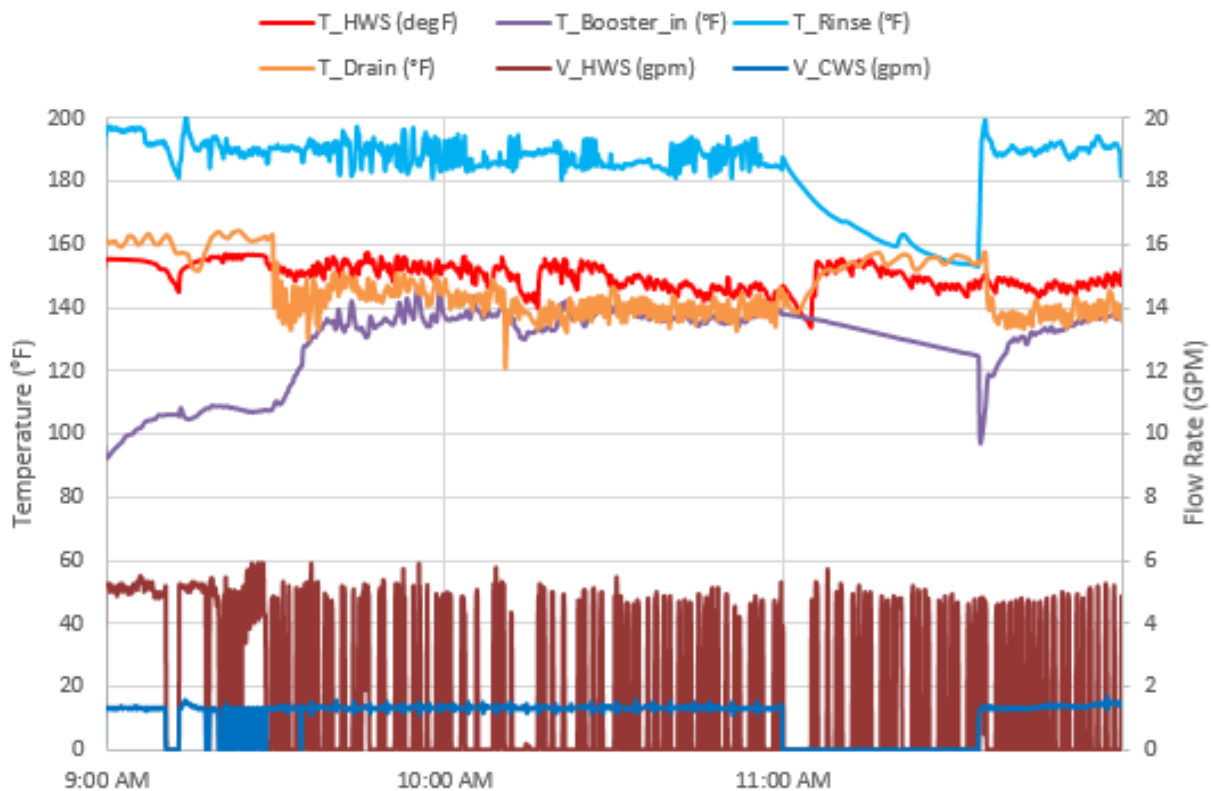
FIGURE 8. MEIKO OPERATING PROFILE

Next, it was necessary to differentiate the hot and cold water use into different categories in order to determine which dishwasher functions consumed the most water. This was done with a combination of the visual analysis above, which allowed researchers to identify which flow rates were associated with which events, and by confirming the identity of flow rates which were visually vague or indistinguishable by graphing the incidence of all flow rates and identifying the peaks. This was aided by the rinse solenoid, which allowed for the rinse flow rate to be filtered out when the rinse was flowing. The rinse solenoid was also used to solve for the amount of rinse time for each machine, which was useful for normalizing results.

WATER USE AND FLOW RATES

Figure 9 shows how often which flow rates entered the Hobart machine. From the hot water incidence graph, it's clear that the hot water rinse flow rate is around 2.3 gpm. The fill and top off flow rate is somewhere between 7 and 10 gpm. There is some variation in the fill and top off flow rate, which is due to different tanks needing water at different times. The flow rate generally increases with the number of tanks filling/topping off at once. From the cold water flow incidence graph, there are defined peaks at 0.7 and 1.4 gpm. This correlates with what's observed in figure 6, where the 0.7 gpm flow rate is running the machine's scrapper. The 1.4 gpm flow rate correlates with the rinse, but the scrapper is always running during the rinse. Thus, the cold water rinse flow rate is 0.7 gpm, and the true rinse flow rate (average combined hot and cold) is 1.47 gpm. This compares well with the rated rinse flow rate in Hobart's specification sheet in in Appendix C.
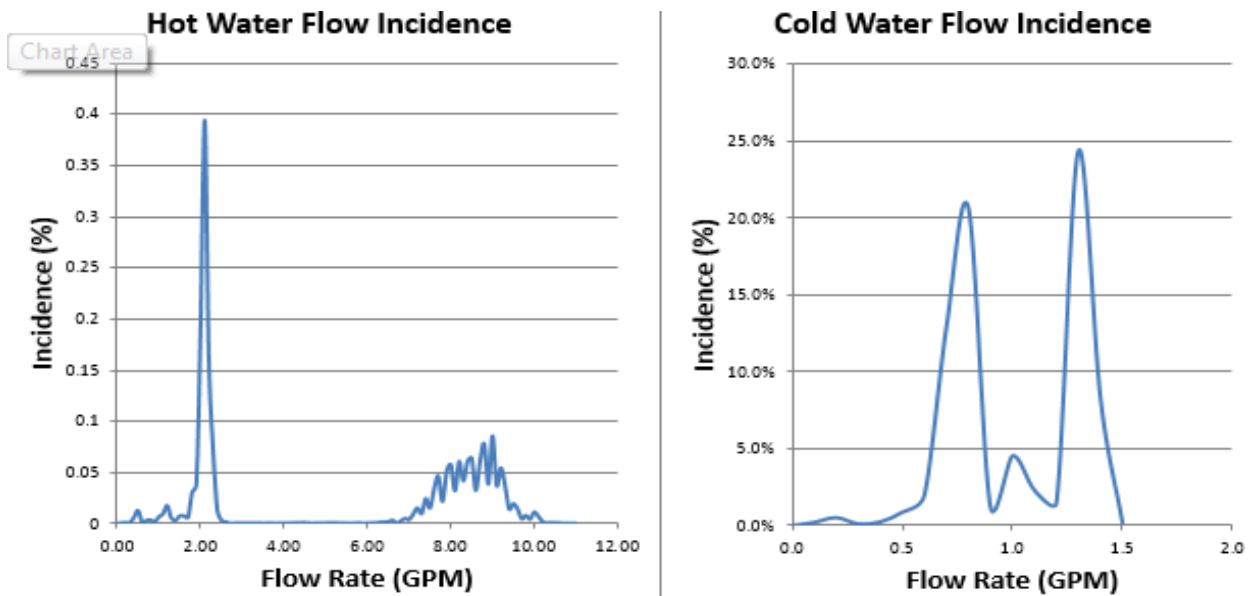
FIGURE 9. HOBART FLOW RATE INCIDENCE

From figure 8, the Meiko's flow rates were more distinct so a flow rate incidence graph was not necessary to distinguish which flow rates could be associated with which operations. The fill and top off flow rates were about 5 gpm, and the rinse water flow rate was 1.56 gpm of only cold water. This compares well with the rated rinse flow rate in Meiko's specification sheet in in Appendix D. Note: the specification sheet for the larger model was not available at the time of publication. Thus, the illustration from a European In-flight catering brochure Appendix E provides the correct rinse flow rate.

After correctly differentiating water use and filtering the data by associated flow rate, the daily water use associated with each machine function was solved for in Table 3. The total hot and cold water use per day was also solved for.

TABLE 3. DAILY WATER USE

	Fill	Top Off	Rinse	Temper	Total Hot	Total Cold	Total Water
Hobart Use (gal/d)	1,254	329	1,330	412	2,656	670	3,326
Meiko Use (gal/d)	506	282	1448		788	1,448	2,236

The Hobart's two most significant uses of water were the fill and rinse functions. Because both of these functions use hot water, the total hot water consumption for this machine was fairly high. The amount of water specifically used to keep the tanks clean (i.e. the sum of the fill and the top off water) was 1,583 gallons per day.

The Meiko machine used about 2/3 as much water as the Hobart. The most significant difference is the amount of water used to keep the tanks clean, as the Meiko used 788 gallons per day. This is an important measure of how well each machine's tank cleaning system works. The Meiko uses substantially less hot water than the Hobart, which means

the Meiko puts less of an energy load on the building's water heater than the Hobart. This is largely due to the fact that the Hobart is dependent on hot water for its rinse. Normalized to a per hour rinse basis, the Hobart consumes water at a rate of 223 gal/h and the Meiko consumes water at a rate of 143 gal/h. In other words, the Meiko consumes about 64% as much water as the Hobart.

The Hobart machine was observed to dump and fill much more frequently than the Meiko (Table 4), which had massive implications for both the total water consumption and the total energy consumption.

TABLE 4. DUMPS AND FILLS PER DAY

Machine	Rinse Hours per day	# Dumps/Fills per day
Hobart FT900	14.9	6.9
Meiko M-iQ	15.6	3.8

The Hobart had to dump its tanks almost twice as frequently as the Meiko, which means that the Hobart was much less effective at filtering debris from its tanks. This results in about a 750 gallon per day disparity in hot water consumption between the two machines, which has huge energy consequences at the boiler.

Table 5 shows the rinse flow rate for each machine as measured at Gate Gourmet and compares these flow rates to each manufacturers' rated flow rate.

TABLE 5. MEASURED VS. SPECIFIED RINSE FLOW RATES

Machine	Measured Rinse Flow Rate (gpm)	Manufacturer Rated Rinse Flow Rate (gpm)
Hobart FT900	1.47	1.50
Meiko M-iQ	1.56	1.45

Normally, when machines in the field age, their rinse flow rate begins to deviate from the manufacturer's rating fairly significantly due to lack of maintenance, internal parts wearing down and a mismatch between the manufacturer's recommended inlet water pressure and the pressure of the building's supply. Researchers have observed rinse flow rates as high as four times the manufacturer's rating. However, the machines monitored in this study were operating extremely close to their specified flow rates, which means that they were probably commissioned acceptably. This is also an indication that each machine has been relatively well maintained. The newest generation of flight conveyors including the Meiko M-iQ and Hobart FT1000 have upgraded their control strategy to maintain constant rinse pressures by opting for a holding tank and rinse pump versus depending on a water pressure regulator and gauge as the latter can fail or fall out of specification more readily or easily be changed by non-sanctioned staff or chemical suppliers. These are important technologies to prevent some of the waste normally associated with machines aging.

WATER TEMPERATURES

Next, the volume-weighted average temperature was solved for at each significant location on the dishwasher in Table 6. The volume-weighted temperature is preferable to a straight average temperature because it places more weight on higher flow rates. The most important of these temperatures is the final rinse temperature, because it needs to be at

Pacific Gas and
Electric Company®

least 180°F for both machines while rinsing in order to meet health department specifications. Neither of these machines experienced an insufficient temperature for their rinse water.

TABLE 6. VOLUME-WEIGHTED AVERAGE TEMPERATURES					
	Hot In (°F)	Cold In (°F)	Booster In (°F)	Rinse(°F)	Drain°(F)
Hobart	147	51	142	196	110
Meiko	145	55	128	188	126

It's important to note that the average booster inlet temperature was lower for the Meiko than for the Hobart. This is a direct consequence of which water source was used for the rinse water; the Meiko was using mostly cold water through its heat exchanger whereas the Hobart was using mostly hot inlet water, thus the Hobart's booster inlet temperature closely resembles the machine's hot inlet temperature. Because the difference between the Meiko's booster inlet and final rinse temperature is greater than the Hobart's (60°F vs. 54°F, respectively) the energy demand per rinse volume was greater for the Meiko machine.

ENERGY USE

Next, the daily electricity consumption at three key locations was measured in Table 7. The Meiko's booster heater had to work slightly harder than the Hobart's booster heater. One reason for this is because the Meiko had a larger number of rinse hours per day. It rinsed about 5% longer than the Hobart, but used 13% more energy. Another reason for this booster heater energy difference is that the Meiko had to keep up with a larger temperature swing.

TABLE 7. AVERAGE DAILY ELECTRICITY USE				
	Tank Heaters, Pumps and Controls (kWh)	Booster Heater (kWh)	Blower Dryer Fans and Heaters (kWh)	Total electricity use (kWh)
Hobart	1,222	188	653	2,063
Meiko	805	214	502	1,522

The difference between tank heater energies is largely due to the Hobart having a larger number of dumps and fills per day than the Meiko. The load placed on a tank heater during a dump and fill is substantial because a high volume of inlet water is introduced into the system at a temperature substantially lower than the tank's setpoint. Additionally, the pattern of the top-off water consumption drove tank heater electrical consumption, as tank top-offs also shocked the tanks with moderate volumes of sub-setpoint temperature water. The blower dryer fans and heaters were sub-metered separately from the rest of the Hobart machine, but the Meiko's blower dryer was not monitored. The Meiko's blower dryer energy consumption was calculated by multiplying an average input rate by the amount of time each component was on per day. There is a sizeable difference in the electrical consumption attributed to each machines' blower dryers. The Hobart had 2 blower dryers, and the Meiko had 4 much smaller blower dryers. The total energy consumption of each machine is listed in Table 8.

TABLE 8. DAILY ENERGY USE

Machine	Total Electric use per day (kWh)	Est Boiler Energy use per day (therm)	Total Energy Use (therm/d)
Hobart	2,063	31.2	101.6
Meiko	1,522	9.3	61.2

Because the Meiko used primarily cold water for its rinse and the Hobart used primarily hot, there was a significant difference in the load each machine placed on the building's boiler in Table 8. The boiler energy use per day was calculated assuming that the water inlet to the boiler was at the average annual cold water temperature of 65°F for the bay area, the outlet temperature was nominally 10°F higher (165°F) than the measured hot water supply temperature to each machine (in other words, the water loses 10°F between the boiler and the point of use) and that the boiler ran at a daily operating efficiency of 70%. Because of the differences in electric consumption at each machine and the differences in the load placed on the building's boiler, it was observed that the Meiko unit consumed about 60% as much energy per day as the Hobart machine.

DATA ANALYSIS

NORMALIZING THE DATA

The results from Gate Gourmet were normalized to each machine's rinse time. The water consumption results are presented in Table 9. FN has devised this industry method to compare different dishwashers because it filters out operating differences between dishwashers and sites. These normalized results are comparable to other machines monitored by FN (Delagah 2015, Delagah et al. 2017).

TABLE 9. WATER USE NORMALIZED TO A PER HOUR RINSE BASIS (GAL/HR)

	Fill	Top Off	Rinse	Temper	Total Hot	Total Cold	Total
Hobart	84	22	89	28	178	45	223
Meiko	32	18	93	0	51	93	143

By looking at hourly consumption rates in Table 9, it's easy to see that the Hobart is using hot water at more than three times the rate of the Meiko, and that the Meiko is using about twice as much cold water than the Hobart. It's also easy to see the relative consequence of each machines' operating problems; the Hobart's heat exchanger is driving its hot water consumption, as almost half of its hot water is being used to rinse. In contrast, the top-off issue with the Meiko causes less of a hot water consumption penalty. Even if the entire 18 gal/hR of top-off water could be attributed to a malfunction, it's still a relatively small part of the total operating picture.

Table 10 presents the normalized electricity consumption for each machine.

TABLE 10. ELECTRICITY USE NORMALIZED TO A PER HOUR RINSE BASIS (KWH/HR)

	Tank Heaters and Controls	Booster Heater	Blower Dryers	Total
Hobart	81.9	12.6	43.7	138.2
Meiko	51.6	13.8	32.2	97.6

It is important to note that while the Meiko's booster heater consumed more energy than the Hobart's on a daily basis, it actually consumed less energy per hour of rinse time in Table 10. The four blower dryers on the Meiko unit used significantly less electricity that the two on the Hobart unit. The total normalized energy consumption is presented in table 11.

TABLE 11. ENERGY USE NORMALIZED TO PER HOUR RINSE BASIS (ENERGY/HR)

	Total Electric use (kWh)	Est. Boiler Energy use (therms)	Total Energy Use (therms)
Hobart	138.2	2.1	6.8
Meiko	97.6	0.6	3.9

In total, the Meiko consumed 42% less energy than the Hobart at 3.9 therms versus 6.8. It consumed gas at the boiler at less than 1/3 of the rate of the Hobart (Table 11).
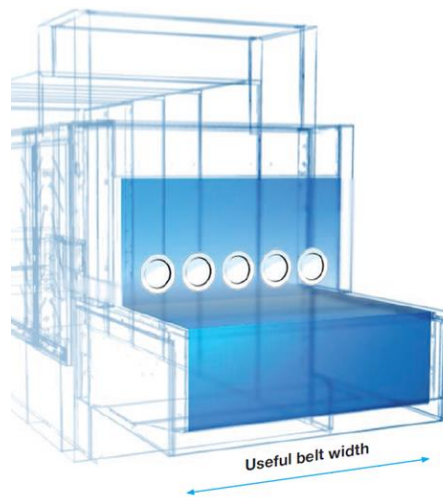
Useful belt width

FIGURE 10. USEFUL BELT WIDTH OF CONVEYOR DISHMACHINE (PHOTO CREDIT: MEIKO)

Table 12 shows the energy consumption per hour rinse normalized to the conveyor's useful belt width (Figure 10) and the actual belt speed of each machine. This was done because the Meiko machine was substantially wider than the Hobart and therefore had a higher maximum throughput capacity, but also ran at a slower belt speed than the Hobart. When measured in the field, the Meiko ran at a belt speed of 4.9 ft/min and the Hobart ran slightly faster at 5.9 ft/min with four staff tending to each machine. Interestingly, the Meiko's maximum speed is actually a little higher than the Hobart's – 9 vs. 8.5 ft/min. It is also anecdotally notable that the staff at the site had to stop and restart the Hobart unit fairly

frequently in order to keep up with the faster belt. This is an indication that the rated maximum speeds, from which manufacturers estimate their maximum throughput numbers, are wildly higher than any staff can keep up with, and that the throughputs listed on specification sheets are unrealistic for most applications.

When normalized to the size of the machine, the Meiko used 55% as much energy as the Hobart. This means that per unit of machine width and unit of runtime, the Hobart uses 1.8 times as much energy to wash the same load of dishes.

TABLE 12. ENERGY USE PER HOUR RINSE NORMALIZED TO CONVEYOR USEFUL BELT WIDTH AND ACTUAL CONVEYOR SPEED				
Machine	Belt Width (in)	Actual Conveyor Speed (ft/min)	Electricity Use (norm. kWh)	Est. Boiler Gas Use (norm. kBtu)	Total Energy Use (norm. kBtu)
Hobart	30.5	5.9	0.76	1.17	3.78
Meiko	38.6	4.9	0.51	0.31	2.08

HEAT EXCHANGER AND BOOSTER HEATER PERFORMANCE

One consequence of the Hobart's high number of dumps and fills per day is that its tank heaters had to work much harder to maintain a stable temperature. This partially explains the disparity between the two machines' total electric use per day. The booster heaters for each machine expended close to the same amount of energy per day. This isn't surprising because the booster heater on each machine had to heat a similar volume of water for a similar temperature rise. Electric booster heaters also have similarly high (>85%) efficiencies and don't generally vary too much in design. There are two contributing factors to the difference in boiler energy use. The first is the difference in hot water use to keep the tank water clean, and the second is the fact that the overwhelming majority of the Hobart's rinse water is hot water and most of the Meiko's rinse water is cold. Overall, the Meiko is consuming energy at just under half the rate at which the Hobart is consuming energy. This is fairly congruous with the difference in overall water consumption.

An energy balance was drawn around each booster heater in order to assess the booster energy efficiency for each machine. Then, an energy balance was drawn around both the booster heater and the heat exchanger to determine the overall rinse efficiency. Then, the booster efficiency was subtracted from the overall rinse efficiency to yield the amount of work the heat exchanger did to heat water to the final rinse temperature relative to the amount of work the booster did.

Figure 11 is a schematic of how exhaust heat recovery is supposed to work, and includes control volumes drawn around the booster heater and around the whole rinse assembly. The booster heater efficiency was defined by the green control volume. It is the amount of energy it takes to heat up each warm water inlet (shown by the orange droplet) to the hot water outlet (shown by the red droplet) divided by the amount of electrical energy consumed by the booster heater. The overall rinse efficiency was defined by the yellow control volume. It is the amount of energy that it takes to heat up the warm water from the water heater plus the cold water inlet to the heat exchanger up to the hot water booster outlet divided by the electrical energy consumption. In other words, it considers the amount of energy added to the final rinse water by the heat exchanger as well as the amount of energy added by the booster heater.
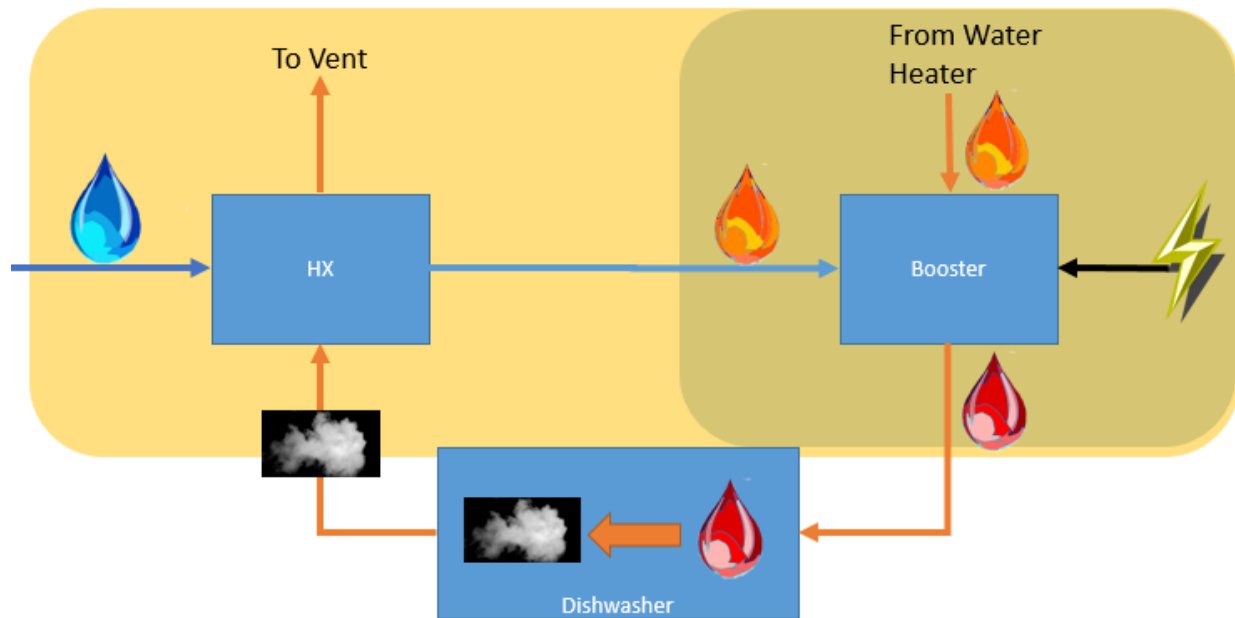
FIGURE 11. CONTROL VOLUMES FOR EFFICIENCIES

Table 13 shows the results of the following set of equations.

$$\eta_{Booster} = \frac{E_{WBO} - (E_{HXO} + E_{WBIHOT})}{E_{Boost}} \qquad \text{(Eqn. 1)}$$

$$\eta_{Overall\ Rinse} = \frac{E_{WBO} - (E_{WBIHOT})}{E_{Boost}} \qquad \text{(Eqn. 2)}$$

$E_{WBO} = Energy\ in\ water\ at\ the\ booster\ outlet = m_{out} * C_P * \left(T_{Boost,\ out} - T_{Cold,\ in}\right)$ (Eqn. 3)

$E_{HXO} = Energy\ at\ HX\ outlet = m_{cold,\ in} * C_P * \left(T_{Boost,\ in} - T_{Cold,\ in}\right)$ (Eqn. 4)

$E_{WBIHOT} = Energy\ in\ hot\ water = m_{hot,\ in} * C_P * (T_{Hot} - T_{Cold,in})$ (Eqn. 5)

$E_{Boost} = Electric\ or\ gas\ energy\ supplied\ to\ the\ booster\ heater$ (Eqn. 6)

TABLE 13. DAILY BOOSTER OPERATING EFFICIENCY AND OVERALL RINSE EFFICIENCY

	Booster Efficiency (%)	Overall Rinse Efficiency (%)	ORE – BE (%)
Hobart FT900	88	89	1
Meiko	98	199	101

The booster heater daily operating efficiencies were typical of modern electric water

heaters, which generally have efficiencies above 85%. The Meiko performed significantly better due to a low water volume and minimizing the exposed surface area. The added heat shielding around the exposed side of the booster to protect wiring and other electronics probably provided a reflective surface for the heat emanating from the unit. Lastly, the rapid start feature of the booster heater allows the unit to act as an instantaneous heater. The unit doesn't react to idle heat losses when the unit is not rinsing until the next rinse period which increases the daily operating efficiency of the unit.

The difference between the overall rinse efficiency and the booster efficiency is a measure of how much energy the heat exchanger is contributing to the final rinse water, and therefore a measure of overall heat exchanger performance. There is a massive difference between the two machines' overall rinse efficiencies. The Hobart's small difference between booster efficiency and overall rinse efficiency means that the heat exchanger is contributing almost no energy to the final rinse, perhaps due to fouling of the heat exchanger if not manually cleaned on a routine basis. In contrast, the Meiko's heat exchanger is doing almost as much as much work on the final rinse as its booster heater. The Meiko unit has a rinse arm placed over the heat exchanger that blows out the food particulates and slime buildup on a daily basis that allows the unit to operate with minimal maintenance while maintaining heat exchanger effectiveness.

These results were surprising, so the percentage of energy contributed to each machine's booster heater from the heat exchanger and from the building's domestic water heater were solved for directly in Table 14.

TABLE 14. ENERGY SEEN AT THE BOOSTER HEATER		
	% Energy from HX	**% Energy from Water Heater**
Hobart FT900	2.5	97.5
Meiko	95.4	4.6

The Hobart machine used almost no cold water for its final rinse and was therefore completely dependent on the building's water heater. The Meiko only used hot water for the rinse while its heat exchanger was warming up, and otherwise was able to sufficiently preheat cold water with its heat exchanger. The Meiko's heat exchanger performed much better than the Hobart's for a few reasons. The Meiko probably had a much larger exchanger, both in terms of contact surface area and in terms of thermal mass. The large surface area ultimately drove its overall rate of heat transfer. Additionally, because an easy way to increase surface area for a shell-and-tube-type heat exchanger is to add extra tube length and the rinse flow rate was fixed, it probably takes a much longer time for an element of rinse water to flow all the way through the Meiko's heat exchanger than that of the Hobart, which means that it has more time to interact with the steam and to warm up. The reason the Meiko HX probably had a larger thermal mass than the Hobart's is because it took a long time (on the order of 15 minutes) to warm up from cold to its operating temperature around 135°F. This large thermal mass incurred an energy penalty each time it needed to warm up, but the heat exchanger was ultimately able to retain heat during its rinse cycles. This heat retention was beneficial because it allowed the heat exchanger to operate near steady state for the entire rinse cycle. This also helped to ensure that the final rinse temperature would never fall below 180°F because the booster heater never had to handle a major reduction in its inlet temperature.

Pacific Gas and Electric Company®

WATER AND ENERGY SAVINGS POTENTIAL

The annual energy savings potential of the improved technologies on the Meiko were calculated by taking the average consumption per hour rinse and multiplying by the average rinse time of both machines at Gate Gourmet, which was 15.25 h/d. Table 15 shows annual water, gas and electricity use results and savings estimates. For context, this method was used to calculate the savings potential with a Hobart FT1000, which was monitored in the 2015 report referenced earlier. The Hobart FT1000 had a few different operating parameters. The wares that the café had to clean were generally larger and more heavily soiled, which increased the rate that it had to be dumped and filled. It also only operated for 7 h/d because it was installed in a corporate campus kitchen which had set operating hours. Had this machine run all day, there would be some efficiency gains. This is because the machine would not have had to start up from scratch and would have had less idle losses.

TABLE 15. ANNUAL WATER AND ENERGY SAVINGS POTENTIAL

	Annual Water Use (HCF)	Annual Electricity Use (kWh)	Est. Annual Gas Use (therms)	Total Energy Use (therms)
Hobart FT900	1,659	769,516	11,651	37,907
Hobart FT1000	1,973	739,610	8,549	33,785
Meiko M-iQ	1,068	543,591	3,311	21,858
Savings (FT900 – Meiko)	591	225,925	8,340	16,048
Savings % (FT900 – Meiko)	36%	29%	72%	42%
Savings (FT1000 – Meiko)	905	196,019	5,238	11,927
Savings % (FT1000 – Meiko)	46%	27%	61%	35%

Overall, the improved technologies available for the Meiko machine show an annual savings potential of 225 MWh of electrical energy and 8340 therms of gas savings at the water heater per dishmachine replaced over the Hobart FT900. There are also significant coincident demand savings. It is interesting that the electricity savings between the Meiko and the Hobart FT1000 are similar to the electricity savings between the Meiko and the Hobart FT900, but the gas savings are so different. This is likely due to the fact that the Hobart FT1000 was a brand new machine. It therefore probably did not have the same kinds of problems with its heat exchanger as the FT900. This disparity highlights the energy impact of that particular maintenance issue.

The annual water and energy savings potential was then normalized to each machines conveyor belt width and conveyor belt speed in Table 16. The Meiko unit used approximately 39% less water, 73% less gas and approximately 33% less electricity versus the Hobart FT900 on an annual basis per inch of machine width and ft/min of belt speed. The savings from the Meiko unit versus the FT1000 were significantly less at 50% water

savings, 64% gas savings and 32% electricity savings. When combining gas and electricity use, the total energy savings of the Meiko unit versus the FT900 and FT1000 units are 45% and 40%, respectively.

TABLE 16. ANNUAL WATER AND ENERGY USE AND SAVINGS POTENTIAL PER UNIT OF USEFUL BELT WIDTH AND ACTUAL CONVEYOR SPEED				
	Water/UBWACS (norm. gal)	Electricity/UBWACS (norm. kWh)	Gas/ UBWACS (norm. therms)	Total Energy/ UBWACS (norm. therms)
Hobart FT900	6,896	4,276	65	211
Hobart FT1000	8,390	4,205	49	192
Meiko	4,224	2,874	18	116
Savings (FT900 – Meiko)	2,672	1,402	47	95
Savings % (FT900 – Meiko)	**39%**	**33%**	**73%**	**45%**
Savings (FT1000 – Meiko)	4,165	1,331	31	77
Savings % (FT1000 – Meiko)	**50%**	**32%**	**64%**	**40%**

DEMAND SAVINGS POTENTIAL

The average input rate for each machine's rinse cycle was calculated. This was done by calculating the instantaneous input rate for each five second data interval and taking the average of these instantaneous input rates during rinse operation over the whole range of data. The average input rate for the Hobart FT900 during its rinse cycle was 104 kW, and the average input rate for the Meiko during its rinse cycle was 73 kW. Therefore, there is a demand savings potential of 31 kW.

FINANCIAL ANALYSIS

The purchase price for a Meiko unit is estimated at $170,917, and the installation cost of a new flight conveyor dishmachine is estimated at $25,457. The purchase price includes the unit's extra tank, blower dryers and extra size. The total cost to install is therefore $196,373. Hobart no longer supplies the FT900D, but supplies the FT1000 model in its stead. The purchase price for a Hobart FT1000 is estimated at $134,207, and the cost to buy and install a new unit is $159,664. Projected useful service life of each machine is 15 years.

TECHNOLOGY ENERGY IMPACT

Gate Gourmet is in a building with an area of 125,000 ft^2. Tables 10 and 11 compare the EUI and EI of the Hobart FT900 and the Meiko. The gas EI of the Meiko was 3.1 kBtu/ft^2, the electricity EI of the Meiko was 4.1 kWh/ft^2. The gas EI of the Hobart FT900 was 9.3 kBtu/ft^2 and the electricity EI was 6.2 kWh/ft^2. Tables 17 and 18 list the EUIs, fuel shares and EIs for electricity and gas for commercial restaurants and reflect the change in EUI and EI that these technologies represent.

Pacific Gas and Electric Company®

TABLE 17. RESTAURANT ELECTRIC EUIS, FUEL SHARES, AND EIS

End Use	Electric EUI (kWh)	Electric Fuel Share	Electric EI (kWh)
Heating	0.34	14.30	0.05
Cooling	8.22	70.10	5.76
Ventilation	4.21	76.80	3.24
Water Heating	2.22	17.00	0.38
Cooking	10.44 / **8.34**	99.50	10.38 / **8.28**
Refrigeration	9.87	100.00	9.87
Interior Lighting	6.45	100.00	6.45
Office Equipment	0.64	98.50	0.63
Exterior Lighting	2.36	85.60	2.02
Miscellaneous	1.39	81.00	1.13
Process	1.21	0.50	0.01
Motors	1.37	20.00	0.27
Air Compressors	0.62	2.90	0.02
All End Uses			40.20 / **38.10**

TABLE 18. RESTAURANT GAS EUIS, FUEL SHARES, AND EIS

End Use	Natural Gas EUI (kBtu/End-Use ft^2)	Natural Gas Fuel Share	Natural Gas EI (kBtu/ft^2)
Heating	13.45	57.60	7.75
Cooling	0.00	0.00	0.00
Water Heating	55.86 / **49.48**	87.00	48.61 / **42.41**
Cooking	177.85	86.20	153.29
Miscellaneous	1.34	0.50	0.01
Process	42.59	0.80	0.33
All End Uses			209.99 / **203.79**
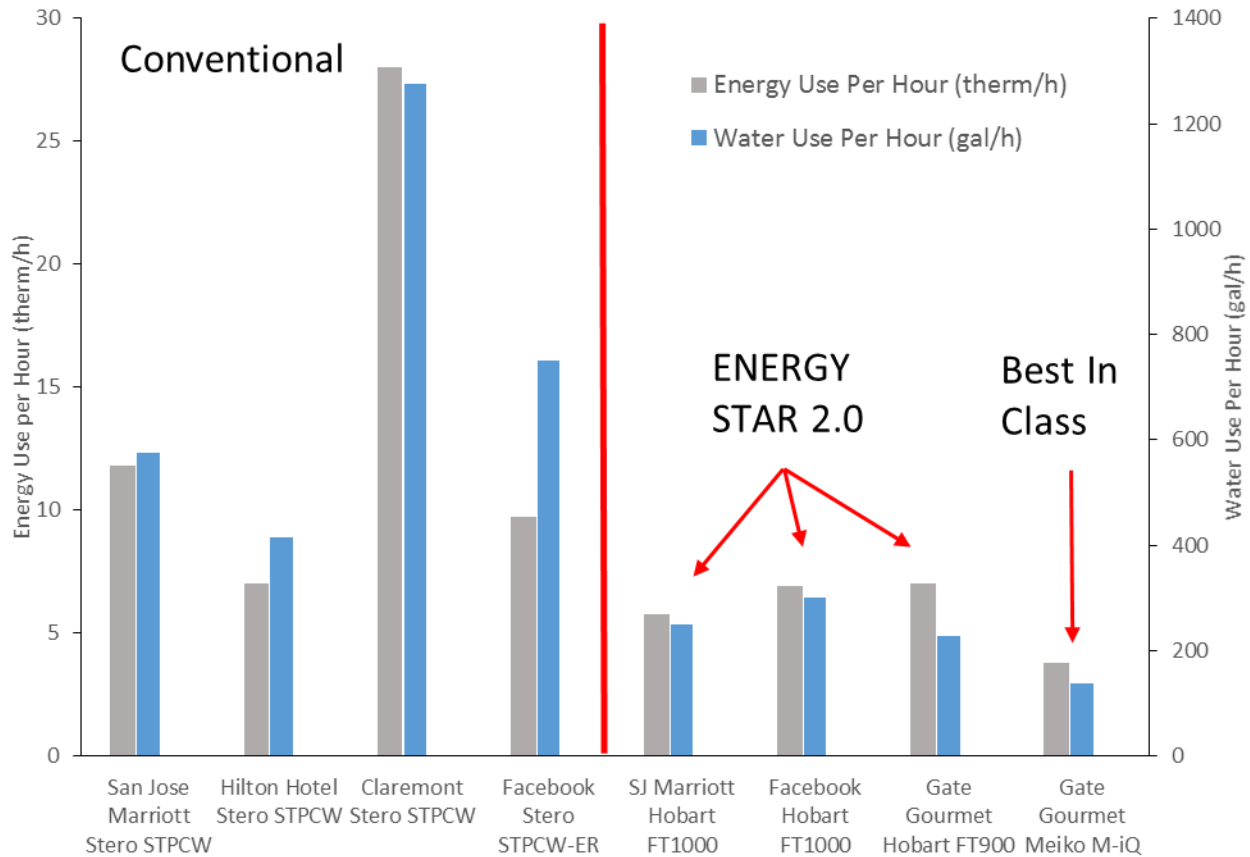
FIGURE 12. ENERGY AND WATER CONSUMPTION COMPARED TO CONVENTIONAL FLIGHT TYPE DISHMACHINES

Figure 12 shows the energy and water use per hour rinse of eight commercial dishmachines monitored by FN. It is worth mentioning that in the grand scheme of commercial dishmachines, the two machines monitored in this ET study are two of the least water and energy intensive on the market. The red vertical line in figure 10 represents the boundary between Energy Star machines and conventional machines. There is a significant savings potential between the two best machines on the market, but the most significant savings potential is between any conventional machine and the Meiko M-iQ. The utility needs to begin a program that supports the early retirement of any non-best in class machines to realize as much savings as possible. Table 12 shows the water and energy savings potential between the Meiko unit and an average conventional flight conveyor machine. These savings were calculated assuming a 15.25 hour rinse time.

TABLE 19. ENERGY AND WATER SAVINGS POTENTIAL FROM CONVENTIONAL MACHINE

	Water (gal/y)	Energy (combined therms/y)
Conventional	3,198,000	66,138
Meiko	1,240,000	21,858
Savings	1,957,068	44,280

EVALUATIONS

The new generation best-in-class machine outperformed the prior-generation unit by a large margin. It did the same amount of work but used substantially less energy and water. This was largely because the Meiko machine's tank filtering system required tanks to be dumped and filled about half as frequently as the Hobart's. This was the most important of the studied technologies because it had a significant impact on hot water consumption. The difference in the heat exchanger efficiencies was also significant because the Meiko was basically able to replace the building's water heater with its heat exchanger for its rinse water needs. The Hobart heat exchanger appeared to be functioning poorly which may be a maintenance issue.

The Meiko M-IQ uses energy at roughly half the rate of the Hobart FT900 even though it has a 22% higher production capacity due to a wider conveyor belt. There was a 541 kWh/d reduction in electric energy use, and a 21.9 therm/d reduction in boiler energy use. There was also a 31 kW coincident demand reduction. The Meiko's GreenEye technology would allow it to use even less energy in operations with slow periods, but these savings were not verified in this study because of the operating parameters of the site.

As mentioned earlier in this report, the greatest barrier to market transformation is that dishmachines are capital-intensive pieces of equipment with extremely long lifetimes compared to other commercial foodservice equipment. The industry holds onto malfunctioning machines that guzzle energy and water as long as the machine successfully cleans dishes. There is a disconnect between adequate energy and water performance and an operator's perception of adequate performance. When machines stop successfully cleaning dishes, a common industry practice is to increase the final rinse pressure or temperature on older machines, trading efficiency for performance. These and other band-aid maintenance solutions keep old machines in inefficient operation for far longer than would be ideal because the cost of new machines is so high.

Another major barrier is that the manufacturers and major players like National Sanitation Foundation, Leadership in Energy and Environmental Design, and Energy Star rate machines on only rinse performance for a known volume of wares or per rack in a lab setting. This practice does not measure the total dishwasher water and energy use in addition to the energy used at the water heater that provides hot water to the unit. Since the test method only tests the machines for short test intervals with clean plates, there is no way to measure water, energy and detergent savings from minimizing tank fills or innovative functions that are able to run the conveyor belt in a manner that optimizes dishwashing efficiency during part load conditions. Thus, one of the biggest takeaways is that the unit that has an extra wash tank, additional blower dryers and higher rinse flow rate that on paper looks like the more resource intensive machine actually uses 50% less water and energy when installed in the field. Market transformation is hindered when the institutionalized reviewing bodies that recognize high-efficiency dishwashers are not able to keep up with or rapidly adjust to new technologies that increase performance outside of the few performance parameters that they choose to focus on. Also credit should be given to manufacturers that integrate diagnostics and metering that mitigate short and long term performance degradation of their unit.

FINANCIAL ANALYSIS

The Meiko costs about half as much to run as the Hobart per hour of rinse. The results at Gate Gourmet in Table 13 were compared to one other machine previously monitored by FN for context. The Hobart FT1000 monitored at Facebook had a rinse time of 7.0 hour per day (Delagah et. al 2017). For this comparison, the rinse time for this machine was normalized to 15.25 hours per day. The researchers acknowledge that the FT1000 if operating for 15.25 hours would have lowered its utility costs per hour of rinse due to less frequent idling of the machine over its operating span. The Hobart FT1000 is the model that Hobart is currently selling on the market. Overall, the Hobart FT1000 and the Hobart FT900 cost about the same to operate due to previously stated factors. Table 20 shows the annual utility costs of each Gate Gourmet machine as well as the Hobart FT1000.

TABLE 20. NORMALIZED ANNUAL UTILITY COSTS					
	Water Use (HCF/y)	**Electricity Use (kWh/y)**	**Est. Domestic Boiler Gas Use (therms/y)**	**Total Utility Cost**	**Utility Cost Per Hour Rinse ($/h)**
Hobart FT900	1,659	769,516	11,651	$176,443	$31.68
Hobart FT1000	1,973	739,610	8,549	$170,645	$30.64
Meiko	1,068	543,591	3,311	$118,140	$21.21

The current average utility costs in California which will be used for all operating cost analysis in this report are $1.10/therm for natural gas use, $0.19/kWh for electricity use and demand charges, and $10.50/HCF for water and sewer costs.

Because Gate Gourmet was running 4 Hobart machines and one Meiko, researchers calculated the savings associated with replacing all 4 Hobart FT900s with Meiko M-iQs. The results of these calculations are presented in table 21. This analysis does not include chemical costs, and assumes all 4 FT900s use roughly the same amount of water and energy per day.

TABLE 21. ANNUAL UTILITY SAVINGS IF ALL 5 GATE GOURMET MACHINES WERE MEIKOS		
	Daily Cost	**Yearly Cost**
1 Hobart	$483	$176,443
4 Hobarts	$1,934	$705,773
1 Meiko	$324	$118,140
Current Utility Cost	$2,257	$823,913
Utility Cost for 5 Meikos	$1,618	$590,701
Savings	$639	$233,212

The simple payback time of replacing one Hobart FT900D with a Meiko is estimated at 2.6 years. The method of calculation can be found in Appendix J. It is worth noting that because the estimated savings potential of the Hobart FT1000 was so low, the simple payback time

exceeds the projected useful service life of 15 years.

MARKET READINESS

The technologies on the Meiko unit are currently on the market and available for customers to purchase. These technologies increase the efficiency of the dishroom and solve multiple maintenance problems, and likely increase the lifetime of the machine while ensuring proper machine operation. The substantial cost savings and low simple payback time make a reasonable business case to retire even high-efficiency machines early. As discussed earlier, the capital cost of these machines, existing test procedures and recognition programs are some of the major barriers to market. Once implemented in the market, there are some behavioral changes that staff would have to make to fully utilize the energy-saving potential of the M-iQ. Because the machine is smarter and can ask operators to change behavior (i.e. GreenEye, maintenance alarms) there is bound to be additional learning curve in any dishroom. These technologies will also require dishroom staff, managers and maintenance staff to be better trained, including utilizing the wireless communication features of the machine that make it much more convenient to check the performance of the machine and evaluate staff operating and maintenance practices.

RECOMMENDATIONS

Two important technologies were not evaluated as a part of this study. Meiko's M-iQ line of dishmachines is equipped with a load-sensing technology called GreenEye which can shut off sections of its belt when the full capacity of the machine is not being used. This was not included as a part of this study because Gate Gourmet was such a high-traffic facility that GreenEye was never utilized during the time of submetering. Hobart has released a new dishmachine that uses heat pump technology similar to what is available in building water heaters in order to increase its efficiency. These two technologies need to be evaluated to give a more complete and detailed understanding of modern commercial flight-type dishmachines.

Because researchers were able to diagnose a possible problem with the Hobart's heat exchanger, researchers have reached out to Hobart in hopes that they can resolve the issue by recommissioning the machine. It is recommended to continue monitoring the machine after the necessary repairs are made. This new set of data would be useful for a number of reasons. It would show the savings associated with recommissioning the heat exchanger, which would provide useful data to utilities to make a case for a retro-commissioning program for both young and old machines. Because it has been shown in many previous reports that even machines that are relatively well-maintained rarely operate close to the manufacturer's ratings, there is likely a high value in a utility-funded retro-commissioning program. For older machines, a program where a third party can submeter and either recommission for immediate savings or make a business case for replacement would be useful. For younger machines, a recommissioning program is needed.

Utilities should incorporate a new category of energy efficiency into its existing EE program to incentivize customers to purchase best-in-class flight conveyor dishwashers for deemed rebates. For custom rebates, it is important to rely only on water and energy submetering from the existing and replacement machine to calculate annual savings from the replacement project. Previous reliance on conveyor belt motor run time is an insufficient

parameter that does not accurately account for the fresh water rinse time of the machine or added features or issues of the machine that impact its real world water and energy use.

Looking at a specification sheet or ENERGY STAR spreadsheet as a purchaser, it is not apparent that there are appreciable utility savings to justify the cost of selecting a best-in-class unit. It is also recommended that an early retirement and replacement program be put in place because the water and energy savings potential associated with replacing conventional and energy efficient machines with best-in-class machines ranges from 50% to 80%. A market characterization study of flight conveyor machines has been provided as a standalone report to justify the need for a future utility program.

For the aforementioned reasons, we recommend the following to PG&E:

- Fund additional studies to evaluate GreenEye savings and heat pump dishmachines
- Fund additional monitoring at Gate Gourmet to evaluate the savings potential of recommissioning the FT900's heat exchanger
- Begin a third-party submetering, retrocommissioning and dishmachine replacement program
- Consider best-in-class dishmachines as a new tier of energy efficient dishwashers above Energy Star and provide additional incentives for using best in class machines

REFERENCES

Delagah, Amin. 2015. *Conveyor Dishwasher Performance Field Evaluation Report*. Los Angeles, CA: The Metropolitan Water District of Southern California. FSTC Report Number P20004-R0. http://bewaterwise.com/icp_projects.html

Delagah, A., Davis, R., Slater, M., Karas, A. 2017. Results from 20 Field Monitoring Projects on Rack and Flight Conveyor Dishwashers in Commercial Kitchens. Atlanta, GA: American Society of Heating, Air-Conditioning and Refrigeration Engineers (ASHRAE). January Conference Paper.

APPENDICES:

Appendix A: Instrumentation List

Hobart		Meiko	
Data Collected	**Instrument**	**Data Collected**	**Instrument**
Hot Water Volume	Badger Water Meter	Hot Water Volume	Badger Water Meter
Cold Water Volume	Badger Water Meter	Cold Water Volume	Badger Water Meter
Machine Electricity	Wattnode Modbus	Machine Electricity	Wattnode Modbus
Booster Electricity	Wattnode Modbus	Booster Electricity	Wattnode Modbus
Blower #1 Electricity	Wattnode Modbus		
Blower #2 Electricity	Wattnode Modbus		
Hot Water Inlet Temp	Type T Thermocouple	Hot Water Inlet Temp	Type T Thermocouple
Cold Water Inlet Temp	Type T Thermocouple	Cold Water Inlet Temp	Type T Thermocouple
Drain Temp	Type T Thermocouple	Drain Temp	Type T Thermocouple
Booster Inlet Temp	Type T Thermocouple	Booster Inlet Temp	Type T Thermocouple
Booster Outlet (Rinse) Temp	Type T Thermocouple	Booster Outlet (Rinse) Temp	Type T Thermocouple
PreWash Tank Temp	Type T Thermocouple	Wash Tank 1 Temp	Type T Thermocouple
Wash Tank Temp	Type T Thermocouple	Wash Tank 2 Temp	Type T Thermocouple
Power Rinse Tank Temp	Type T Thermocouple	Power Rinse Tank Temp	Type T Thermocouple
Final Rinse Tank Temp	Type T Thermocouple	Final Rinse Tank Temp	Type T Thermocouple
Rinse Solenoid Status	Read Switch	Ambient Temp	Type T Thermocouple
		Rinse 1 Solenoid	Read Switch
		Rinse 2 Solenoid	Read Switch
		Rinse 3 Solenoid	Read Switch
		Rinse Pump Status	Read Switch
		Blowers Status	Read Switch
		Heaters Status	Read Switch
		Machine Status	Read Switch
		Wash Status	Read Switch

The information was gathered with two DataTaker DT80 Series 3 data loggers, one for each machine. These data loggers were connected to the internet through a 3G modem, so data could be downloaded by researchers remotely.

Appendix B: Instrumentation Specification

- Temperature sensors:
  - Thermocouple Wire: Therm-X Class-1 Type-T Teflon extension wire, model number is TT(f)-T-24 PFA, tolerance of ±1.8°F or 0.75%, sensor range -330 to 650°F. Wire will be affixed to the outer copper pipe walls. The interface will be treated with heat-sink compound, wrapped with electrical tape, and covered with foam pipe insulation. www.thermx.com/Thermocouple_wire/wire_selection.htm

- Electric metering:
  - Continental Control Systems WattNode pulse electric power metering, single- and three-phase metering, energy and power, pulse output. www.ccontrolsys.com/w/WattNode_Pulse_-_Specifications
  - Continental Control Systems standard and mini hinged split core current transformers, low voltage 0.333 Vac out, five to 250 A, accuracy ±1%. www.ccontrolsys.com/w/ACT_Series_Split-Core_Current_Transformers www.ccontrolsys.com/w/CTM_Series_Split-Core_Current_Transformers

- Water metering:
  - 5/8" Badger Recordall M25 Industrial disc meter with 198.4 pulses/gal output, accuracy ±1.5% of reading, flow range of 0.5 to 30 gpm, cold water meter. www.badgermeter.com/Flow-Instrumentation/Mechanical-Flow-Meters/Recordall/Disc-Meter.htm
  - 5/8" Badger Recordall M25 Industrial disc meter with 198.4 pulses/gal output, accuracy ±1.5% of reading, flow range of one to 30 gpm, hot water meter.

- Data logger:
  - DataTaker DT80 Series 2 or 3, configured to record at five-second intervals, capable of logging from ten isolated thermocouple inputs and eight counter inputs. www.dataloggerinc.com/downloads/UM-0085-B8-DT8xUsersManual.pdf
  - Pace Scientific XR5-8X-SE, three pulse inputs, eight analog inputs, logging rates of one second to 12 hours, temperature accuracy ±0.15°C from 10 to 40°C ±0.3°C from -25°C to 75°C. www.pace-sci.com/data-loggers-xr5.htm

- Cell modem:
  - U.S. Robotics M2M 3G CDMA/GSM Cellular Gateway, model USR3510. www.usr.com/en/products/cellular-m2m-modems-gateways/cellular-m2m-usr3510/

Appendix C: Hobart FT900D Specification Sheet

FT900D DUAL RINSE FLIGHT-TYPE DISHWASHER

HOBART

701 S Ridge Avenue, Troy, OH 45374
1-888-4HOBART • www.hobartcorp.com

FT Dual Rinse (flight type) Models—many additional variations of these model specifications are available. Engineering data furnished on request.

Entire FT900D Series is listed by UL and NSF and meets requirements of ASSE Standard No. 1004.

*Numbers in parentheses, after model number from left to right, represent length in feet of the following respectively; Load section, Power Wash/Power Rinse and Dual Rinse section, and Final Rinse/Unload section.

	FT900D Series (5,7/10/5, 7, 9, 11)*
Machine Ratings (Mechanical) Conveyor Speed — Feet per minute	1 - 8.5
Dishes per Hour	14,316
Floor Space - Feet — Machine length plus 10½" total for load and unload platform overhangs	*Example: FT920D = 5' Load + 10' Center + 5' Unload + 10½" Platform Overhangs = 20'10½" long
Overall Dimensions (H x W) — inches (standard height)	80¹¹⁄₁₆ (C) x 47 (B)
Motor — Horsepower	Pre-Wash - 3; Wash - 3; Rinse - 3; Dual Rinse - ¼; Conveyor - ½
Tank Capacity — Gallons	Pre-Wash - 40; Wash - 40; Rinse - 40; Dual Rinse - 12.5
Pump Capacity Gallons per minute—Weir Test	Pre-Wash - 150; Wash - 292; Rinse - 292; Dual Rinse - 8
Final Rinse — Minutes of operation during one hour of continuous operation	60 at continuous loading condition
Rate of Final Rinse — Gallons per minute at 20 PSI flow pressure	1.5
Final Rinse Consumption — Gallons per hour at 20 PSI flow pressure	90
Exhaust Requirements — Cubic feet per minute without Blower Dryer	750 (at standard air conditions)
Electric Heat Requirements —	Disconnect switches are recommended for each power circuit connected to dishwasher. These disconnect switches are NOT furnished by Hobart and should be installed by the electrical contractor at the time of installation. Circuit breakers optional at extra cost.
Tank Heat - Kilowatt (Regulated)	Total tank heat - 62KW (Wash, Rinse and Dual Rinse)
Optional Electric Booster - Kilowatt	15 KW - 140°F incoming water raised to 190°F (85°F rise) (180°F minimum) 30 KW - 105°F or above incoming water raised to 190°F (85°F rise) (180°F minimum)
Steam Heat Requirements —	24 kw - 140° Incoming Water
Steam Consumption	Approximately 34.5 lbs. per hour = 1 boiler H.P. (BHP)
Tank Heat - Pounds per hour - maximum (Regulated) - based on 15 to 52 PSI steam at the machine and on the customer supplying final rinse water at minimum (A) (20 PSIG)	175 lbs./150°F Wash minimum/160°F Rinse minimum
Optional Steam Booster - Pounds per hour - maximum - based on 20 PSI steam at 20 PSI water flowing - 120°F incoming water raised to 190°F (70°F rise) (180°F minimum)	67 lbs. - Std. Ht.; 67 lbs. - 6" HTS
Peak Rate of Drain Flow — Gallons per minute Initial rate with full tanks	38
Shipping Weight Crated	Varies by individual model - consult your Hobart representative

(A) If only 10-12 PSIG Steam Pressure available at machine - specify Low Pressure Steam Option.
(B) With all rear panels and plumbing removed, machine width is 39⅛" (minimum dimension for installation purposes).
(C) Highest item on the center section is the control box - 80¹¹⁄₁₆". Can be adjusted lower 2" for door clearance.

NOTE: Refer to specific specification sheets for machines without Blower Dryer (FT900D).

As continued product improvement is a policy of Hobart, specifications are subject to change without notice.

Pacific Gas and Electric Company®

Appendix D: Meiko M-iQ B-L44 Spec. Sheet

The larger L94 Series Unit has additional wash tank and additional blower dryers. Total fill = 131 gallons.

M-iQ Flight - B-M74 Series - Technical Specifications

Operating Capacities and Conveyor Specifications (NSF Rated)

	B-M74 V6 N** P8	B-M74 V8 N** P8
Conveyor belt speed (max.)	6.0' (1.8m)/min.	6.5' (2.0m)/min.
Dishes per hour (max.) [1]	9,995	10,828
Water consumption/hr. (max)	56.2 gal. (212.7 liters)	56.8 gal. (215.0 liters)
Horizontal clearance	2' 5-1/2" (750mm)	2' 5-1/2" (750mm)
Vertical clearance	1' 6-1/4" (465mm)	1' 6-1/4" (465mm)
Minimum peg spacing	2-1/8" (54mm)	2-1/8" (54mm)

[1] Maximum dishes per hour as calculated with NSF formula (120 x CS x CW / PD), where CS = conveyor speed in ft/min, CW = conveyor width in inches and PD = peg distance in inches. This formula assumes full belt utilization regardless of conveyor speed or ware size. This loading generally cannot be achieved under actual operating conditions. For assistance with ware throughput calculations and machine selection, contact MEIKO at **sales@meiko.us**.

[2] Heat load shown is for dishwasher only and does not include heat emitted by ware exiting the machine. Heat emitted by ware is site-specific and outside the scope of this spec sheet. For assistance, contact MEIKO at **sales@meiko.us**.

Venting Specifications

	With standard loading sections (load height 3' 1/4" / 920mm)	With lowered loading sections (load height 2' 7-1/2" (800mm)
Machine exhaust	155 CFM (263m³/h)	155 CFM (263m³/h)
Recommended room air	345 CFM (586m³/h)	445 CFM (756m³/h)
Recommended total	500 CFM (850m³/h)	600 CFM (1019m³/h)
Recommended extraction area	3' (900mm) W x 4' (1220mm) L	3' (900mm) W x 5' (1520mm) L

Machine heat load [2]

	Sensible	Latent	Total
@ 208V/60Hz/3Ph	19,108 BTU/hr (5.6 kW)	9,554 BTU/hr (2.8 kW)	28,662 BTU/hr (8.4 kW)
Per addl blwr dryer	+ 1,024 BTU (0.3 kW)	+ 341 BTU (0.1 kW)	+ 1,365 BTU (0.4 kW)
@ 230V/60Hz/3Ph	18,426 BTU/hr (5.4 kW)	9,213 BTU/hr (2.7 kW)	27,639 BTU/hr (8.1 kW)
Per addl blwr dryer	+ 1,024 BTU (0.3 kW)	+ 682 BTU (0.2 kW)	+ 1,706 BTU (0.5 kW)
@ 460V/60Hz/3Ph	19,449 BTU/hr (5.7 kW)	9,554 BTU/hr (2.8 kW)	29,003 BTU/hr (8.5 kW)
Per addl blwr dryer	+ 1,365 BTU (0.4 kW)	+ 1,024 BTU (0.3 kW)	+ 2,389 BTU (0.7 kW)

Water and Drain Specifications

Minimum water temperatures:
- Prewash tank .... No minimum - 110-140°F (43-60°C) typical
- Wash tank .... 150°F (66°C)
- Power rinse .... 162°F (72°C)
- Final rinse .... 180°F (82°C)

Incoming water temperatures:
- Initial fill line .... 110°-140°F (43°-60°C)
- Final rinse line .... Cold as available, 50°F (10°C) recommended

Incoming water line sizes:
- Initial fill line .... 1/2" NPT
- Final rinse line .... 1/2" NPT

	B-M74 V6 N** P8	B-M74 V8 N** P8
Initial fill	67.6 gal. (276.0 liters)	76.1 gal. (288.0 liters)
Consumption at 100% cap.	56.2 gal. (212.7 liters)/hr	56.8 gal. (215.0 liters)/hr
Recommended water hardness		1-3 grains/gal

Drain specifications:
- Connection (standard) .... 2" (50mm) OD
- Connection (with no-hub) .... 1-1/2" pipe
- Recommended floor drain (min.) .... 4" (100mm)
- Maximum drain flow rate .... 15 gals. (56.8 liters) per minute

Machine Electrical Specifications

	208 V/60 Hz/3 Ph				230 V/60 Hz/3 Ph				460 V/60 Hz/3 Ph			
	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4	TB1	TB2	TB3	TB4
Electric tank heat, B-M74 V6 N** P8	29.15 A	94.33 A	9.00 A	52.50 A	29.05 A	84.60 A	7.50 A	45.60 A	19.91 A	43.50 A	5.00 A	23.70 A
Electric tank heat, B-M74 V8 N** P8	35.25 A	94.33 A	9.00 A	52.50 A	35.15 A	84.60 A	7.50 A	45.60 A	23.06 A	43.50 A	5.00 A	23.70 A
Steam tank heat/elec. blower dryer, B-M74 V6 N** P8	45.11 A	–	–	–	42.59 A	–	–	–	27.19 A	–	–	–
Steam tank heat/steam blower dryer, B-M74 V6 N** P8	36.11 A	–	–	–	35.09 A	–	–	–	22.19 A	–	–	–
Steam tank heat/elec. blower dryer, B-M74 V8 N** P8	51.21 A	–	–	–	48.69 A	–	–	–	30.34 A	–	–	–
Steam tank heat/steam blower dryer, B-M74 V8 N** P8	42.21 A	–	–	–	41.19 A	–	–	–	25.34 A	–	–	–
Per additional elec. blower dryer section (electric machine)	+ 2.25 A	–	+9.00 A	–	+ 2.25 A	–	+ 7.50 A	–	+ 1.30 A	–	+ 5.00 A	–
Per additional elec. blower dryer section (steam machine)	+ 11.25 A	–	–	–	+ 9.75 A	–	–	–	+ 6.30 A	–	–	–
Per additional steam blower dryer section	+ 2.25 A	–	–	–	+ 2.25 A	–	–	–	+ 1.30 A	–	–	–

Component Electrical Specifications

Prewash pump motor, B-M74 V6 N** P8	1.0 hp (0.75 kW)
Prewash pump motor, B-M74 V8 N** P8	3.0 hp (2.20 kW)
Wash pump motor	3.0 hp (2.20 kW)
Power rinse pump motor	1.0 hp (0.75 kW)
Final rinse pump motor	0.75 hp (0.55 kW)
Vent motor	0.17 hp (0.13 kW)
Conveyor motor	0.34 hp (0.25 kW)
Blower dryer motor (each)	0.67 hp (0.50 kW)
Loading deck flushing pump	0.134 hp (0.10 kW)
M-iQ Filter pump, prewash	0.134 hp (0.10 kW)
M-iQ Filter pump, wash	0.134 hp (0.10 kW)
M-iQ Filter pump, power rinse	0.134 hp (0.10 kW)
Control system, 208V/60Hz/3Ph or 230V/60Hz/3Ph	0.48 kW
Control system, 460V/60Hz/3Ph	3.30 kW

Electric Heating Elements (electrically-heated units only)

	208 V/60 Hz/3 Ph	230 V/60 Hz/3 Ph	460 V/60 Hz/3 Ph
Wash tank heat	14.88 kW	15.52 kW	15.40 kW
Power rinse tank heat	19.12 kW	18.18 kW	19.20 kW
Booster heater (max.) [1]	18.90 kW	18.30 kW	18.90 kW
Blower dryer heat (each)	3.20 kW	3.00 kW	4.00 kW

[1] Maximum heater output shown. Incoming cold water is pre-heated by heat captured from machine exhaust air prior to being heated to sanitizing 180°F (82°C) by booster heater. Booster heater incorporates variable output and is automatically regulated to ensure proper final rinse temperature, regardless of incoming water temperature or machine operating status (startup, operation, idle).

Typical booster output at operating temperature:
- B-M74 V6 N** P8 .... 7.025 kW
- B-M74 V8 N** P8 .... 7.100 kW

Steam Specifications (steam-heated units only)

Steam supply connection	1-1/2" NPT
Condensate return connection	1" NPT

Steam supply pressure (must be specified):

7-14 PSI (0.51-1.0 bars)   15-22 PSI (1-1.5 bars)   23-29 PSI (1.6-2.0 bars)

Steam consumption (max.):
- Machine with electric blower dryer .... 195 lbs/hr (56.47 kW)
- Machine with steam heated blower dryer .... 206 lbs/hr (59.66 kW)
- Per additional steam blower dryer section .... + 11 lbs/hr (3.20 kW)

Note: All specifications are subject to change without notice based on MEIKO's dedicated product improvement program.

Page 7 • M-iQ Flight - B-M74 Series • Updated 2-15 • MEIKO • 1349 Heil Quaker Blvd. • LaVergne, TN 37086 • (800) 55-MEIKO • www.meiko.us • sales@meiko.us

Pacific Gas and Electric Company®

Appendix E: Meiko M-iQ B-L94 V8 N24 P8 Illustration

Optional for all machines:
Freefall and collecting boxes

M-iQ multi purpose
Passing height: 465 mm

	Belt width	Machine length Incl. Free fall*	Belt speed	Capacity: Full size trays Incl. 50% bulk equipment	Quantity of rinse water**	
					M-iQ Full load	with GreenEye-Technology with gap optimisation up to
	mm	mm	(m/min)	(trays/h)	l/h	
B-M74 V8 N33 P8	750	10,050	1.20	230	215	-50%
B-L74 V8 N24 P8	750	11,250	1.50	290	240	-50%
B-M94 V8 N33 P8	980	11,850	1.20	300	330	-50%
B-L94 V8 N24 P8	980	13,550	1.50	375	330	-50%
B-XL94 V8 N24 P8	980	14,750	1.95	500	340	-50%
B-L124 V8 N44 P8	1220	13,750	1.50	465	420	-50%
B-XL124 V8 N44 P8	1220	14,950	1.95	610	420	-50%

* Depending on length of feeding and discharge section
** Water quantities can vary depending on purpose of use

Appendix F: Hobart Average Daily Use Data Summary

	Hot Water Use (gal/d)	Cold Water Use (gal/d)	Tank Fills Hot (gal/d)	Tank Top Offs Hot (gal/d)	Rinse Hot (gal/d)	Rinse Cold (gal/d)	Rinse Only (gal/d)	Tempering Cold (gal/d)	Total Water Use (gal/d)
12/9/2016	2242	947	983	399	996	288	1283	555	3189
12/10/2016	2608	1030	1318	429	1039	396	1434	589	3638
12/11/2016	2558	795	1161	419	1118	291	1409	495	3353
12/12/2016	2689	973	1261	474	1137	371	1509	603	3663
12/13/2016	2883	908	1530	383	1133	309	1441	578	3790
12/14/2016	2442	1071	1063	346	1164	433	1597	636	3513
12/15/2016	2624	565	1076	341	1276	205	1481	366	3188
12/16/2016	2746	131	961	394	1255	17	1273	131	2877
12/17/2016	2677	120	999	342	1284	11	1295	124	2797
12/18/2016	2969	71	1029	286	1541	0	1541	92	3040
12/19/2016	2825	444	1057	398	1374	148	1522	293	3269
12/20/2016	3517	673	2104	397	1169	250	1419	424	4190
12/21/2016	2695	1021	1386	331	1100	400	1499	606	3716
12/22/2016	2258	439	1054	321	828	169	996	292	2697
12/23/2016	2656	413	1145	321	1107	143	1250	281	3070
12/24/2016	2582	1066	1354	321	1014	421	1435	629	3648
12/25/2016	2500	960	1174	315	1131	348	1479	615	3461
12/26/2016	2577	912	1458	332	914	316	1231	599	3489
12/27/2016	2417	831	1079	286	1065	343	1408	494	3248
12/28/2016	2553	389	1081	385	905	132	1037	269	2941
12/29/2016	2806	133	1123	343	1169	28	1197	124	2939
12/30/2016	2682	122	1101	302	1216	14	1231	127	2804
12/31/2016	3942	110	2240	255	1422	8	1429	124	4053
1/1/2017	2736	100	1183	251	1284	3	1287	119	2836
1/2/2017	2736	599	1340	240	1110	248	1358	355	3335
1/3/2017	2490	1075	1149	293	1131	475	1605	604	3565
1/4/2017	2665	1202	1543	365	892	573	1466	620	3868
1/5/2017	2027	1124	874	252	1037	507	1543	606	3151
1/6/2017	2810	1121	1521	310	1112	486	1599	639	3931
1/7/2017	2683	1223	1468	273	1099	569	1668	647	3906
1/8/2017	2384	1154	1195	257	1104	520	1625	623	3538
1/9/2017	2584	507	1275	303	976	184	1160	323	3091
1/10/2017	1813	253	852	248	603	82	685	186	2066
1/15/2017	2486	711	1046	306	1078	283	1361	432	3198
1/16/2017	2696	776	1237	345	904	299	1203	479	3472
1/17/2017	2506	939	1211	288	873	370	1243	567	3445
1/18/2017	2948	473	1565	362	693	160	853	326	3421
1/19/2017	2923	80	1456	306	505	1	506	100	3002
Average	**2656**	**670**	**1254**	**329**	**1073**	**258**	**1330**	**412**	**3326**

Pacific Gas and Electric Company®

	Number of Fills	Rinse Hot Time (h)	Rinse Cold Time (h)	Hot + Cold Rinse Time (h)	Rinse Flow Rate (gpm)	Hot in (°F)	Cold In (°F)	Booster In (°F)	Booster Out (°F)
12/9/2016	7	12.1	2.6	14.7	1.45	143	48	148	189
12/10/2016	7	12.6	3.7	16.3	1.47	145	48	147	188
12/11/2016	7	13.1	2.4	15.5	1.52	145	48	148	189
12/12/2016	7	13.4	3.3	16.7	1.51	144	47	146	189
12/13/2016	8	13.2	2.6	15.8	1.52	140	47	147	191
12/14/2016	8	13.7	3.9	17.6	1.51	154	52	147	197
12/15/2016	7	14.6	1.4	16	1.54	149	52	144	196
12/16/2016	7	13.8	0.2	14	1.52	150	50	144	197
12/17/2016	7	14.1	0.1	14.2	1.52	151	47	146	201
12/18/2016	7	16.2	0	16.2	1.59	155	46	130	189
12/19/2016	7	15.5	0.8	16.3	1.56	126	49	124	191
12/20/2016	10	13.5	1.9	15.4	1.54	120	51	140	195
12/21/2016	8	13.2	3.6	16.8	1.49	153	50	143	196
12/22/2016	6	10.4	1.4	11.8	1.41	153	45	140	189
12/23/2016	7	13	0.9	13.9	1.50	150	45	145	193
12/24/2016	7	12.3	3.9	16.2	1.48	148	55	144	198
12/25/2016	7	13.2	3	16.2	1.52	149	54	145	199
12/26/2016	7	11.3	3	14.3	1.43	148	54	143	199
12/27/2016	7	12.8	3.1	15.9	1.48	146	55	143	199
12/28/2016	7	11.2	0.9	12.1	1.43	148	53	145	199
12/29/2016	7	13.7	0.3	14	1.43	148	55	144	200
12/30/2016	7	14	0.2	14.2	1.44	148	52	139	197
12/31/2016	8	15.9	0	15.9	1.50	148	51	146	199
1/1/2017	7	14	0	14	1.53	149	47	140	197
1/2/2017	7	13.2	2	15.2	1.49	148	52	143	197
1/3/2017	7	13.3	4.3	17.6	1.52	148	53	143	199
1/4/2017	6	11	5.7	16.7	1.46	149	54	143	200
1/5/2017	6	12.2	4.7	16.9	1.52	149	53	144	201
1/6/2017	8	13	4.4	17.4	1.53	149	55	144	197
1/7/2017	6	12.9	5.3	18.2	1.53	149	54	144	199
1/8/2017	7	12.8	4.7	17.5	1.55	150	54	144	199
1/9/2017	8	11.7	1.4	13.1	1.48	147	52	143	197
1/10/2017	4	8.4	0.6	9	1.27	150	54	143	197
1/15/2017	5	12.8	2.4	15.2	1.49	150	54	140	198
1/16/2017	4	11.1	2.8	13.9	1.44	149	54	140	198
1/17/2017	7	11	3.6	14.6	1.42	148	54	140	198
1/18/2017	6	9.2	1.5	10.7	1.33	149	54	141	198
1/19/2017	6	7.3	0	7.3	1.16	141	57	126	197
Average	**6.9**	**12.7**	**2.3**	**14.9**	**1.47**	**147**	**51**	**142**	**196**

	Booster Energy (kWh/d)	Total Electric (kWh/d)	Peak Load (15 min AVG)	Est. Boiler Use (therms)
12/9/2016	196	2047	105	26.4
12/10/2016	162	2078	105	30.7
12/11/2016	159	1928	105	30.1
12/12/2016	170	2084	105	31.6
12/13/2016	176	2070	105	33.9
12/14/2016	170	2141	105	28.7
12/15/2016	198	2106	105	30.9
12/16/2016	221	2142	105	32.3
12/17/2016	212	2058	105	31.5
12/18/2016	233	2321	105	34.9
12/19/2016	279	2311	105	33.2
12/20/2016	255	2096	105	41.3
12/21/2016	181	2183	105	31.7
12/22/2016	190	1992	105	26.5
12/23/2016	172	2047	104	31.2
12/24/2016	160	2184	104	30.4
12/25/2016	160	2046	104	29.4
12/26/2016	149	1867	104	30.3
12/27/2016	195	1941	104	28.4
12/28/2016	175	1921	104	30.0
12/29/2016	208	2126	104	33.0
12/30/2016	197	2099	104	31.5
12/31/2016	214	2114	104	46.3
1/1/2017	200	1994	104	32.2
1/2/2017	194	2208	104	32.2
1/3/2017	179	2121	104	29.3
1/4/2017	193	2028	104	31.3
1/5/2017	210	2018	105	23.8
1/6/2017	169	2081	105	33.0
1/7/2017	174	2168	105	31.5
1/8/2017	163	2065	105	28.0
1/9/2017	175	2072	105	30.4
1/10/2017	129	1525	105	21.3
1/15/2017	177	1980	104	29.2
1/16/2017	176	2071	104	31.7
1/17/2017	168	2078	104	29.5
1/18/2017	174	2066	104	34.7
1/19/2017	213	2003	104	34.4
Average	**188**	**2063**	**104**	**31.2**

Pacific Gas and Electric Company®

Appendix G: Meiko Average Daily Use Data Summary

	Hot Water Use (g/d)	Cold Water Use (g/d)	Tank Fills Hot (gal/d)	Tank Top Offs Hot (gal/d)	Rinse (gal/d)	Total Water Use (gal/d)	# Fills	Hot + Cold Rinse Time (h)	Rinse Flow Rate (gpm)
12/9/2016	357.8	1428.9	329.4	28.4	1429	1786.7	3	15.2	1.566766
12/10/2016	543.5	1437.3	495	48.5	1437	1980.8	4	14.5	1.652098
12/11/2016	288.7	1357.7	266.6	22.1	1358	1646.4	4	14.3	1.582429
12/12/2016	369.3	1476.5	336.3	33	1476	1845.8	3	15.6	1.577436
12/13/2016	485.3	1382.4	452	33.3	1382	1867.7	4	14	1.645715
12/14/2016	529	1497	514.9	14.1	1497	2026	4	15.5	1.609684
12/15/2016	399.8	1521.9	379.8	20	1522	1921.7	4	16.1	1.575466
12/16/2016	540	1498.7	517.9	22.2	1499	2038.7	4	15.3	1.632535
12/17/2016	504.5	1439	469	35.6	1439	1943.5	3	14.8	1.620485
12/18/2016	455.2	1453.9	405.3	49.9	1454	1909.1	3	15.1	1.604736
12/19/2016	316.6	1389.5	280.7	35.9	1389	1706.1	3	14.5	1.597076
12/20/2016	324.8	1504.3	310.8	14	1504	1829.1	5	16.1	1.557286
12/21/2016	457.6	1476	418.6	38.9	1476	1933.6	3	15.4	1.597421
12/22/2016	441.6	1542.8	423.5	18	1543	1984.4	4	16.3	1.577555
12/23/2016	565.7	1431.3	514	51.2	1431	1997	4	14.3	1.668181
12/24/2016	448	1503.5	405.7	42.4	1503	1951.5	4	15.5	1.616617
12/25/2016	430.1	1411.1	371.7	58.4	1411	1841.2	3	14.5	1.621992
12/26/2016	240.7	1465.1	220.6	20.1	1465	1705.8	3	15.8	1.545481
12/27/2016	440.7	1547.8	405.7	35	1548	1988.5	4	16.3	1.582605
12/28/2016	431.4	1478	409.9	21.4	1478	1909.4	4	15.5	1.589239
12/29/2016	1101.8	1557.8	522.5	579.2	1558	2659.6	5	13.1	1.981905
12/30/2016	1173.2	1492.2	515.2	658	1492	2665.4	3	17.8	1.397227
12/31/2016	491.4	1450.6	415.8	75.6	1451	1942	4	20.5	1.179347
1/1/2017	1538.6	1428.3	683.2	855.5	1428	2966.9	3	15.7	1.51622
1/2/2017	1974.9	1475.6	660.7	1314.2	1476	3450.5	4	14	1.756705
1/3/2017	1917.3	1454.2	795.4	1121.8	1454	3371.5	4	14.2	1.706835
1/4/2017	1696.2	1501.9	650.6	1045.6	1502	3198.1	4	15.6	1.604572
1/5/2017	1693.9	1508.4	705	988.4	1508	3202.3	4	15.5	1.621946
1/6/2017	1814.9	1484.4	1002.3	812.6	1484	3299.3	5	13.6	1.819075
1/7/2017	1688.6	1392.3	1006.1	682.5	1392	3080.9	4	12.4	1.87141
1/8/2017	640.3	1384	450.7	189.7	1384	2024.3	3	16	1.441694
1/9/2017	652.7	1355.5	643.6	9.1	1356	2008.2	4	16.6	1.360966
1/10/2017	485.4	1305.2	461.6	23.7	1305	1790.6	4	15.4	1.412591
1/15/2017	718.6	1442.2	453.2	265.4	1442	2160.8	4	19	1.265112
1/16/2017	790.3	1330	531.7	258.7	1330	2120.3	5	17.1	1.296302
1/17/2017	1396.3	1434.7	831.6	564.8	1435	2831	4	16.3	1.466924
1/18/2017	803.5	1377.3	544	259.5	1377	2180.8	3	17.3	1.326848
1/19/2017	805.2	1412.6	428.8	376.4	1413	2217.8	3	17.7	1.330119
Average	**788**	**1448**	**506**	**282**	**1448**	**2236**	**3.8**	**15.6**	**1.56**

	Hot in (°F)	Cold In (°F)	Booster In (°F)	Booster Out (°F)	Booster Energy (kWh/d)	Machine Energy (kWh)	Total Electric (kWh/d)	Peak Load (15 min AVG)	Est. Boiler Use (therms)
12/9/2016	143	57.6	133.3	188.9	193.9	1290	1483.9	69.5	4.2067057
12/10/2016	143	57.4	132	188.4	199.3	1272.7	1472	71.7	6.3900071
12/11/2016	136	56.6	130.6	188.7	193	1258.3	1451.3	72.1	3.3942871
12/12/2016	134	56.2	130.6	188.6	209.9	1346.7	1556.6	73.6	4.3419129
12/13/2016	138	56.6	129.2	188.7	198.4	1249.9	1448.3	70.9	5.7057414
12/14/2016	143	57.2	132.1	187.9	203.6	1355.6	1559.2	71	6.2195286
12/15/2016	149	57.5	131.1	188.6	212.3	1328.4	1540.7	71.8	4.7005057
12/16/2016	145	56.4	126.7	189	226.2	1313.5	1539.7	73	6.3488571
12/17/2016	155	55.9	124.3	188	225.8	1289.4	1515.2	72.2	5.9314786
12/18/2016	157	55.6	124	187.6	228.3	1291.1	1519.4	73.9	5.3518514
12/19/2016	97.9	55.6	122.2	187.4	223	1298.5	1521.5	73.5	3.7223114
12/20/2016	121	55.6	123.3	188	238.8	1344.5	1583.3	74.4	3.81872
12/21/2016	148	55.3	127.3	189.2	220.6	1310.6	1531.2	72.3	5.3800686
12/22/2016	157	55.5	128.3	189.9	227.7	1375.5	1603.2	74.1	5.1919543
12/23/2016	151	55.1	123.4	189.9	228.2	1290.1	1518.3	72.1	6.6510157
12/24/2016	149	54.6	125.7	189.6	231.6	1326.1	1557.7	73.3	5.2672
12/25/2016	149	54	126.5	189.8	214.3	1269.9	1484.2	73.7	5.0567471
12/26/2016	147	53.6	124.9	189.9	228.7	1352	1580.7	73.1	2.8299443
12/27/2016	149	53.6	127.5	189.3	230.8	1396.7	1627.5	74	5.1813729
12/28/2016	144	53.9	128.2	188	215.9	1366.2	1582.1	73.3	5.0720314
12/29/2016	148	53.8	125.6	188.3	239.8	1378.4	1618.2	75.4	12.95402
12/30/2016	149	53.7	126	188.2	228	1340.5	1568.5	74.9	13.79348
12/31/2016	148	53.7	128.5	188.4	213.5	1311	1524.5	72.9	5.77746
1/1/2017	149	53.5	121	189.5	235.1	1352.4	1587.5	77.5	18.08954
1/2/2017	148	52.8	124.9	189.7	229.9	1425.2	1655.1	77.7	23.219181
1/3/2017	149	53.1	127.2	188.5	217.2	1347.5	1564.7	72.6	22.54197
1/4/2017	150	54.2	128.7	187.7	216.7	1314.8	1531.5	71.4	19.942466
1/5/2017	149	52.8	130.7	188	213.9	1382.8	1596.7	74.5	19.915424
1/6/2017	149	53	130.8	187.6	208.8	1362.9	1571.7	75.3	21.338039
1/7/2017	149	53.2	127.9	188	207.1	1253.8	1460.9	72.9	19.853111
1/8/2017	150	54	128	187.3	204.1	1231.9	1436	70.3	7.5280986
1/9/2017	148	54.5	128.2	186.7	197.6	1177.9	1375.5	67.9	7.6738871
1/10/2017	149	55	128.3	185.9	186.9	1174.1	1361	66.9	5.7069171
1/15/2017	148	54.7	131.6	187	195.6	1301.7	1497.3	73	8.4486829
1/16/2017	146	54.9	129.3	189.4	194.9	1234.8	1429.7	70.9	9.29167
1/17/2017	149	56	127.1	188.8	216.8	1244.2	1461	69.5	16.416499
1/18/2017	147	55.4	130.2	187.9	194.8	1234.7	1429.5	69.3	9.4468643
1/19/2017	142	55.5	131.8	188.6	197.2	1275.4	1472.6	71.2	9.4668514
Average	145	55	128	188	214	1307	1522	73	9.3

Pacific Gas and Electric Company®

Appendix H: Payback Period Calculations

	Water Use Per Hour Rinse (gph)	Electricity Use Per Hour Rinse (kWh)	Gas Use Per Hour Rinse (therms/h)	Energy Use Per Hour Rinse (Btu/h)	Rinse Time (h)	Total Water Use (gal)	Electricity Use (kWh)	Probable Contribution to Peak Demand	Boiler Gas Use (therms)	Annual Water Use (HCF)
Hobart FT900 (90 gph rinse)	223	139	2.10	682,562	15.3	3412	2119	104	32.1	1665
Meiko Mi-Q (57 gph rinse)	143	97.5	0.7	402670	15.3	2188	1492	79	10.7	1068

	1st-Year Annual Operating Cost	2nd-Year Annual Operating Cost	3rd-Year Annual Operating Cost	4th-Year Annual Operating Cost	5th-Year Annual Operating Cost	6th-Year Annual Operating Cost	7th-Year Annual Operating Cost	8th-Year Annual Operating Cost	9th-Year Annual Operating Cost	10th-Year Annual Operating Cost
Hobart FT900 (90 gph rinse)	$ 192,425	$ 198,818	$ 205,487	$ 212,445	$ 219,708	$227,291	$235,211	$243,486	$252,135	$ 261,177
Meiko Mi-Q (57 gph rinse)	$ 131,767	$ 133,032	$ 134,384	$ 135,827	$ 137,368	$139,015	$140,774	$142,655	$144,665	$ 146,814

	Purchase Price	Installation Cost	Cost of Replacement Unit Installed	Water Incentives	Electricity Savings Incentive	Demand Charge Savings Incentive	Gas Savings Incentive	Estimated Total Incentive	Capital Cost After Incentives	
Meiko Mi-Q (57 gph rinse)	$ 170,917	$ 25,457	$ 196,373	$ 2,090	$ 18,317	$3,750	$7,818	$31,976	$164,397	

	1st-Year Cost After Incentives	2nd-Year Cost	3rd-Year Cost	4th-Year Cost	5th-Year Cost	6th-Year Cost	7th-Year Cost	8th-Year Cost	9th-Year Cost	10th-Year Cost
Meiko Mi-Q (57 gph rinse)	$ 103,739	$ 37,953	$ (33,150)	$ (109,769)	$ (192,108)	$(280,384)	$(374,821)	$(475,652)	$(583,122)	$(697,486)

	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year
Water Cost ($/HCF) 7.4%↑/Year	5.08	5.5	5.9	6.3	6.8	7.3	7.8	8.4	9.0	9.7
Sewer Cost ($/HCF) 7.4%↑/Year	8.64	9.3	10.0	10.7	11.5	12.3	13.3	14.2	15.3	16.4
Electricity Cost ($/kWh) 3.2%↑/Year	0.19	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Gas Cost ($/therm) 0%↑/Year	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Chemical Cost ($/gallon) 3%↑/Year	0.008	0.008	0.008	0.008	0.009	0.009	0.009	0.009	0.010	0.010
Simple Payback (years)	**2.7**									

Pacific Gas and Electric Company®