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Water Energy Nexus at a California Tomato Processing Facility

Pumping System Assessment

CONSULTANT DRAFT FINAL

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CEC

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EXECUTIVE SUMMARY

Introduction:

This report provides results from a US Department of Energy (DOE) Pump Energy Systems Assessment (ESA) conducted during the summer of 2012. The ESA includes an inventory of all motors, pumps, and a steam turbine used to power process water in the facility.

A Pump Calculator is developed to evaluate the energy demand per unit of water and establish Water Energy Intensity ratios. This ESA Report supports research conducted by the University of California, Davis to pilot the Water Energy Nexus (WEN) at a California tomato processing facility. The Pump Calculator is used to identify pumping systems in need of performance improvements.

Research Methods:

The Pump ESA was conducted by three Certified Energy Experts utilizing DOE data collection protocols and evaluation software tools[1]. CIFAR researchers provided technical support to collect data, use the DOE Pumping System Assessment Tool (PSAT), design the Pump Calculator, and conduct data analysis.

CIFAR researchers visited the facility to collect name plate data, meter water flows, measure pipe inlet, outlet and length, elbows and valves, and use data loggers to account for power system demand.

<u>The following information was obtained to conduct the ESA:</u>

- Electricity demand, consumption and cost.
- Operating hours.
- Pump and motor nameplate ratings
- Operating duty (fraction of time the pump runs at specified condition)
- Flow rate
- Pump total head (calculated from pressure and line dimensional data)
- Electric power current and voltage
- Maintenance information.

[1]US DOE Industrial Best Practices Program. APPENDIX A.
http://www1.eere.energy.gov/manufacturing/tech_deployment/software_psat.html

Results:

The Pump Calculator is used to assess pump performance and derive WEN intensity ratios. Fixed variables include 2,250 hours of operation and the electricity cost is estimated at $0.15 per kWh. The Pump Calculator[2] provides the following results:

- The overall WEN Pumping System requires 2,775 horse power (HP).
- The HP demands 1,390 kW of electricity.
- The pumping load consumes over 3.1 million kWh of electricity.
- The overall weighted average pump efficiency is 53.6 percent.
- The overall WEN Pumping System load represents 37.4 percent of the total electricity consumed at the facility.

Summary of Recommendations:

The Pump Calculator is used to identify locations where overall pumping plant efficiency (OPE) can be improved to increase pump productivity and reduce total kWh used per unit of water pumped. The Pump Calculator is also showing a technical deviation among a number of pumps that are performing above their pump load safety specifications.

The ESA recommends visiting each of these pumps to confirm the accuracy of the results. At a minimum, facility management will be able to ascertain the potential safety and reliability concerns identified by the Pump Calculator. Additional efforts in partnership with the PGE utility company are to repair, retrofit or replace pumps that have an OPE below 60 percent.

The ESA encourages facility management to adopt these short-term energy efficiency measures. A new base line can be calculated using the Pump Calculator tool to track WEN resource improvements. The Pump Calculator could also be used to establish priorities for a pump maintenance continuous improvement program.

[2] Pump Calculator provided in a separate Excel file.

PUMP SYSTEM ASSESSMENT

Introduction:

A Pump Energy System Assessment (ESA) is conducted at a California tomato processing facility by US Department of Energy (DOE) Certified Energy Experts. The ESA methodology follows DOE assessment protocols and the use of software tools to calculate overall pumping system efficiency (OPE). The ESA identifies motor and turbine driven pumps dedicated to Process Water, including fresh water supply, steam condensate and tomato water vapor recovery, water recycling, cooling towers, cleaning in place (CIP) and discharge of wastewater.

Locations with similar functions in the production process where energy is used to power water are identified as WEN Points. A Pump Calculator is developed to calculate the amount of energy consumed per unit of water used. The Pump Calculator is provided to the tomato processing facility as a tool to evaluate pumping system performance, to identify energy efficiency improvement opportunities and to track continuous improvements.

Tomato Facility Process Overview:

The facility operates at full capacity 24 hours per day, 7 days per week between the middle of July through the middle of October. The facility can process between 240 to 270 truckloads of tomatoes per day, the equivalent of 12 to 13.5 million pounds. During a typical production season, paste would be normally produced 100 percent of the time, with the dice tomato and MPE production lines working at 85 percent of the time.

Tomatoes are unloaded from truck bins to collection channel flumes, moving fruit along conveyor belts and water-driven flumes. Tomatoes are rinsed and sorted for quality before being delivered to the production sections of the facility. Tomatoes that are processed into paste products are delivered to the hot brake chopping units. From the hot brakes the tomato pulp is transported by product pumps to the extraction units that produce refined juice. Tomatoes used for diced products are delivered to steam powered skin-peelers and dicing machines.

Fresh water is supplied by two wells producing over 357 million gallons of water per season. All the water is filtered using two sand filters but only 6 percent of the fresh water is treated using the reverse osmosis (RO) systems. The remaining water is used to unload tomatoes in the flumes and CIP systems.

Research Methods:

The ESA was conducted using DOE data collection protocols and evaluation software tools[3]. Researchers interviewed facility personnel and conducted walkthrough visits to identify WEN Points where pumps and fans are used for process water. Name plate data is collected and site measurements are conducted to obtain base line and system performance data.

The Pump ESA was conducted during full capacity operating conditions at the tomato processing facility. The Pump Calculator uses a Coefficient of Usage for to estimate the amount of time each pump is utilized. It is assumed that the facility operates at one hundred percent capacity during 85 percent of the production season.

Power use data (kW, Volts, AMPS) is collected using Dent Instruments energy data loggers and evaluated with the E-Log software. Pump system flows (GPM) are collected with the use of a Greyline Instruments DFM 5.0 Logging Doppler Flow Meter. To calculate Total Dynamic Head[4] (Total Head), data is collected by installing pressure gauges to pump inlets and by measuring pipe diameters, pipe lengths, elbows and valves. Pump curves and turbine performance data is obtained from equipment manufacturers.

The DOE Pump System Assessment Tool (PSAT) is used to calculate the overall pumping plant efficiency (OPE). Power, flow and total head measurements are not obtained for all pump assets. Either because the flow meter could not measure hot liquids, restricted access to electric panels, or pipe measurements where difficult to reach.

The Pump Calculator provides a color coded system to identify sources of data and the method used to calculate OPE, as shown in Figure 1.

COLOR LEGEND
Data Measured
Data Calculated
Data Calculated Using PSAT
Data Assumed
Nameplate Data
?? *No data available*

Figure 1. Data Sources

[3]US DOE Industrial Best practices Program. APPENDIX A.
http://www1.eere.energy.gov/manufacturing/tech_deployment/software_psat.html
[4] head is energy per unit of weight.

The following glossary provides a brief explanation of each legend:

- **Data Measured** – Data obtained by researchers using measurement tools to record water flow, electric power demand and Total Head.

- **Data Calculated** – Results obtained by the interaction between data points using mathematical equations to derive pump load, HP used and other data recorded in the Pump Calculator.

- **Data Calculated Using PSAT** – The DOE PSAT software tool is used to calculate pumping plant efficiency using data measured at the facility.

- **Data Assumed -** Data was assumed in cases where data was not measured but where the data could be predicted using researcher's and facility staff expertise to draw a reasonable level of certainty.

- **Nameplate Data** – Data displayed in motor, turbine and pump assets.

Pump Calculator Nomenclature:

The Pump Calculator can be used as a decision making tool to identify pumping systems that are underperforming. When using the Pump Calculator notice cells that are highlighted in red, as follows:

- In the case of pump loads (HP used/Motor HP), red highlights indicate that the pump load is higher than the unit or smaller than half. These values may indicate a dimensioning error in the system.
- In the case of efficiencies, red highlights indicate pumps whose efficiency is smaller than 60%. Some of the possible explanations could be maintenance issues or wrong dimensions.

Lessons Learned:

To facilitate the process of conducting future pump system evaluations, the facility will benefit from the installation of permanent flow meters in the feedwater pumping system. The installation of additional pressure gauge inlets will also facilitate the measurement of operational pressures to calculate Total Head.

Results

The Pump Calculator is used to assess pump performance and derive WEN intensity ratios. Fixed variables include 2,250 hours of operation and the electricity cost is estimated at $0.15 per kWh. The Pump Calculator[5] provides the following results:

[5] Appendix A.

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- The overall WEN Pumping System requires 2,775 horse power (HP).
- The HP demands 1,390 kW of electricity.
- The pumping load consumes over 3.1 million kWh of electricity.
- The overall weighted average pump efficiency is 53.6 percent.
- The overall WEN Pumping System load represents 37.4 percent of the total electricity consumed at the facility.

Table 1 provides a summary of the electricity consumed by each WEN Point to identify locations with greatest consumption. The Steam System pumps are the largest consumers of WEN electricity at almost 15 percent, not including the equivalent electricity used by the steam turbine driven feedwater pump. The fresh water supply system consumes 9.3 percent of total facility electricity, including well pumps and the RO system. Pressure losses do occur when fresh water is delivered through the centrifugal sand filter system. Combined Flume WEN Points consume 6.5 percent. The overall WEN Pumping System load represents almost 47 percent of the total electricity consumed at the facility. The CIP System was not evaluated because of flow data acquisition constraints, but it is assumed to represent a small fraction of the total electricity used.

Table 1. Facility Electricity Use and WEN Point Power Intensity

Pump and Fan System Electricity Consumption		
Total Plantwide kWh		8,369,000.00
Total price of electricity	$	1,255,350.00
Pumps kWh		3,127,076.26
Fans kWh		775,853.00
Total WEN kWh		3,902,929.26
WEN Proportion of Total kWh Use		**46.64%**
WEN Points - Power Intensity		
Water supply		9.30%
MPE Flume		3.25%
Paste Flume		1.77%
Diced Flume		1.47%
Steam System		14.62%
Cooling Towers		13.68%
Wasterwater System		1.67%
Cost of WEN Electricity	**$**	**585,439.39**
WEN Points		**45.76%**

Data Quality Evaluation:

The quality of the analysis conducted depends on the quality of the data collected, measured and thus calculated. CIFAR researchers consider data collected to be of high quality, but are aware of potential limitations to data measured, particularly flow measurements. The Pump Calculator is used to determine the proportion of pumps for which all of the required data needed to calculate OPE was obtained without and with assumptions, as follows:

- **Total HP Calculated without Assumptions** – 61.4 percent of the total combined HP of the system's pumps was determined experimentally using facility measurements.
- **Total HP Calculated with Assumptions** – 82 percent of the total combined HP of the WEN pumps was either determined experimentally and/or assumed with a reasonable degree of certainty.

WEN Points:

WEN Points represent the aggregation of pumping assets used in a similar function within the tomato processing facility, including the Steam System, the fresh water Supply System, the Flume System, the Cooling Tower System and the Wastewater System.

In addition to pumps, WEN Points include other assets like boilers and fans that are utilized simultaneously to achieve a production function. In the case of the Steam System there are multiple WEN assets that are required to produce steam. In addition to the pumps used to feed water to boilers, there are fans used to achieve boiler combustion efficiency and to meet air emission quality standards. The Cooling Tower System also utilizes fans in addition to pumps. A separate CIFAR document integrates the use of boilers, pumps and fans to evaluate the Tomato WEN for the facility[6].

The Pump Calculator is used to calculate a WEN intensity ratio by WEN Point and for the overall facility. Table 2 provides information to estimate total water resources supplied to the facility, including fresh well water and recovered tomato water. Over 357 million gallons of water are used to process 15.75 million tons of tomatoes, or the equivalent to 44 tons of tomatoes are processed for every 1,000 gallons of water used. The WEN intensity is calculated at 8.75 kWh for every 1,000 gallons of water used.

[6] Amón, et, al, Tomato WEN, 2013, unpublished.

Table 2. Overall Facility Water Energy Intensity

Facility Water Energy Nexus	Values
Total Water Pumped (Gallons)	357,297,000
Total WEN Pumps (kWh)	3,902,929
WEN Intensity (kWh/1,000G)	11
Processed Tomatoes (Tons)	15,750,000
WEN Intensity (PT/1,000G)	44

Pump Calculator Data Base:

- Each WEN Point data set includes pump name, flow rate, motor HP, volts, name plate amps, running amps, power factor, kW to motor, HP used, pump load, motor RPM, motor efficiency, total head, pumping plant efficiency, coefficient of use, and kW used.

- Assets within each WEN Point are aggregated to account for total HP used, the overall weighted average load and the weighted average efficiency. Each WEN Point is summarized to account for peak kW use, kW use, kWh use and the cost of operating this WEN Point.

Pump Calculator WEN Points

Fresh Water Supply and Treatment Pumping System WEN Point:

Fresh water for the tomato processing facility is provided by two wells using electric motors to pump water from deep aquifers to the surface. Water is pressurized to 80 psi and aggregated into a manifold before it is subjected to sand water filtration treatment. Some of the water is further filtered using Reverse Osmosis (RO) systems and delivered to boilers and to pump seal. The majority of the fresh water is delivered to the tomato unloading flumes, cooling towers and process cooling systems, and to clean surfaces and equipment.

Table 3 provides detailed information about pumping system characteristics for both wells and the reverse osmosis treatment system. Notice that the pump load for the North Ag Well is 1.11, indicating a possible pump load dimension error in the system. This pump's OPE is low and has the potential to be significantly improved. The pump OPE of the two 60 HP RO System High Pressure Pumps is very low indicating maintenance issues or wrong dimensions.

Table 3. Supply-Side Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Supply-Side Groundwater Pumping 100%															
North Ag. Well #2(236 ft water level)	1,558.00	275.00	460.00	330.00	403.97	0.70	225.30	306.41	1.11	1,770.00	0.95	439.00	0.61	0.90	202.77
South Ag. Well #3 (241 ft water level)	1,400.00	250.00	460.00	282.00	290.11	0.70	161.80	220.05	0.88	1,775.00	0.95	450.00	0.78	0.80	129.44
Water Treatment Systems															
RO Product Water Discharge Pump #1	96.00	20.00	460.00	23.00	24.27	0.70	13.54	18.41	0.92	3,450.00	0.90	??	??	1.00	13.54
RO Product Water Discharge Pump #2	96.00	20.00	460.00	23.00	24.27	0.70	13.54	18.41	0.92	3,450.00	0.90	??	??	0.00	0.00
RO System #1 High Pressure Pump	160.00	60.00	460.00	66.00	72.82	0.70	40.61	55.23	0.92	3,450.00	0.93	69.30	0.04	0.95	38.58
RO System #2 High Pressure Pump	160.00	60.00	460.00	66.00	72.82	0.70	40.61	55.23	0.92	3,450.00	0.93	69.30	0.04	0.35	14.21

Table 3A shows a total of 685 HP connected to the supply-side pumping system. The water supply costs are $116,690, including the electricity costs from well pumping and RO water treatment.

Table 3A. Supply-Side WEN Point Summary

WEN Point Total	HP	685.00	Peak kW	414.18
	Weighted Avg. Load	100.28%	kW	345.75
	Overall W. Avg. Load	92.06%	kWh	777,932.67
	Weighted Avg. Eff.	56.61%	Price	116,689.90

Table 3B provides a summary of the water energy intensity for the two well pumping plants. When aggregated, the two well pumping plants utilize over 747,000 kWh, or 2.1 kWh for every 1,000 gallons of water pumped. Notice that the North well is less productive than the South well by delivering 415 gallons for each kWh used, as compared to 577 gallons per kWh used in the South well.

Table 3B. Supply-Side Water Energy Intensity

Supply -Side Well Pump Energy Intensity	Water G/2250h	kWh	kWh/1000G	G/kWh
North Well	189,297,000	456,233	2	415
South Well	168,000,000	291,240	2	577
Both Wells	357,297,000	747,473	2	478

ESA Recommendations:

The supply-side pump data collection and evaluation was conducted before the North well failed in mid-season. The data provided in Table 3, reflects those operational conditions. The ESA recommends conducting a new PGE pump efficiency test, and evaluate options to improve the water energy productivity of the North well. The ESA results seem to indicate that the RO system design is not properly matched to production conditions. It merits further review.

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Boiler Room Feed Water Pumping System WEN Point:

Approximately 6 percent of the well water is treated with the RO system before it is delivered as feedwater from the de-aerator (DA) tank to the boilers. Table 4 provides characteristics of the motor and turbine driven pumping system delivering feedwater to boilers # 1, 2 and 3.

The pumping plant efficiency for these pumps is assumed at 50 percent for all motor driven pumps. Researchers were unable to open the electric panel to measure electric power demand. Flow measurements were not obtained using the Doppler flow meter because the tool does not perform well when measuring high temperature fluids. US DOE Pump Expert provided technical support evaluating pump curves and name plate data to reach the assumed pumping plant efficiency[7], increasing the level of certainty.

Table 4. Boiler Feedwater Pumping System

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Boilers #1 & #2														
Feedwater pump, South, lower level	240.00	150.00	460.00	161.00	98.88	0.70	75.00	0.92	3,570.00	0.95	??	0.50	0.60	33.09
Feedwater pump, North, lower level	240.00	150.00	460.00	161.00	98.88	0.70	75.00	0.92	3,570.00	0.95	??	0.50	0.60	33.09
Feedwater pump, South, upper level	240.00	25.00	460.00	59.00	30.34	0.70	23.01	0.92	1,180.00	0.95	??	0.50	0.60	10.15
Feedwater pump, North, upper level	240.00	25.00	460.00	59.00	30.34	0.70	23.01	0.92	1,180.00	0.95	??	0.50	0.60	10.15
Boiler #3														
Feedwater pump, North	134.40	50.00	460.00	69.50	60.68	0.70	46.03	0.92	3500-4500	0.95	425.00	0.50	1.00	33.84
														120.33
PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Feedwater Turbine Driven Pump, South	134.50	55.00	460.00	108.29	147.28	??	3,550.00	0.95	425.00	??	1.00	108.29	1.00	??

Table 4A provides information about other pumps used in the steam system that are dedicated to Process Water. These assets include motor driven pumps in the Condensate Recovery System, the MVR System, the Hot Brake System and the Evaporator System.

[7] Mr. Greg Case US DOE Pump System Expert, research team meeting, November 2012.

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Notice that the calculated pump OPE of the Condensate Recovery Tank at the MVR System is extremely low. Also low is the calculated OPE of the Hot Well return pump to the REYMSA cooling tower.

Also relevant is to review the potential reasons why the calculated pump load of the T-60 Evaporators is higher than 100 percent. A pump load measurement over 100 percent may indicate that the pumps are not properly sized for the application.

Table 4A. Steam System WEN Pumping Assets

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Condensate Recovery System															
Condensate Return Tank South Pump	??	20.00	460.00	26.00	24.27	0.70	13.54	18.41	0.92	1,170.00	0.92	??	??	1.00	13.54
Condensate Return Tank North Pump	??	20.00	460.00	26.00	24.27	0.70	13.54	18.41	0.92	1,170.00	0.92	??	??	1.00	13.54
MVR System															
Evaporated Water Recovery Pump	??	7.50	460.00	18.00	9.10	0.70	5.08	6.90	0.92	1,760.00	0.95	??	??	1.00	5.08
Condensate Recovery Tank	130.00	7.50	460.00	9.00	9.10	0.70	5.08	6.90	0.92	1,800.00	0.91	1.00	0.04	1.00	5.08
Hot Brake System															
Condensate Recovery Tank	??	10.00	460.00		12.14	0.70	6.77	9.21	0.92	1,770.00	0.95	??	??	1.00	6.77
Evaporator System															
T- 60 Evaporator: Hot Well Return Pump to	2,200.00	75.00	465.00	93.00	122.39	0.70	69.00	93.84	1.25	880.00	0.95	103.80	0.58	1.00	69.00
T- 60 Evaporator: Hot Well Return Pump to	2,200.00	75.00	476.00	93.00	112.00	0.70	64.64	87.91	1.17	880.00	0.95	103.80	0.63	1.00	64.64
T- 60 Evaporator: Hot Well Return Pump to	2,200.00	75.00	475.00	95.60	105.00	0.70	60.47	82.24	1.10	885.00	0.93	103.80	0.67	1.00	60.47
HDE Hot Well Return Pump to Cooling Tower 1	1,725.00	50.00	473.00	61.70	59.20	0.70	33.95	46.17	0.92	1,185.00	0.94	90.00	0.66	1.00	33.95
HDE Hot Well Return Pump to Cooling Tower 2.	1,725.00	50.00	465.00	61.70	52.80	0.70	29.77	40.48	0.81	1,185.00	0.94	90.00	0.68	1.00	29.77
MPE Hot Well Return Pump to REYMSA Cooling Tower 1	550.00	30.00	465.00	35.30	19.00	0.70	10.71	14.57	0.49	1,750.00	0.95	22.50	0.23	1.00	10.71

Table 4B shows that a total of 820 HP are dedicated to the Steam System water energy nexus. The calculated weighted average load is over 100 percent and the calculated weighted average efficiency is below 60 percent, possibly indicating potential maintenance issues or inadequate system dimensions.

Table 4B. Steam System WEN Point Summary

WEN Point Total	HP electrical	820.00	Peak kW	490.52	Turb. kW Eq.	108.29
	Weighted avg. Load	102.88%	kW	432.86	Turb HP	55.00
	Overall w. avg. Load	92.06%	kWh	973,942.24		
	Weighted avg. eff.	54.51%	Price	$146,091.34		

Table 4C provides a summary of the water energy intensity for the five motor driven feedwater pumps. All five pumps deliver over 72 million gallons of feedwater[8] from the AD tank to the boilers, consuming over 270 thousand kWh. At the assumed pumping plant efficiency of 50 percent, these pumps operate at a WEN intensity ratio of 3.75 kWh per every 1,000 gallons of water pumped.

Table 4C. Steam System Water Energy Intensity

Steam System WEi	Water G/2250h	kWh Used	kWh/1,000G
Boiler Feedwater WENi	72,264,547	514,395	7
Boiler Fans WEi	72,264,547	249,750	3
Total	72,264,547	764,145	11

ESA Recommendations:

By calculating pump specific operating conditions, researchers are able to identify and prioritize pumps that are in need of efficiency improvements or pump load corrections. Increasing pumping system performance will lower the WEN Point's energy intensity and increase water delivery productivity. Adjusting pump load to end-use application will enhance the life-time productivity of the pump.

The ESA recommends procuring further data to conduct a comprehensive review of the boiler feedwater pumping system performance. This WEN Point is identified as the largest energy use WEN Point at almost 12 percent of the total facility electricity used. Considering the low assumed 50 percent pumping systems OPE, there are potential cost savings by improving pumping system productivity.

[8] Calculated value using 267,700 pounds of feedwater per hour used by three boilers to produce process steam, or equal to 32,253 gallons of water per hour.

The ESA also recommends a review of the T-60 Evaporator pumps that are performing above 100 percent pump load. Pumps operating below 60 percent efficiency could also be adjusted or repaired.

MPE Flume Pumping System WEN Point:

The MPE Flume System consumes fresh and recycled water to push tomatoes from truck beds and for transport along a water flume system using high pressure driven water booms. Table 5 provides name plate data for all pumps utilized in the MPE Flume. Researchers concentrated data collection efforts to measure performance characteristics for the largest pumps in the flume system. The unloading flume pumps for the booms and elevator are operating at very low pumping plant efficiency.

Table 5. MPE Flume Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Truck Unloading Flume Systems															
Trash Removal motor #1	??	1.00	460.00	3.40	1.21	0.70	0.68	0.92	0.92	1,725.00	0.79	??	??	1.00	0.68
Trash Removal motor #2	??	1.00	460.00	3.40	1.21	0.70	0.68	0.92	0.92	1,725.00	0.79	??	??	0.50	0.34
Auger motor	??	1.00	460.00	1.46	1.21	0.70	0.68	0.92	0.92	1,750.00	0.95	??	??	1.00	0.68
Rotary screen motor #1	??	0.75	460.00	1.00	0.91	0.70	0.51	0.69	0.92	1,750.00	0.95	??	??	1.00	0.51
Rotary screen motor #2	??	1.00	460.00	1.30	1.21	0.70	0.68	0.92	0.92	1,656.00	0.95	??	??	1.00	0.68
Sand hydrocyclone Separator	??	5.00	460.00	7.40	6.07	0.70	3.38	4.60	0.92	1,170.00	0.88	??	??	0.00	0.00
Discharge Pump to Settling Pond	240.00	10.00	460.00	12.50	12.14	0.70	6.77	9.21	0.92	1,750.00	0.92	??	??	0.25	1.69
Unloading Flume Pump (Booms)	1,800.00	40.00	460.00	46.00	48.55	0.70	27.08	36.82	0.92	1,775.00	0.95	26.30	0.29	1.00	27.08
Unloading Flume (Elevator)	1,800.00	40.00	460.00	52.00	48.55	0.70	27.08	36.82	0.92	1,800.00	0.95	26.30	0.30	1.00	27.08
Plant Flume Secondary Recirculation Pump															
Secondary Flume Recirculation	943.00	40.00	460.00	46.00	29.40	0.70	28.10	38.21	0.96	1,770.00	0.95	64.00	0.65	1.00	28.10

Table 5A shows that almost 140 HP are connected to power the MPE Flume. The weighted average efficiency at 44 percent indicates the potential to target these pumps for adjustment or repair.

Table 5A. MPE Flume WEN Point Summary

WEN Point Total	**HP**	139.75	**Peak kW**	131.50
	Weighted avg. Load	95.52%	**kW**	120.91
	Overall w. avg. Load	92.06%	**kWh**	272,038.52
	Weighted avg. eff.	43.81%	**Price**	40,805.78

The water energy intensity for the MPE Flume is not calculated because researchers could not collect data on the amount of fresh water that is delivered to this specific WEN Point location.

ESA Recommendations:

The ESA recommends adjusting or repairing the 40 HP unloading flume pumps. Another recommendation is to install flow meters and pressure gauge inlets to calculate the amount of fresh water that is delivered to the MPE flume. This data can be used to estimate the potential to supplement fresh water with recoverable tomato water. A separate CIFAR report provides a Tomato Water Case Study estimating the technical potential to recover tomato water[9].

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[9] Amon, et, al, Tomato Water Case Study, 2013. Unpublished.

Paste Flume Pumping System WEN Point:

The Paste Flume System utilizes fresh and recycled water to flush tomatoes from truck beds and to transport fruit along the flume system. Two elevators are used to transport and rinse tomatoes with high pressure water sprayers and to be delivered through flumes powered by pressurized water booms.

Table 6 provides name plate data for all pumps utilized in the Paste Flume. Researchers concentrated data collection efforts to measure and calculate performance characteristics for the largest pumps in the flume system. Notice that three of the largest pumps for which data is available are operating below 60 percent efficiency. Researchers were unable to measure the remaining three large pumps in the Paste System. A very low weighted average efficiency ratio indicates the opportunity to evaluate all large pumps in this flume.

Table 6. Paste Flume Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Truck Unloading station															
North Unloading Flume Recirculation (Booms)	2,000.00	30.00	460.00	46.00	36.41	0.70	20.31	27.62	0.92	1,775.00	0.95	8.12	0.17	0.95	19.29
South Unloading Flume Recirculation (Booms)	2,600.00	25.00	460.00	52.00	30.34	0.70	16.92	23.01	0.92	1,800.00	0.95	8.12	0.39	0.95	16.08
Discharge Pump #1 to Settling Pond	??	7.50	460.00	10.20	9.10	0.70	5.08	6.90	0.92	??	0.95	??	??	1.00	5.08
Discharge Pump #2 to Settling Pond	??	7.50	460.00	10.20	9.10	0.70	5.08	6.90	0.92	??	0.95	??	??	0.00	0.00
Secondary Flume System															
South Secondary Flume Recirculation	??	30.00	463.00	36.00	21.30	0.70	11.96	16.26	0.54	1,800.00	0.95	14.00	??	1.00	11.96
North Secondary Flume Recirculation	??	25.00	460.00	29.80	30.34	0.70	16.92	23.01	0.92	??	0.95	??	??	0.80	13.54
Paste Unloading Pumps															
North Paste Flume pump	No Data	25.00	460.00	32.00	30.34	0.70	16.92	23.01	0.92	1,180.00	0.93	79.26	??	0.95	16.08
South Paste Flume pump	988.00	30.00	460.00	39.00	34.00	0.70	18.96	25.79	0.86	1,180.00	0.93	54.90	0.53	0.95	18.01

Table 6A shows that 180 HP are connected to power the Paste Flume. The weighted average efficiency at 27 percent indicates the potential to target these pumps for adjustment or repair.

Table 6A. Paste Flume WEN Point Summary

WEN Point Total	**HP**	180.00	**Peak kW**	76.26
	Weighted avg. Load	85.75%	**kW**	65.94
	Overall w. avg. Load	92.06%	**kWh**	148,363.00
	Weighted avg. eff.	27.04%	**Price**	22,254.45

ESA Recommendations:

The ESA recommends adjusting or repairing the 40 HP unloading flume pumps. Another recommendation is to procure the means to calculate the amount of fresh water that is delivered to the MPE. This data can be used to estimate the potential to supplement fresh water with recoverable tomato water.

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Diced Flume Pumping System WEN Point:

The Diced Flume System utilizes fresh and recycled water to flush tomatoes from truck beds and to transport fruit along the flume system. One elevator is used to transport and rinse tomatoes with high pressure water sprayers and to be delivered to flumes driven by pressurized water booms.

Table 7 provides name plate data for all pumps utilized in the Diced Flume. Calculated pumping plant efficiency is extremely low for four pumps for which data was collected and measured.

Table 7. Diced Flume Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Truck Unloading Station															
Blower Pump	??	10.00	460.00	9.50	12.14	0.70	6.77	9.21	0.92	1,745.00	0.95	??	??	0.85	5.75
Unloading Flume Recirculation (Boom)	1,000.00	20.00	468.00	24.00	18.20	0.70	10.33	14.04	0.70	1,800.00	0.95	12.00	0.21	0.85	8.78
Secondary Flume Recirculation pump #1	??	15.00	471.00	17.30	13.00	0.70	7.42	10.10	1.70	1,800.00	0.95	7.50	??	0.85	6.31
Secondary Flume															
Secondary Flume Recirculation pump #2	800.00	10.00	468.00	123.00	11.93	0.70	6.77	9.21	0.92	1,800.00	0.90	9.00	0.18	0.85	5.75
Tertiary Flume															
Reject Tomato Flume Recirculation	650.00	15.00	471.00	17.90	25.00	0.70	14.28	19.42	1.29	1,760.00	0.95	7.00	0.06	0.85	12.13
Dice Cooling Recycle Tank															
Cooling Water Collection Tank Recirculation Pump	180.00	20.00	460.00	24.00	24.27	0.70	13.54	18.41	0.92	3,325.00	0.86	6.00	0.01	0.85	11.51
Steam Peeling Condensate															
Flume to Steam Peeler Recirculation Pump	??	7.50	460.00	10.10	9.10	0.70	5.08	6.90	0.92	1,770.00	0.89	??	??	0.85	4.32

Table 7A shows that 180 HP are connected to power the Paste Flume. The weighted average efficiency at 27 percent indicates the potential to target these pumps for adjustment or repair.

Table 7A. Paste Flume WEN Point Summary

Wen Point Total	**HP**	97.50	**Peak kW**	64.18
	Weighted avg. Load	117.83%	**kW**	54.55
	Overall w. avg. Load	92.06%	**kWh**	122,743.51
	Weighted avg. eff.	10.93%	**Price**	$18,411.53

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ESA Recommendations:

A very low weighted average efficiency ratio of 11 percent indicates the need to evaluate all pumps in this flume.

Cooling Tower Pumping System WEN Point:

The Cooling Tower Pumping System consumes significant amounts of electricity to power the pumps used to distribute and recirculate hot water from evaporator systems to cooling tower facilities.

Table 8 provides name plate data, estimates, calculations and assumptions for pumps utilized in the cooling towers, including the Main Tower, the Oil Tower, the REYMSA Tower, the Diced Tower, and the South and North Towers. Notice that the calculated pump OPE for most pumps is over 60 percent, except for a low pump OPE in the North Flash Cooler pump.

Notice that although flow rate measurements were obtained for the Oil Cooling Tower, researchers were unable to measure Total Head and thus unable to calculate pumping plant efficiency. The relatively small sized pumps did not merit further efforts to collect additional data.

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Table 8. Cooling Towers Pumping System

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Main Cooling Tower 5 Cells															
Distribution Pump to Flash Coolers	2,115.00	100.00	460.00	134.00	82.50	0.70	46.01	62.58	0.63	1,760.00	0.95	76.10	0.71	1.00	46.01
Distribution Pump to T-60 & HD Evapotrator	2,665.00	100.00	467.00	134.00	98.00	0.70	55.49	75.46	0.75	1,760.00	0.95	87.80	0.83	1.00	55.49
Distribution Pump to Evaporators #1 East	??	15.00	473.30	39.00	18.00	0.70	10.33	14.05	0.94	1,765.00	0.95	84.40	??	1.00	10.33
Distribution Pump to Evaporators #2 Middle	??	15.00	460.00	39.00	18.21	0.70	10.15	13.81	0.92	1,765.00	0.95	84.40	??	1.00	10.15
Distribution Pump to Evaporators #3 West	??	15.00	465.00	39.00	17.20	0.70	11.92	16.21	1.08	1,765.00	0.95	84.40	??	1.00	11.92
MVR Cooling Tower Distribution Pump to T-60 & HD Evaporator	??	20.00	460.00	23.00	24.27	0.70	13.54	18.41	0.92	3,525.00	0.95	??	??	0.05	0.68
Oil Cooling Tower															
Recirculation pump #1	380.00	15.00	460.00	17.20	20.03	0.70	11.17	15.19	1.01	3,525.00	0.92	??	??	1.00	11.17
Recirculation pump #2	500.00	10.00	460.00	12.70	12.14	0.70	6.77	9.21	0.92	1,175.00	0.91	??	??	1.00	6.77
REYMSA Cooling Tower 2 Cells															
Distribution Pump to MPE Evaporator/Flash Cooler	2,367.00	40.00	460.00	46.00	33.00	0.70	18.40	25.03	0.63	1,175.00	0.94	27.20	0.76	1.00	18.40
Diced Cooling Tower															
Distribution Pump #1	400.00	15.00	460.00	18.00	18.21	0.70	10.15	13.81	0.92	3,530.00	0.91	??	??	1.00	10.15
Distribution Pump #2	500.00	10.00	460.00	12.70	12.14	0.70	6.77	9.21	0.92	1,175.00	0.91	??	??	1.00	6.77
South Flash Cooling Tower															
Flash Cooler Hot Well Return Pump to Cooling Tower	1,028.00	30.00	460.00	39.00	37.00	0.70	20.64	28.06	0.94	1,580.00	0.91	69.20	0.63	0.85	17.54
Supply pump	??	25.00	460.00	32.00	30.34	0.70	16.92	23.01	0.92	1,180.00	93.00	85.00	??	0.85	14.38
North Flash Cooling Tower															
Flash Cooler Hot Well Return Pump to Cooling Tower	1,028.00	75.00	465.00	84.00	98.00	0.70	55.25	75.14	1.00	1,580.00	0.95	69.20	0.35	1.00	55.25

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Table 8A shows that 485 HP are connected to power the pumps at the Cooling Towers. The 66 percent weighted average efficiency makes this WEN Point a low priority location for pumping plant efficiency improvements, which is a positive result, considering the high power requirements from the Cooling Towers.

Table 8A also shows the total amount of horse power connected to cooling tower fan systems and the seasonal electricity consumption.

Table 8A. Cooling Towers WEN Point Summary

Pump HP	485	**Peak kW**	294
Weighted avg. Load	1	**kW**	275
Overall w. avg. Load	1	**kWh**	618,797
Weighted avg. eff.	1	**Price**	92,820
Fans HP	595	**Fans Peak kW**	438
		Fans Kwh	526,103
Total WEN kWh			**1,144,900**

ESA Recommendations:

The efficiency of the 75 HP pump at the Flash Cooler Hot Well Return Pump to Cooling Tower should be improved from the current 35 percent.

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Cleaning in Place Pumping System WEN Point:

The cleaning system is supplied by fresh water at well temperature. There is no flow meter, nor flow measurements where undertaken to account for fresh water delivered to the cleaning pumping system. Facility staff assumes that no more than 2.5 percent of fresh water is used for cleaning purposes.

Table 9 provides name plate data from the cleaning system pumps. Researchers chose not to invest time and resources with these two pumps considering low use patterns. As shown by the coefficient of use, it is assumed that the two 60 HP pumps are only operational 15 percent of the time.

Table 9. Cleaning Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Cleaning Systems															
Rotojet Pump #1	60.00	60.00	460.00	72.00	72.82	0.70	40.61	55.23	0.92	3,530.00	0.95	??	??	0.15	6.09
Rotojet Pump #2	60.00	60.00	460.00	??	72.82	0.70	40.61	55.23	0.92	??	0.95	??	??	0.15	6.09
Rotary Screen Rince Pump	??	30.00	460.00	??	36.41	0.70	20.31	27.62	0.92	??	0.95	??	??	1.00	20.31

Table 9A shows a total of 150 HP connected to cleaning system pumps. The costs are assumed to be less than $11,000

Table 9A. Cleaning Pumping System WEN Point Summary

WEN Point Total	**HP**	150.00	**Peak kW**	101.53
	Weighted avg. Load	??	**kW**	32.49
	Overall w. avg. Load	92.06%	**kWh**	73,104.41
	Weighted avg. eff.	??	**Price**	$ 10,965.66

ESA Recommendations:

No recommendations are provided because researchers did not collect field measurements to calculate pump OPE.

Waste Water Pumping System WEN Point:

Wastewater is collected at one central sump before pumping to adjacent agricultural fields. Wastewater sources include: the In-Plant Pump Delivery System that collects wastewater from throughout the facility; the main cooling tower and the flumes. Wastewater from the flumes flows to adjacent aerated lagoons for treatment before being gravity fed to the Wastewater Pumping Station. Wastewater from the main cooling towers is also gravity fed.

Table 10 provides detailed information about wastewater pumping system characteristics, including the Wastewater Pumping Station, the In-Plant Pump Delivery System and the Pond Aerators.

Notice that the calculated pumping plant efficiency for the South Lift pump is critically low. It is important to note that this number is calculated using the DOE PSAT but it only represents one data point measurement. Researchers obtained pump performance data by running each pump individually at maximum pumping capacity. Pump performance was not measured under normal operational conditions. As such the accuracy of the pumping plant efficiency should be regarded as incomplete.

Table 10. Wastewater Pumping System Characteristics

PUMP	FLOW RATE (GPM)	MOTOR HP	VOLTS	NAME PLATE AMPS	RUNNING AMPS	POWER FACTOR	kW TO MOTOR	HP USED	PUMP LOAD	MOTOR RPM	MOTOR EFFICIENCY	TOTAL HEAD (ft)	PUMPING PLANT EFFICIENCY	COEFFICIENT OF USAGE	kW USED
Wastewater Pumping Station															
North Lift Pump #1	3,100.00	75.00	459.00	86.00	71.60	0.70	39.85	54.19	0.72	1,780.00	0.90	46.00	0.61	0.50	19.92
South Lift Pump #2	1,900.00	75.00	459.00	86.00	71.60	0.70	39.85	54.19	0.72	1,780.00	0.90	29.00	0.24	0.50	19.92
In-Plant Pump Delivery System															
North Lift Pit	2,268.00	25.00	462.00	28.90	25.00	0.70	14.00	19.04	0.76	1,760.00	0.89	27.70	0.64	0.30	4.20
South Lift Pit	2,268.00	25.00	454.00	28.90	28.50	0.70	15.69	21.34	0.85	1,760.00	0.89	30.30	0.57	0.30	4.71
Pond Aerators															
Wastewater pond Aerator #1	??	10.00	460.00	12.00	12.14	0.70	6.77	9.21	0.92	1,745.00	0.87	??	??	1.00	6.77
Wastewater pond Aerator #2	??	10.00	460.00	12.00	12.14	0.70	6.77	9.21	0.92	1,745.00	0.87	??	??	1.00	6.77

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Table 10A shows a total of 220 HP connected to the wastewater pumping system. The weighted average efficiency of 47 percent is low and could be improved.

Table 10A. Wastewater Pumping System WEN Point Summary

WEN Point Total	Installed HP	220.00	Peak kW	122.92
	Weighted Avg. Load	74.38%	kW	62.29
	Overall W. Avg. Load	92.06%	kWh	140,155.25
	Weighted Avg. Eff.	46.86%	Price	$ 21,023.29

Table 10B provides a summary of the water energy intensity for each of the 75 HP wastewater pumps. The two well pumping plants combined utilize under 90,000 kWh, or 2.7 kWh for every 1,000 gallons of water pumped. Notice that the North Lift pump is much more productive than the South Lift pump by delivering almost 40 percent more gallons of water for each kWh used.

Table 10B. Wastewater Energy Intensity

Wastewater Energy Intensity	Water G/2250h	kWh	kWh/1,000G
In-Plant Pump Delivery System	183,708,000	20,042	0.11
Flume Pond System	153,792,000	30,460	0.20
Central Wastewater system	337,500,000	89,653	0.27
Total Wastewater	337,500,000	140,155	0.42

ESA Recommendations:

Pump performance was not measured under normal operational conditions. The ESA recommends obtaining additional timely data from the Wastewater Pumping System[10]. The accuracy of the pumping plant efficiency should be regarded as incomplete. The ESA recommends the facility to utilize PGE's Agriculture and Food Wastewater Energy Program (WEP) resources[11], for them to undertake additional pumping plant system assessments and provide system improvement recommendations and incentives.

[10] ASME EA-2 Pump Assessment Guidance, 2010.
[11] PGE' Agriculture and Food Wastewater Energy Program (WEP), 2012 http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/partnersandtradepros/eeis/search/AgriculturE_FoodWastewaterEnergyProgram_10_18_10%20v1.pdf

Summary of Recommendations

The Pump Calculator is used to identify locations where OPE can be improved to increase pump productivity and reduce total kWh used per unit of water pumped. The Pump Calculator is also showing a technical deviation among a number of pumps that are performing above their pump load safety specifications. Theoretically these motor driven pumps should not be supporting high power loads and would have triggered motor safety shut down systems.

The ESA recommends visiting each of these pumps to confirm the accuracy of the results. At a minimum, facility management will be able to ascertain the potential safety and reliability concerns identified by the Pump Calculator. Additional efforts in partnership with the PGE utility company are to repair, retrofit or replace pumps that have an OPE below 60 percent.

Improve System Efficiency:

Internal leaks caused by excessive impeller clearances or by worn or misadjusted parts can reduce the efficiency of pumps. Corrective actions include restoring internal clearances and replacing or refurbishing worn or damaged throat bushings, wear rings, impellers, or pump bowls. Changes in process requirements and control strategies, deteriorating piping, and valve losses all affect pumping system efficiency[12].

The ESA encourages facility management to adopt these short-term energy efficiency measures. A new base line can be calculated using the Pump Calculator tool to track WEN resource improvements. The Pump Calculator could also be used to establish priorities for a pump maintenance continuous improvement program.

Further Research:

Appendix A provides technical resources from the US DOE Industrial Best Practices Program to help facility management with the process to identify appropriate efficiency measures and how to implement improvements[13].

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[12] DOE, Test for Pumping System Efficiency, 2005.
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/test_pumping_system__pumping_systemts4.pdf

[13] US DOE Steam Systems Program
http://www1.eere.energy.gov/manufacturing/tech_deployment/steam.html

Appendix A.
Educational Publications

Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #7 • September 2006

Industrial Technologies Program

Suggested Actions

Consider impeller trimming when any of the following apply:

- The head provided by an oversized, throttled pump exceeds process requirements.
- System bypass valves are open, indicating excess flow rate.
- The pump is operating far from its design point.
- The operating head and (or) flow rate are greater than process requirements.

Resources

Improving Pumping System Performance: A Sourcebook for Industry, DOE and Hydraulic Institute.

Hydraulic Institute—HI is a non-profit industry association for pump and pump system manufacturers; it provides product standards and a forum for the exchange of industry information for management decision-making. In addition to the ANSI/HI pump standards, HI has a variety of energy-related resources for pump users and specifiers, including training, guidebooks, and more. For more information, visit www.pumps.org, www.pumplearning.org, and www.pumpsystemsmatter.org.

U.S. Department of Energy—DOE's Pumping System Assessment Tool (PSAT) can help you assess pumping system efficiency and estimate energy and cost savings. PSAT uses pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database.

Visit the BestPractices Web site at www.eere.energy.gov/bestpractices for more information on PSAT and for upcoming training in improving pumping system performance and in becoming a qualified pumping system specialist.

Trim or Replace Impellers on Oversized Pumps

As a result of conservative engineering practices, pumps are often substantially larger than they need to be for an industrial plant's process requirements. Centrifugal pumps can often be oversized because of "rounding up," trying to accommodate gradual increases in pipe surface roughness and flow resistance over time, or anticipating future plant capacity expansions. In addition, the plant's pumping requirements might not have been clearly defined during the design phase.

Because of this conservative approach, pumps can have operating points completely different from their design points. The pump head is often less than expected, while the flow rate is greater. This can cause cavitation and waste energy as the flow rate typically must be regulated with bypass or throttle control.

Oversized and throttled pumps that produce excess pressure are excellent candidates for impeller replacement or "trimming," to save energy and reduce costs. Trimming involves machining the impeller to reduce its diameter. Trimming should be limited to about 75% of a pump's maximum impeller diameter, because excessive trimming can result in a mismatched impeller and casing. As the impeller diameter decreases, added clearance between the impeller and the fixed pump casing increases internal flow recirculation, causes head loss, and lowers pumping efficiency.

For manufacturing standardization purposes, pump casings and shafts are designed to accommodate impellers in a range of sizes. Many pump manufacturers provide pump performance curves that indicate how various models will perform with different impeller diameters or trims. The impeller should not be trimmed any smaller than the minimum diameter shown on the curve.

Net positive suction head requirements (NPSHR) usually decrease at lower flow rates and can increase at the higher end of the pump head curve. The NPSHR at a given flow rate will normally be greater with a smaller impeller, but engineers should consult with the pump manufacturer to determine variations in NPSHR before trimming the impeller. Manufacturers can often provide trim correction charts based on historical test data.

How Impeller Trimming Works

Trimming reduces the impeller's tip speed, which in turn reduces the amount of energy imparted to the pumped fluid; as a result, the pump's flow rate and pressure both decrease. A smaller or trimmed impeller can thus be used efficiently in applications in which the current impeller is producing excessive head. Pump and system curves can provide the efficiency or shaft power for a trimmed impeller. If these curves are not available, affinity laws can be used to predict the variations in pumping performance with changes in the impeller diameter:

$$
\begin{aligned}
Q_2 / Q_1 &= D_2 / D_1 \\
H_2 / H_1 &= (D_2 / D_1)^2 \\
bhp_2 / bhp_1 &= (H_2 Q_2) / (H_1 Q_1) \\
&= (D_2 / D_1)^3
\end{aligned}
$$

where

Q = pump flow rate, in gallons per minute (gpm)

H = head, in feet (H_1 is head for the original impeller; H_2, for a trimmed impeller)

bhp = brake horsepower

D = impeller diameter, in inches

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In practice, impeller trimming is typically used to avoid throttling losses associated with control valves, and the system flow rate will not be affected.

Note that, in contrast to centrifugal pumps, the operating regions of mixed-flow and axial-flow pumps are limited because of flow rate instabilities. Therefore, consult with the pump manufacturer before changing the impeller diameter. Removing stages is often advisable for a multistage centrifugal pump that is oversized for current operating conditions.

When a pump serves a critically important process, it might not be possible to wait for the impeller to be trimmed. In that case, consider ordering another impeller and continuing operation until the new impeller can be installed.

Example

A double-suction centrifugal pump equipped with an impeller 14 inches in diameter is throttled to provide a process cooling water flow rate of 3,000 gpm. The pumping system operates for 8,000 hours per year with a head of 165 feet (ft) and pump efficiency (η) of 80%. The pump requires 156 bhp. Pump and system curves indicate that a trimmed impeller can supply the 3,000-gpm required flow rate at a head of 125 ft. From the affinity laws, the diameter of the trimmed impeller is approximately as follows:

$$(H_2Q_2) / (H_1Q_1) = (D_2 / D_1)^3$$

Holding Q constant,

$$\begin{aligned} D_2 &= D_1 \times (H_2 / H_1)^{1/3} \\ &= 14 \times (125 / 165)^{1/3} \\ &= 12.76 \text{ inches} \end{aligned}$$

Assuming that the pump efficiency remains unchanged, installing a 12¾-inch trimmed impeller reduces input power requirement to the following:

$$\begin{aligned} bhp_2 &= (H_2 \times Q_2) / (3{,}960 \times \eta) \\ &= (125 \times 3{,}000) / (3{,}960 \times 0.8) \\ &= 118.4 \text{ bhp} \end{aligned}$$

Estimated energy savings, assuming a 94% motor efficiency, are as follows:

$$(bhp_1 - bhp_2) \times 0.746 \text{ kW/hp} \times 8{,}000 \text{ hours/year} / 0.94 = 238{,}720 \text{ kWh/year}$$

At an electricity cost of 5 cents per kWh, total cost savings are estimated to be $11,936 per year.

Reference

Match Pumps to System Requirements, U.S. Department of Energy Pumping Systems Tip Sheet #6, 2005.

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September 2006
Pumping Systems Tip Sheet #7

http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/trim_replace_impellers7.pdf

Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #6 • October 2005

Industrial Technologies Program

Suggested Actions

- Survey your facility's pumps.
- Identify flow rates that vary 30% or more from the BEP and systems imbalances greater than 20%.
- Identify misapplied, oversized, or throttled pumps and those with bypass lines.
- Assess opportunities to improve system efficiency.
- Consult with suppliers on the cost of trimming or replacing impellers and replacing pumps.
- Determine the cost-effectiveness of each improvement.

Resources

DOE and Hydraulic Institute, *Improving Pumping System Performance: A Sourcebook for Industry.*

Hydraulic Institute—HI is a non-profit industry association for pump and pump system manufacturers; it provides product standards and a forum for the exchange of industry information for management decision-making. In addition to the ANSI/HI pump standards, HI has a variety of energy-related resources for pump users and specifiers, including training, guidebooks, and more. For more information, visit www.pumps.org, www.pumplearning.org, and www.pumpsystemsmatter.org.

U.S. Department of Energy—DOE's Pumping System Assessment Tool (PSAT) can help you assess pumping system efficiency and estimate energy and cost savings. PSAT uses pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database.

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Match Pumps to System Requirements

An industrial facility can reduce the energy costs associated with its pumping systems, and save both energy and money, in many ways. They include reducing the pumping system flow rate, lowering the operating pressure, operating the system for a shorter period of time each day, and, perhaps most important, improving the system's overall efficiency.

Often, a pumping system runs inefficiently because its requirements differ from the original design conditions. The original design might have been too conservative, or oversized pumps might have been installed to accommodate future increases in plant capacity. The result is an imbalance that causes the system to be inefficient and thus more expensive to operate.

Correct Imbalanced Pumping Systems

If the imbalance between the system's requirements and the actual (measured) discharge head and flow rate exceeds 20%, conduct a detailed review of your plant's pumping system. Calculate the imbalance as follows:

$$\text{Imbalance (\%)} = [(Q_{meas} \times H_{meas})/(Q_{req} \times H_{req}) - 1] \times 100\%,$$

where

Q_{meas} = measured flow rate, in gallons per minute (gpm)
H_{meas} = measured discharge head, in feet
Q_{req} = required flow rate, in gpm
H_{req} = required discharge head, in feet.

A pump may be incorrectly sized for current needs if it operates under throttled conditions, has a high bypass flow rate, or has a flow rate that varies more than 30% from its best efficiency point (BEP) flow rate. Such pumps can be prioritized for further analysis, according to the degree of imbalance or mismatch between actual and required conditions.

Energy-efficient solutions include using multiple pumps, adding smaller auxiliary (pony) pumps, trimming impellers, or adding a variable-speed drive. In some cases, it may be practical to replace an electric motor with a slower, synchronous-speed motor—e.g., using a motor that runs at 1,200 revolutions per minute (rpm) rather than one that runs at 1,800 rpm.

Conduct quick reviews like this periodically. Especially for multipump systems, this can be a convenient way to identify opportunities to optimize a system at little or no cost.

Example

This example shows the energy savings that can be obtained by not using an oversized pump. Assume that a process requires 1,500 tons of refrigeration during the three summer months, but only 425 tons for the remaining nine months. The process uses two chilled water pumps operating at 3,500 gpm and requiring 200 brake horsepower (bhp) each. Both are used in summer, but two-thirds of the flow rate is bypassed during the remaining months.

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One 3,500-gpm pump is therefore replaced with a new 1,250-gpm pump designed to have the same discharge head as the original unit. Although the new pump requires only 50 bhp, it meets the plant's chilled water requirements most of the year (in all but the summer months). The older pump now operates only in the summer.

Assuming continuous operation with an efficiency (η_m) of 93% for both motors, we can calculate the energy savings from operating the smaller pump as follows:

$$\text{Savings} = (200 \text{ hp} - 50 \text{ hp})/\eta_m \times 0.746 \text{ kW/hp} \times (9 \text{ months}/12 \text{ months}) \times 8{,}760 \text{ hours/year}$$
$$= 790{,}520 \text{ kWh/year}$$

At an average energy cost of 5 cents per kWh, annual savings would be about $39,525.

References

Variable Speed Pumping: A Guide to Successful Applications, Hydraulic Institute and Europump (www.pumps.org), 2004.

Conduct an In-Plant Pump Survey, DOE Pumping Systems Tip Sheet, 2005.

Trim or Replace Impellers on Oversized Pumps, DOE Pumping Systems Tip Sheet, 2005.

Optimize Parallel Pumping Systems, DOE Pumping Systems Tip Sheet, 2005.

Adjustable Speed Pumping Applications, DOE Pumping Systems Tip Sheet, 2005.

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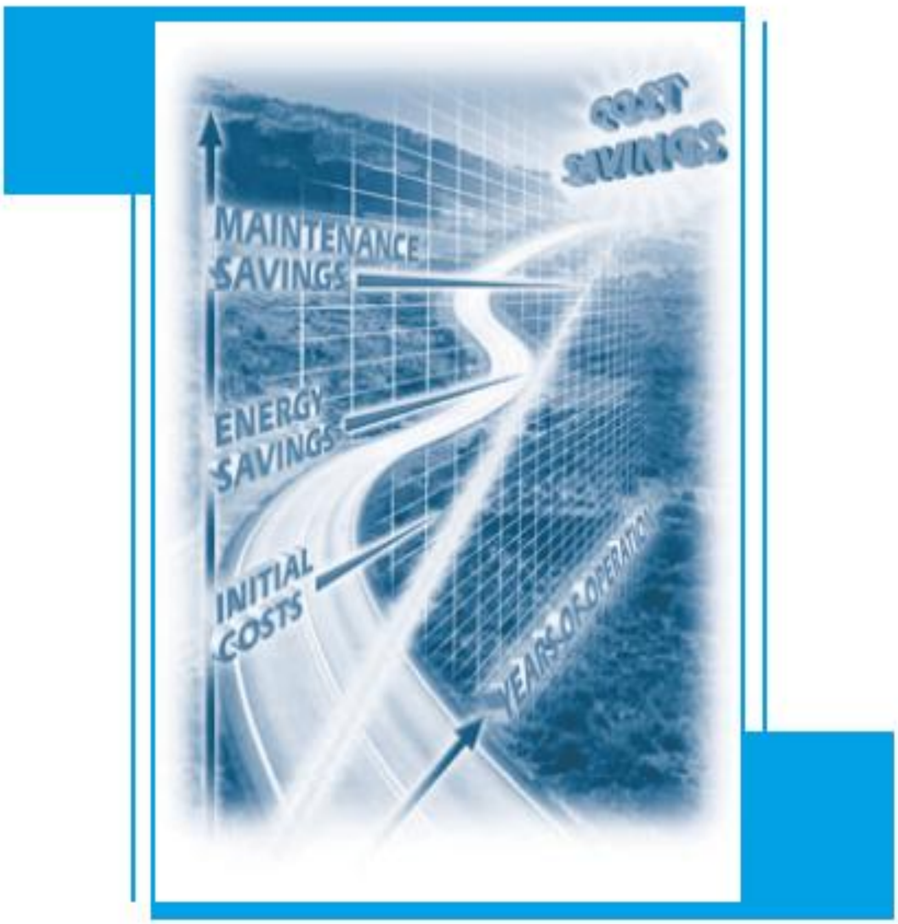
Pumping Systems Tip Sheet #6

http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/pumping_6.pdf

PUMP LIFE CYCLE COSTS:

A GUIDE TO LCC ANALYSIS FOR PUMPING SYSTEMS

EXECUTIVE SUMMARY



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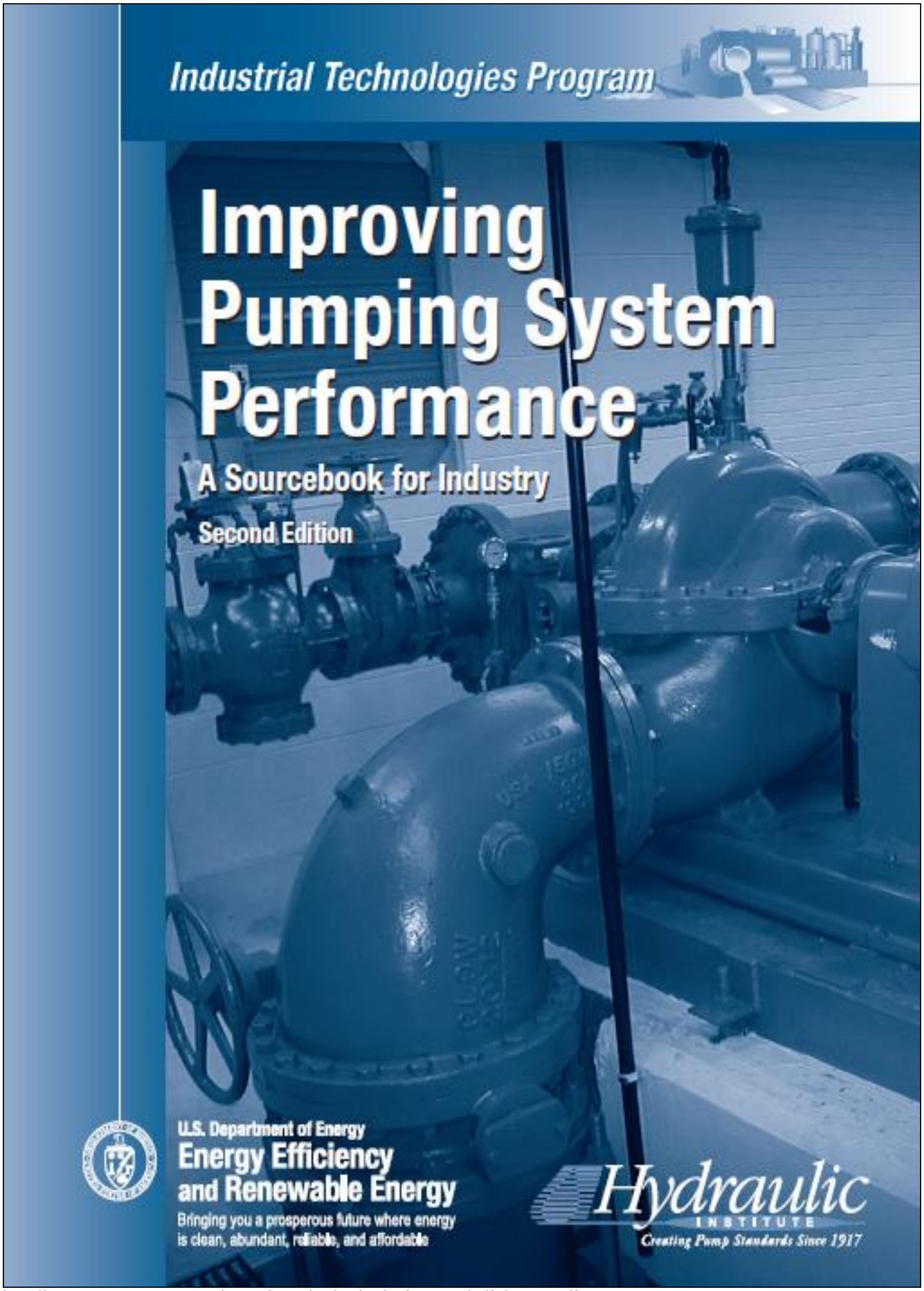

http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/pump.pdf

Energy Tips – Pumping Systems

Suggested Actions

- Consider operating the minimum number of pumps that the system requires at any given time; one exception might involve off-peak pumping to storage tanks.
- Evaluate and compare multiple-pump scenarios to single-pump systems with adjustable speed controls

Resources

Additional information can be found in "Multiple Pump Arrangements," a fact sheet included in Improving Pumping System Performance: A Sourcebook for Industry; see the Resources section of the ITP BestPractices Web site, www.eere.energy.gov/bestpractices, for this sourcebook.

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Optimize Parallel Pumping Systems

When multiple pumps operate continuously as part of a parallel pumping system, there can be opportunities for significant energy savings. For example, lead and spare (or lag) pumps are frequently operated together when a single pump could meet process flow rate requirements. This can result from a common misconception—that operating two identical pumps in parallel doubles the flow rate. Although parallel operation does increase the flow rate, it also causes greater fluid friction losses, results in a higher discharge pressure, reduces the flow rate provided by each pump, and alters the efficiency of each pump. In addition, more energy is required to transfer a given fluid volume.

Parallel Pumping Basics

Designers can expand the operating range of a pumping system by specifying a parallel pumping configuration (see the figure). A greater increase in flow rate will be seen when adding a parallel pump to a static head-dominated system. Parallel pumps can be staged and controlled to operate the number of pumps needed to meet variable flow rate requirements efficiently.

The total system flow rate is equal to the sum of the flow rates or contributions from each pump at the system head or discharge pressure. Parallel pumps provide balanced or equal flow rates when the same models are used and their impeller diameters and rotational speeds are identical. When possible, a recommended design practice is to have parallel pumps moved from beyond Best Efficiency Point (BEP) at low system flow rates (fewer pumps operating) to the left of BEP at the highest flow rate. An ideal scenario will allow the pumps to have the highest possible average operating efficiency for the overall flow rate vs. time profile.

Dissimilar pumps may be installed in parallel, as well, as long as the pumps have similar shutoff head characteristics and/or are not operated together continuously unless provisions are made to prevent dead-heading.

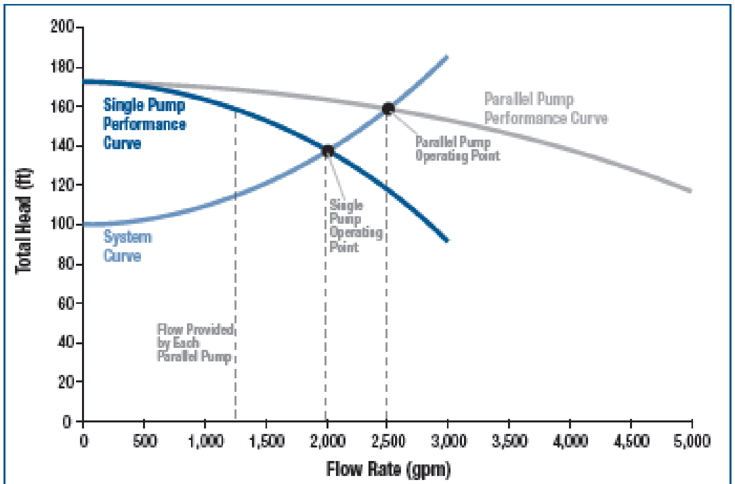

Figure 1. Composite pump curve for two identical pumps operating in parallel

Applications

In general, parallel pumps provide good operating flexibility in static head-dominated systems, but are not nearly as effective in friction-dominated systems. It is advisable to avoid operating two pumps in parallel whenever a single pump can meet system requirements. One exception is certain storage applications with time-of-day energy rates or high "peak period" demand charges. Also, be sure to take into consideration the amount of energy consumed by multiple pumps in contrast to the amount consumed by a single pump with adjustable speed drive control. Multiple pumps should be selected with head-versus-capacity performance curves that rise at a constant rate when these pumps approach no-flow or shutoff head.

Some efficient, high-head/low-capacity, centrifugal pumps used in process industries have "drooping" pump performance curves. These pumps supply peak pressure at a certain flow rate, and the pumping head decreases in approaching no-flow conditions. Identical pumps with drooping head-versus-capacity curves should not operate in parallel at variable flow rates under conditions in which capacity requirements can approach zero.

Example

A split-case centrifugal pump operates close to its BEP while providing a flow rate of 2,000 gallons per minute (gpm) at a total head of 138 feet (ft). The static head is 100 ft. The pump operates at an efficiency of 90% while pumping fluid with a specific gravity of 1. With a drive motor efficiency of 94%, the pumping plant requires 61.4 kW of input power.

When an identical parallel pump is switched on, the operating point of the composite system shifts to 2,500 gpm at 159 ft of head (see the figure). Each pump now operates at 80% efficiency while providing a capacity of 1,250 gpm. Although the fluid flow rate increases by only 25%, the electric power required by the pumping system increases by 62.2%:

$$P_2\,\text{pumps} = 0.746\ \text{kW/hp} \times (2{,}500\ \text{gpm} \times 159\ \text{ft}) / (3{,}960 \times 0.8 \times 0.94) = 99.6\ \text{kW}$$

For fluid transfer applications, it is helpful to examine the energy required per million gallons of fluid pumped. When a single pump is operating, the energy intensity (EI) is as follows:

$$EI_1 = 61.4\ \text{kW} / (2{,}000\ \text{gpm} \times 60\ \text{minutes/hour} \times \text{million gallons}/10^6\ \text{gallons}) = 512\ \text{kWh/million gallons}$$

When both pumps are operating, the EI increases as follows:

$$EI_2 = 99.6\ \text{kW} / (2{,}500\ \text{gpm} \times 60\ \text{minutes/hour} \times \text{million gallons}/10^6\ \text{gallons}) = 665\ \text{kWh/million gallons}$$

When both pumps are operating in parallel, approximately 30% more energy is required to pump the same volume of fluid. The electrical demand charge (kW draw) increases by more than 62%. If the current practice or baseline energy consumption is the result of operating both pumps in parallel, pumping energy use will decrease by 23% if process requirements allow the plant to use a single pump.

Reference

Control Strategies for Centrifugal Pumps with Variable Flow Rate Requirements, U.S. Department of Energy Pumping Systems Tip Sheet #12, 2006.

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http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/38945.pdf

Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #4 • September 2005

Industrial Technologies Program

Test for Pumping System Efficiency

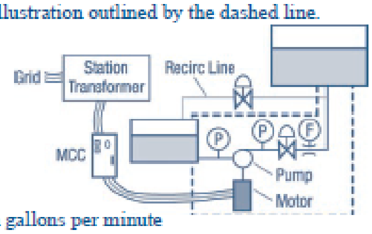
A pump's efficiency can degrade as much as 10% to 25% before it is replaced, according to a study of industrial facilities commissioned by the U.S. Department of Energy (DOE), and efficiencies of 50% to 60% or lower are quite common. However, because these inefficiencies are not readily apparent, opportunities to save energy by repairing or replacing components and optimizing systems are often overlooked.

Define Pumping System Efficiency

System efficiency incorporates the efficiencies of the pump, motor, and other system components, as shown in the area of the illustration outlined by the dashed line.

Pumping system efficiency (η_{sys}) is defined as follows:

$$\eta_{sys} = \frac{Q_{req} \times H_{req} \times SG}{5308 \times P_e},$$



where

Q_{req} = required fluid flow rate, in gallons per minute
H_{req} = required pump head, in feet
SG = specific gravity
P_e = electrical power input.

Only the required head and flow rates are considered in calculating system efficiency. Unnecessary head losses are deducted from the pump head, and unnecessary bypass or recirculation flow is deducted from the pump flow rate.

Conduct Efficiency Tests

Efficiency tests help facilities staff identify inefficient systems, determine energy efficiency improvement measures, and estimate potential energy savings. These tests are usually conducted on larger pumps and on those that operate for long periods of time. For details, see Hydraulic Institute standards ANSI/HI 1.6-2000, Centrifugal Pump Tests, and ANSI/HI 2.6-2000, Vertical Pump Tests.

Flow rates can be obtained with reliable instruments installed in the system or preferably with stand-alone tools such as a sonic (Doppler-type) or "transit time" flow meter or a Pitot tube and manometer. Turbulence can be avoided by measuring the flow rate on a pipe section without fittings at a point where there is still a straight run of pipe ahead.

Improve System Efficiency

Internal leaks caused by excessive impeller clearances or by worn or misadjusted parts can reduce the efficiency of pumps. Corrective actions include restoring internal clearances and replacing or refurbishing worn or damaged throat bushings, wear rings, impellers, or pump bowls. Changes in process requirements and control strategies, deteriorating piping, and valve losses all affect pumping system efficiency.

Potential energy savings can be determined by using the difference between actual system operating efficiency (η_a) and the design (or optimal) operating efficiency (η_o), or by consulting published pump curves, as available, for design efficiency ratings.

Suggested Actions

- Survey the priority pumps in your plant and conduct efficiency tests on them.
- Identify misapplied, oversized, or throttled pumps, or those that have bypass lines.
- Identify pumps with operating points below the manufacturer's pump curve (if available); estimate energy savings of restoring the system to its original efficiency.
- Identify pumps with flow rates of 30% or more from the BEP flow rates, or with system imbalances greater than 20%.
- Determine the cost effectiveness of each improvement.

Resources

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Software tools like DOE's Pumping System Assessment Tool (PSAT) also provide estimates of optimal efficiency. When the required head and flow rate, as well as actual electrical data, are input into the software, PSAT will account for artificial head and flow losses.

The equation for calculating potential energy savings is as follows:

$$\text{Savings} = kW_{in} \times t \times (1 - \eta_a/\eta_o) \text{ ,}$$

where

- savings = energy savings, in kilowatt-hours (kWh) per year
- kW_{in} = input electrical energy, in kilowatts (kW)
- t = annual operating hours
- η_a = actual system efficiency, calculated from field measurements
- η_o = optimal system efficiency.

Example

Efficiency testing and analysis indicate that a 300-horsepower centrifugal pump has an operating efficiency of 55%. However, the manufacturer's pump curve indicates that it should operate at 78% efficiency. The pump draws 235 kW and operates 6,000 hours per year. Assuming that the pump can be restored to its original or design performance conditions, estimated energy savings are as follows:

$$\text{Savings} = 235 \text{ kW} \times 6{,}000 \text{ hours/year} \times [\, 1 - (0.55/0.78)\,] = 415{,}769 \text{ kWh/year.}$$

At an energy cost of 5 cents per kWh, the estimated savings would be $20,786 per year.

References

Centrifugal Tests (ANSI/HI 1.6-2000), Hydraulic Institute, 2000.

Conduct an In-Plant Pumping System Survey, DOE Pumping Systems Tip Sheet, 2005.

Match Pumps to System Requirements, DOE Pumping Systems Tip Sheet, 2005.

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http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/test_pumping_system__pumping_systemts4.pdf

Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #9 • October 2005

Industrial Technologies Program

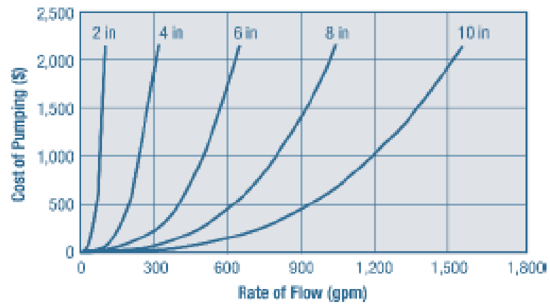
Reduce Pumping Costs through Optimum Pipe Sizing

Every industrial facility has a piping network that carries water or other fluids. According to the U.S. Department of Energy (DOE), 16% of a typical facility's electricity costs are for its pumping systems.

The power consumed to overcome the static head in a pumping system varies linearly with flow, and very little can be done to reduce the static component of the system requirement. However, there are several energy- and money-saving opportunities to reduce the power required to overcome the friction component.

The frictional power required depends on flow rate, pipe size (diameter), overall pipe length, pipe characteristics (surface roughness, material, etc.), and properties of the fluid being pumped. Figure 1 shows the annual water pumping cost (frictional power only) for 1,000 feet of pipe length for different pipe sizes and flow rates.

Figure 1. Annual water pumping cost for 1,000 feet of pipe of different sizes



Based on 1,000 ft. for clean iron and steel pipes (schedule 40) for pumping 70°F water. Electricity rate—0.05 $/kWh and 8,760 operating hours annually. Combined pump and motor efficiency—70%.

Example

A pumping facility has 10,000 feet of piping to carry 600 gallons per minute (gpm) of water continuously to storage tanks. Determine the annual pumping costs associated with different pipe sizes.

From Figure 1, for 600 gpm:

6-inch pipe:	($1,690/1,000 feet) x 10,000 feet	=	$16,900
8-inch pipe:	($425/1,000 feet) x 10,000 feet	=	$4,250
10-inch pipe:	($140/1,000 feet) x 10,000 feet	=	$1,400

After the energy costs are calculated, the installation and maintenence costs should be calculated for each pipe size. Although the up-front cost of a larger pipe may be

Suggested Actions

- Compute annual and life-cycle cost for systems before making an engineering design decision.
- In systems dominated by friction head, evaluate pumping costs for at least two pipe sizes and try to accommodate pipe size with the lowest life-cycle cost.
- Look for ways to reduce friction factor. If your application permits, epoxy-coated steel or plastic pipes can reduce friction factor by more than 40%, proportionately reducing your pumping costs.

Resources

Improving Pumping System Performance: A Sourcebook for Industry, DOE and Hydraulic Institute.

Hydraulic Institute—HI is a non-profit industry association for pump and pump system manufacturers; it provides product standards and a forum for the exchange of industry information for management decision-making. In addition to the ANSI/HI pump standards, HI has a variety of energy-related resources for pump users and specifiers, including training, guidebooks, and more. For more information, visit www.pumps.org, www.pumplearning.org, and www.pumpsystemsmatter.org.

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higher, it may still provide the most cost-effective solution because it will greatly reduce the initial pump and operating costs.

General Equation for Estimating Frictional Portion of Pumping Costs

$$\text{Cost (\$)} = \frac{1}{1706}\text{(Friction factor)}\frac{\text{(Flow in gpm)}^3\text{(Pipe length in feet)}}{\text{(Pipe inner diameter in inches)}^5}\frac{\text{(\# of hours)(\$/kWh)}}{\text{(Combined pump and motor efficiency as a percent)}}$$

Where the friction factor, based on the pipe roughness, pipe diameter, and the Reynolds number, can be obtained from engineering handbooks. For most applications, the value of this friction factor will be 0.015 to 0.0225.

References

United States Industrial Motor Systems Market Opportunities Assessment, Xenergy Inc., prepared for DOE, December 1998.

Piping Handbook, Mohinder K. Nayyar, McGraw-Hill Publications, New York, 1998.

Engineering Data Book, Hydraulic Institute, Second Edition, New Jersey, 1990.

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- Forest Products
- Metal Casting
- Petroleum
- Chemicals
- Glass
- Mining
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Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #2 • October 2005

Industrial Technologies Program

Pump Selection Considerations

Understanding Your Pumping System Requirements

Pumps transfer liquids from one point to another by converting mechanical energy from a rotating impeller into pressure energy (head). The pressure applied to the liquid forces the fluid to flow at the required rate and to overcome friction (or head) losses in piping, valves, fittings, and process equipment. The pumping system designer must consider fluid properties, determine end use requirements, and understand environmental conditions. Pumping applications include constant or variable flow rate requirements, serving single or networked loads, and consisting of open loops (nonreturn or liquid delivery) or closed loops (return systems).

Fluid Properties

The properties of the fluids being pumped can significantly affect the choice of pump. Key considerations include:

- **Acidity/alkalinity (pH) and chemical composition.** Corrosive and acidic fluids can degrade pumps, and should be considered when selecting pump materials.
- **Operating temperature.** Pump materials and expansion, mechanical seal components, and packing materials need to be considered with pumped fluids that are hotter than 200°F.
- **Solids concentrations/particle sizes.** When pumping abrasive liquids such as industrial slurries, selecting a pump that will not clog or fail prematurely depends on particle size, hardness, and the volumetric percentage of solids.
- **Specific gravity.** The fluid specific gravity is the ratio of the fluid density to that of water under specified conditions. Specific gravity affects the energy required to lift and move the fluid, and must be considered when determining pump power requirements.
- **Vapor pressure.** A fluid's vapor pressure is the force per unit area that a fluid exerts in an effort to change phase from a liquid to a vapor, and depends on the fluid's chemical and physical properties. Proper consideration of the fluid's vapor pressure will help to minimize the risk of cavitation.
- **Viscosity.** The viscosity of a fluid is a measure of its resistance to motion. Since kinematic viscosity normally varies directly with temperature, the pumping system designer must know the viscosity of the fluid at the lowest anticipated pumping temperature. High viscosity fluids result in reduced centrifugal pump performance and increased power requirements. It is particularly important to consider pump suction-side line losses when pumping viscous fluids.

End Use Requirements—System Flow Rate and Head

The design pump capacity, or desired pump discharge in gallons per minute (gpm) is needed to accurately size the piping system, determine friction head losses, construct a system curve, and select a pump and drive motor. Process requirements may be met by providing a constant flow rate (with on/off control and storage used to satisfy variable flow rate requirements), or by using a throttling valve or variable speed drive to supply continuously variable flow rates.

The total system head has three components: static head, elevation (potential energy), and velocity (or dynamic) head. Static head is the pressure of the fluid in the system, and is the quantity measured by conventional pressure gauges. The height of the fluid

Suggested Actions

- Accurately identify process flow rate and pressure requirements.
- Measure actual head and flow rate.
- Develop a system curve.
- Select a pump with high efficiency over the expected range of operating conditions.
- Specify electric motors that meet the NEMA Premium™ full-load efficiency standards.
- Use life cycle costing techniques to justify acquiring high efficiency pumps and designing efficient systems.

Resources

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level can have a substantial impact on system head. The dynamic head is the pressure required by the system to overcome head losses caused by flow rate resistance in pipes, valves, fittings, and mechanical equipment. Dynamic head losses are approximately proportional to the square of the fluid flow velocity, or flow rate. If the flow rate doubles, dynamic losses increase fourfold.

For many pumping systems, total system head requirements vary. For example, in wet well or reservoir applications, suction and static lift requirements may vary as the water surface elevations fluctuate. For return systems such as HVAC circulating water pumps, the values for the static and elevation heads equal zero. You also need to be aware of a pump's net positive suction head requirements. Centrifugal pumps require a certain amount of fluid pressure at the inlet to avoid cavitation. A rule of thumb is to ensure that the suction head available exceeds that required by the pump by at least 25% over the range of expected flow rates.

Environmental Considerations

Important environmental considerations include ambient temperature and humidity, elevation above sea level, and whether the pump is to be installed indoors or outdoors.

Software Tools

Most pump manufacturers have developed software or Web-based tools to assist in the pump selection process. Pump purchasers enter their fluid properties and system requirements to obtain a listing of suitable pumps. Software tools that allow you to evaluate and compare operating costs are available from private vendors.

Reference

Centrifugal/Vertical NPSH Margin (ANSI/HI 9.6.1-1998), www.pumps.org, Hydraulic Institute, 1998.

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Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #5 • September 2005

Industrial Technologies Program

Suggested Actions

Establish a pumping system maintenance program that includes the following:

- Preventive actions
- Predictive actions
- Periodic efficiency testing.

Resources

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Maintain Pumping Systems Effectively

Effective pump maintenance allows industrial plants to keep pumps operating well, to detect problems in time to schedule repairs, and to avoid early pump failures. Regular maintenance also reveals deteriorations in efficiency and capacity, which can occur long before a pump fails. Wear ring and rotor erosions, for example, can be costly problems that reduce wire-to-water efficiency by 10% or more.

The amount of attention given to maintenance depends on how important a system is to a plant's operations. Downtime can be expensive when it affects critical processes. Most maintenance activities can be classified as either preventive or predictive. Preventive maintenance addresses routine system needs such as lubrication, periodic adjustments, and removal of contaminants. Predictive maintenance focuses on tests and inspections that detect deteriorating conditions.

Preventive Actions

Preventive maintenance activities include coupling alignment, lubrication, and seal maintenance and replacement. Mechanical seals must be inspected periodically to ensure that either there is no leakage or that leakage is within specifications. Mechanical seals that leak excessively usually must be replaced. A certain amount of leakage is required, however, to lubricate and cool the packing seals. But the packing gland needs to be adjusted if the leakage exceeds the manufacturer's specifications. The packing gland must be replaced if it has to be tightened excessively to control leakage. Overtightening causes unnecessary wear on the shaft or its wear sleeve and increases electric power use. Routine maintenance of pump motors, such as proper lubrication and cleaning, is also vital.

Predictive Actions

Predictive maintenance helps minimize unplanned equipment outages. Sometimes called "condition assessment" or "condition monitoring," it has become easier with modern testing methods and equipment. The following methods apply to pumping systems:

Vibration analysis. Trending vibration amplitude and frequency can detect an impending bearing failure. It can also reveal voltage and mechanical imbalances that could be caused by impeller erosion or coupling problems. Changes in vibration over time are more meaningful than a single "snapshot" of the vibration spectrum.

Motor current signature analysis. Sometimes called "dynamic analysis," this reveals deteriorating insulation, rotor bar damage, electrical system unbalance, and harmonics. It can also pick up system problems such as malfunctioning control valves that cause flow rate disturbances. Tracking the signature over time is more valuable than a single snapshot.

Lubrication oil analysis. This applies only to large, oil-lubricated pumps, and is an expensive procedure. Oil analysis can detect bearing problems caused by metal particles or chemical changes that result from overheating, and seal problems caused by pumped fluid in the oil. It also provides guidance on proper oil-change intervals.

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Periodic efficiency testing. Testing the wire-to-water efficiency and keeping records to spot trends is useful.

Finally, see the checklist of maintenance items below, which can be tailored for many kinds of systems, applications, and facilities.

Basic Maintenance Checklist

- **Packing.** Check for leakage and adjust according to the instructions of the pump and packing manufacturers. Allowable leakage is usually 2 to 60 drops per minute. Add packing rings or, if necessary, replace all the packing.
- **Mechanical Seals.** Check for leakage. If leakage exceeds the manufacturer's specifications, replace the seal.
- **Bearings.** Determine the condition of the bearing by listening for noises that indicate excessive wear, measuring the bearing's operating temperature, and using a predictive maintenance technique such as vibration analysis or oil analysis. Lubricate bearings according to the pump manufacturer's instructions; replace them if necessary.
- **Motor/Pump Alignment.** Determine if motor/pump alignment is within the service limits of the pump.
- **Motor Condition.** Check the integrity of motor winding insulation. These tests usually measure insulation resistance at a certain voltage or the rate at which an applied voltage decays across the insulation. A vibration analysis can also indicate certain conditions within motor windings and lead to early detection of developing problems.

References

Extend Your Motor's Operating Life, DOE Motor Systems Tip Sheet, 2005.

Test for Pumping System Efficiency, DOE Pumping Systems Tip Sheet, 2005.

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http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/maintain_pumping_systemsts5.pdf

Energy Tips – Pumping Systems

Pumping Systems Tip Sheet #1 • September 2005

Industrial Technologies Program

Suggested Actions

- Prescreen the pumps in your facility.
- Survey the systems identified as priorities.

Resources

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Conduct an In-Plant Pumping System Survey

In the United States, more than 2.4 million pumps, which consume more than 142 billion kWh annually, are used in industrial manufacturing processes. At an electricity cost of 5 cents per kWh, energy used for fluids transport costs more than $7.1 billion per year. Even one pump can consume substantial energy. A continuously operated centrifugal pump driven by a fully loaded 100-horsepower motor requires 726,000 kWh per year. This costs more than $36,000, assuming average electricity costs of 5 cents per kWh. Even a 10% reduction in operating costs saves $3,600 per year. Table 1 summarizes the electrical costs of operating this pump.

Table 1. Pumping Energy Costs for Pump Driven by 100-hp Motor (assuming a 90% motor efficiency)

Operating Time	Energy Costs for Various Electricity Costs				
	2 cents per kWh	4 cents per kWh	6 cents per kWh	8 cents per kWh	10 cents per kWh
1 hour	$1.60	$3.30	$4.90	$6.60	$8.20
24 hours	$39	$79	$119	$159	$198
1 month	$1,208	$2,416	$3,625	$4,833	$6,042
1 year	$14,500	$29,000	$43,600	$58,000	$72,600

Surveying Your Pumping Systems

Pumps larger than a minimum size and with significant operating hours should be surveyed to determine a baseline for your current pumping energy consumption and costs, identify inefficient pumps, determine efficiency measures, and estimate the potential for energy savings. The U.S. Department of Energy's (DOE) Pump System Energy Opportunity Screening worksheet will help you identify systems that merit a survey.

The survey team should gather pump and drive motor nameplate information and document operating schedules to develop load profiles, then obtain head/capacity curves (if available) from the pump manufacturers to document the pumping system design and operating points. The team should also note the system flow rate and pressure requirements, pump style, operating speed, number of stages, and specific gravity of the fluid being pumped. If possible, the team should also measure and note the flow rate and the suction and discharge pressures and note conditions that are associated with inefficient pump operation, including indicators such as:

- Pumps with high maintenance requirements
- Oversized pumps that operate in a throttled condition
- Cavitating or badly worn pumps
- Misapplied pumps
- Pumping systems with large flow rate or pressure variations
- Pumping systems with bypass flow
- Throttled control valves to provide fixed or variable flow rates
- Noisy pumps or valves
- Clogged pipelines or pumps
- Wear on pump impellers and casings that increase clearances between fixed and moving parts

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- Excessive wear on wear rings and bearings
- Improper packing adjustment that causes binding on the pump shaft
- Multiple pump systems where excess capacity is bypassed or excess pressure is provided
- Changes from initial design conditions. Distribution system cross-connections, parallel main lines, or changes in pipe diameter or material may change the original system curve.
- Low-flow rate, high-pressure end use applications. An entire pumping system may be operated at high pressure to meet the requirements of a single end use. A booster or dedicated pump may allow system operating pressure to be reduced.

Pumping System Efficiency Measures

Measures to improve pumping plant efficiency include:

- Shut down unnecessary pumps. Re-optimize pumping systems when a plant's water use requirements change. Use pressure switches to control the number of pumps in service when flow rate requirements vary.
- Restore internal clearances.
- Replace standard efficiency pump drive motors with NEMA Premium™ motors.
- Replace or modify oversized pumps.
  - Install new properly sized pumps.
  - Trim or change the pump impellers to match the output with system requirements when the pumping head exceeds system requirements. Consult with the vendor to determine the minimum impeller diameter for a pump casing.
- Meet variable flow rate requirements with an adjustable speed drive or multiple pump arrangement instead of throttling or bypassing excess flow.

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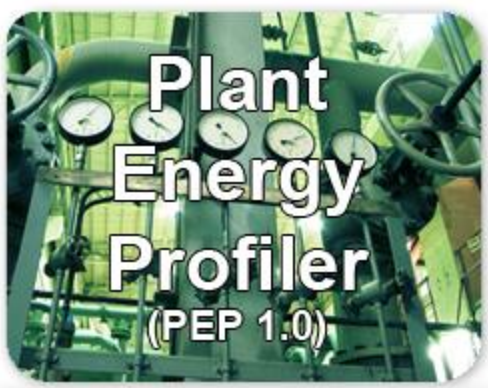
http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/pumping1_conduct.pdf

Software Tools

http://www1.eere.energy.gov/manufacturing/tech_deployment/software_psat.html

Plant Energy Profiler



The Plant Energy Profiler, or PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and identify potential energy and cost savings. PEP is designed so that the users can complete a plant profile in about an hour. PEP provides users with a customized, printable report that shows the details of energy purchases, how energy is consumed, potential cost and energy savings, and a list of next steps that can be followed to save energy. https://save-energy-now.org/EM/tools/Pages/ePEP.aspx

Project Opportunities Tracker

The Project Opportunities Tracker provides a central location for viewing, comparing and prioritizing energy-saving projects. It allows users to sort, edit, and save their recommendations from assessments and tools in one place. In addition to recommendations from tools, a surplus of recommendations from AMO's Industrial Assessment Center database are contained in the eCenter Tool's "project library." Users can import recommendations from this "project library" and add them to their list of

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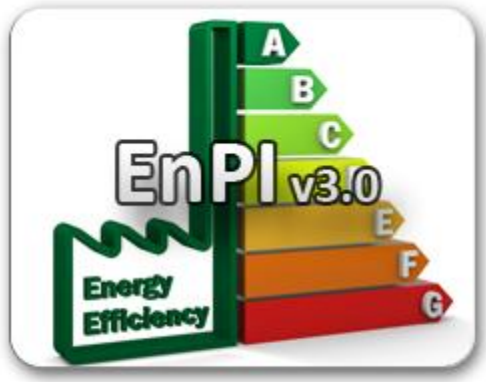
potential opportunities and projects.
https://save-energy-now.org/EM/tools/Pages/PortfolioToolHome.aspx

EnPI 3.0



The EnPI V3.0 is a regression analysis based tool developed by the U.S. Department of Energy to help plant and corporate managers establish a normalized baseline of energy consumption, track annual progress of intensity improvements, energy savings, Superior Energy Performance (SEP) EnPIs, and other EnPIs that account for variations due to weather, production, and other variables. The tool is designed to accommodate multiple users including Better Buildings, Better Plants Program and Challenge Partners, SEP participants, other manufacturing firms, and non-manufacturing facilities such as data centers. https://save-energy-now.org/EM/tools/Pages/EnPI.aspx

Download the DOE eGuide Lite for use in my organization

The DOE eGuide Lite is designed to help you get started with the basics of better energy management. By implementing this guide within your organization you will begin to develop the skills and expertise needed to sustain the energy improvements you implement. It will also prepare your organization for more sophisticated energy management practices like ISO 50001 and Superior Energy Performance, if you choose them.
https://save-energy-now.org/EM/SSPM/Pages/SSPM_UserHome.aspx

Energy Resource Center

http://www1.eere.energy.gov/manufacturing/tech_deployment/ecenter.html