

Industrial Water Energy Nexus Assessment

Campbell Soup California Tomato Processing Facility CALIFORNIA ENERGY COMMISSION

CONSULTANT DRAFT FINAL



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Table of Contents

Abstract	6
Introduction	6
Sustainability Opportunities in California's Tomato Processing Industry	7
Case Study: Tomato Water Recovery Opportunities	7
Research Methods	7
Case Study Sections:	8
II. Tomato Water	8
III. Technical Potential to Produce Tomato Water	8
IV. Technical Potential to Recover Tomato Water	9
V. Tomato Water Recovery Opportunities	0
VI. Tomato Water Energy Nexus	1
VII. Water Energy Intensity 1	1
Wastewater Pumping Energy Intensity1	2
Recovering 70 Million Gallons of Tomato Water per Season1	3
Tomato Water Cooling Tower Load Reduction Technical Potential	4
Benefits from Recovered Tomato Water 1	5
Summary 2	6

Abstract

A Water Energy Nexus assessment was conducted at a Campbell Soup California tomato processing facility to calculate the amount of direct and embedded energy in process water. The assessment results identified energy efficiency measures, improved operational efficiency, the potential for combined heat and power, and hot water conservation opportunities. These recommendations deliver economic benefits from reduced energy costs and significant environmental benefits from the preservation of ground water resources, reduction in unsalable product, lower air pollution emissions and reduced wastewater discharge. A baseline was developed to account for the water energy intensity of processing tomatoes at this facility. This baseline will be used to compare the economic and environmental benefits of adopting resource efficiency measures.

Food companies that integrate the adoption of measurable energy efficiency improvements and invest in water conservation projects may attribute the achievement of sustainability benefits to their investments.

Introduction

The Water Energy Nexus (WEN) was evaluated at a Campbell Soup California tomato processing facility to provide company executives with decision making tools needed to implement company-wide sustainability policies.

The research conducted by the California Institute of Food and Agricultural Research (CIFAR) at the University of California, Davis provides empirical evidence of the benefits that can be achieved from adopting Industrial Best Practices (BPs). Industrial BPs are taught by US Department of Energy Certified Instructors and practiced by Qualified Specialists conducting system assessments. This research paper evaluates the sustainability benefits identified from the results of a DOE Pump and a Steam Energy System Assessment (ESA) conducted during the 2012 production season¹. The paper evaluates the technical potential to recover and conserve hot water resources, achieve energy conservation, and recover excess heat. The hot water recovery effort will require investments in human and physical capital to design and install new infrastructure. The economic and environmental benefits of recovering water resources are consistent with societal environmental principles.

¹ Amón, R., T. Wong, D. Kazama, M. Maulhardt, *Draft California Tomato Processing Facility: Pump System Assessment.* California Energy Commission, 2012, CIFAR.UC Davis; Amón, R., T. Wong, D. Kazama, M. Maulhardt, *Draft California Tomato Processing Facility: Steam System Assessment.* California Energy Commission, 2012, CIFAR.UC Davis.

Sustainability Opportunities in California's Tomato Processing Industry

Empirical research at a tomato processing facility revealed the technical potential to achieve hot water and energy conservation. The company has the opportunity to invest physical capital to reduce the use of thermal and electric energy, conserve ground water and adopt heat recovery opportunities. The challenge for management is to further evaluate the economic return on investment. Food industry companies are sensitive to investing physical capital at a facility that may be subject to closure. Often food companies close facilities that are not competitive, thus lowering the incentive for long-term physical capital sustainability investments at older facilities.

Other reasons for not investing in sustainability technologies depend on the physical location of the processing facility and the type of infrastructure available to dispose of waste residues. For example, a tomato processing facility that is located in a rural area may have access to low-cost options to discharge wastewater residues on agricultural lands. A similar tomato processing facility located in an urban area will be required to discharge wastewater to municipal treatment facilities at a higher cost. The higher cost of production may be an incentive to consider long-term sustainability physical capital investments or an incentive to close the facility and consolidate production at a facility with lower costs per unit produced.

This report offers empirical evidence about the potential to achieve short-term environmental sustainability goals by reducing energy intensity, lowering air pollution emissions and conserving water resources. The following Case Study provides field data to confirm the economic and environmental benefits from conducting energy system assessments and calculating the amount of energy embedded in process water.

Case Study: Tomato Water Recovery Opportunities

This Case Study report illustrates the Water Energy Nexus (WEN) at a Campbell Soup California tomato processing facility. It identifies the potential sources of tomato water* produced by the evaporator systems and calculates the energy savings that result from reducing ground water use, lower wastewater discharge and the reduction of cooling tower fan power demand. The technical potential to recover heat from tomato water was also calculated.

Research Methods

Researchers interviewed facility personnel and conducted walkthrough visits to identify WEN Points (locations) where motors, 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.

Power use data (kW, Volts, AMPS), pump system flows (GPM) and Total Dynamic Head** data are collected and entered into DOE's Pump System Assessment Tool

^{*} Tomato Water is the condensed vapors produced in tomato evaporators

^{**}Head is energy per unit of weight.

(PSAT) to calculate the overall pumping plant efficiency (OPE). The ESA estimated system efficiencies and calculated how much energy is used per unit of water at this facility.

Case Study Sections:

I. Water Supply

Fresh water for the tomato processing facility is provided by two deep wells using electric motor driven vertical pumps. 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 the plant's three boilers and to a number of pumps that require seal water for their operation. The majority of the non-RO fresh water is delivered to the tomato unloading flumes, the single pass cooling systems, the tomato scalder and to the sanitation stations to clean surfaces and equipment.

II. Tomato Water

The Nature of Tomato Water:

- > Tomato Water are the condensed vapors produced in tomato evaporators
- Tomato Water is mineral free, at temperatures ranging from 160 degrees Fahrenheit (°F) to 200° F
- > The water contains a small percentage of carryover tomato solid residues

Hybrid processing tomato varieties contain as much as 95 percent of the fruit weight in water. This water is evaporated to produce tomato paste through the use of a mechanical vapor recompression system (MVR), an array of T-60 evaporators and high density (HD) evaporators.

III. Technical Potential to Produce Tomato Water

A method of understanding evaporation is based on calculations using the percentage of solids in the raw tomato. The difference between starting raw tomato tonnage and finished tonnage in the form of paste is the amount of evaporation vapors or "Tomato Water". The following values are used to estimate the technical potential to produce tomato water at the facility:

- 7,000 tons of tomatoes are processed per 24 hour day, 2,250 hours per season.
- Tomato solids represent 5.2 percent of total weight.
- Tomato paste solids represent 29 percent of total weight.
- Water weighs 8.33 pounds per gallon at room temperature.

To estimate the theoretical amount of tomato water produced per hour, we used the following formulas:

- (1) 7,000 tons/day x 5.2% tomato fruit solids / 29% tomato paste solids
 = 1,255 tons/day
- (2) 7,000 tons/day 1255 tons/day
 - = 5,745 tons of tomato water evaporated
- (3) 5,745 tons x 2,000 pounds per ton / 8.335 pounds per gallon
 - = 1,378,525 gallons per day, or
 - = 57,440 gallons per hour, or
 - = 129,240,000 gallons of tomato water produced per season.

Table 1 provides a summary of the technical potential to produce tomato water at the facility.

	IIIIdi
Tomato Water Technical Potential	Values
TomatoTons Processed per Day	7,000
Tomato Solids Tons per Day	1,255
Tomato Water Tons Evaporated/Day	5,745
Gallons Tomato Water/Day	1,378,483
Gallons Tomato Water/Hour	57,437
Gallons Tomato Water/Season	129,232,774

Table 1.	Tomato	Water	Technical	Potential
1 4010 11	romato	v v ator	10011110001	i otoritiai

IV. Technical Potential to Recover Tomato Water

Tomato water in the amount of 202,350 pounds per hour is produced by evaporators and condensers, hot brakes and flash coolers. Table 2 shows the technical potential to recover over 54 million gallons of tomato water per season.

Tomato Water Recovery Potential	Values
Recoverable Tomato Water Lb/Hr.	202,350
Recoverable Tomato Water Gl/Hr.	24,277
Recoverable Tomato Water Gallons per Season.	54,623,575

Table 2.Tomato Water Recovery Potential

Using the following formulas yield over 54 million gallons of tomato water per season that are potentially recoverable at the facility.

(1) 202,350 (Lbs/hr tomato water) x 8.33 (Lbs/Gal conversion factor)

= 24,277 gallons of tomato water per hour.

(2) 24,277 (Gal tomato water/Hr.) x 2,250 (Hrs per season)

= 54,623,575 gallons of tomato water per season.

The facility currently recovers 12,741 gallons of tomato water per hour that are delivered to the de-aerator (DA) tank for boiler feedwater, as required to produce process steam (see side bar for details). The remaining amount of tomato water is not recovered but delivered to the cooling towers previous to being discharged as wastewater.

V. Tomato Water Recovery Opportunities

A Steam ESA was also conducted by DOE Qualified Specialists to estimate the technical potential to recover tomato water from the DA tank². The Steam ESA data was used to calculate the rate of feedwater consumed by boilers to generate steam, condensate return and blowdown water.

Using data presented in Table 2, researchers estimated that almost 24,277 gallons per hour of tomato water are available for recovery. The side bar provides the method used to calculate the potential to recover an additional 10,020 gallons per hour; tomato water that is already collected but not used for feedwater purposes.

The following sections of this Case Study describe the calculations used to estimate the technical potential to recover and utilize 25,000 gallons of tomato water per hour. Researchers suggest that there are several end-use locations where tomato water can be used to replace well water.

Some of the potential end-use options to utilize available tomato water include:

- As flume water that is used to unload tomatoes from trucks
- To clean facility surfaces with hot water
- As seal water for pumps³

Facility management would need to conduct engineering studies to evaluate the technical and economic potential to recover, store and deliver tomato water to new applications.

Boiler Feedwater Demand:

Three boilers consume 267,700 pounds of feedwater per hour to produce process steam.

• 90% of steam condensate is recovered. = 240,930 pounds per hour.

De-aerator (DA) Tank Feedwater Sources:

- Steam condensate 240,930 pounds/hr.
- Reverse Osmosis System 4,098 pounds per hour.
- Tomato water 22,672 pounds per hour

Tomato Water Recovered from MVR Evaporator and the MPE 2ND Effect for Feedwater Purposes:

(1) 71,000 (MVR) + 15,200 (MPE) + 20,000 (MPE/MVR)
= 106,200 pounds per hour of tomato water recovered.
= 12,741 gallons per hour are assumed

delivered to DA tank.

Recovered Tomato Water Used as Feedwater:

(1) (267,700 - 240,930 - 4,098)
= 22,672 pounds per hour or
= 2,721 gallons per hour needed from tomato water to supplement feedwater demand.

Recovered Tomato Water Not Used as Feedwater:

= 12,741 gallons per hour of tomato water are assumed delivered to DA tank.

Only 2,721 gallons per hour are used to supplement feedwater demand.

= 10,020 gallons of tomato water per hour are recovered but not used as feedwater.

= 22,545,000 million gallons per season.

² Amón, R., T. Wong, D. Kazama, M. Maulhardt, Draft California Tomato Processing Facility: Steam System Assessment. California Energy Commission, 2012, CIFAR, UC Davis.

³ Minimizing the use of the RO system would reduce proportionally the loss of the RO Retentate water that is discharged. One gallon is discharged for every three gallons of water treated.

Depending on the end-use option chosen, research questions will need to be addressed to assess the viability of using recovered tomato water, among them:

- What is the highest temperature tomato water can be to be used as flume water?
- Does the use of hot tomato water provide an advantage as a first rinse with the potential to reduce use of chemicals during the second rinse⁴?
- If the tomato water is used as seal water, would it require the use of Diafiltration membrane treatment⁵ given the chemical oxygen demand (COD) content shown in Table 3⁶?
- If the waste heat from tomato water can be used to replace process steam for heating processes.

Sample Location	COD(mg/L)		
	Replicate		
	А	В	Average
N HDE Paste Discharge	50	64	57
MVR/MPE R.S. Collection Tank	99	95	97
MVR/MPE 2nd Effect	344	353	348.5
MVR/MPE 3rd Effect	139	144	141.5
MVR/MPE 4th Effect	376	384	380

 Table 3. COD Measurements from Discharged Tomato Water Samples

VI. Tomato Water Energy Nexus

Recovering tomato water provides new opportunities to integrate sustainability principles in the design and implementation of resource conservation and efficiency Industrial Best Practices. The following sections of the Case Study describe the methods used to evaluate the relationship between water and energy. Calculations determine the amount of thermal and electric energy that is embedded in water.

VII. Water Energy Intensity

The Case Study understands the Water Energy Intensity (WEi) to be the number of energy units (kWh, BTU) embedded in one gallon of water. The Pump ESA data was used to calculate all WEN Points or locations where energy is used to power process water and to estimate WEi metrics⁷.

⁴Dee Graham, interview 11 16 12. Hot tomato water rinse will remove organic materials from facility surfaces allowing second rinse chemicals to be more effective by not being diluted by the organic residues. Embedded energy in chemicals could be calculated to identify energy savings from this practice.

⁵ Dee Graham, interview 11 16 12. Diafiltration is a technique that uses ultrafiltration membranes to completely remove, replace, or lower the concentration of salts or solvents from solutions containing proteins, peptides, nucleic acids, and other biomolecules. http://www.pall.com/main/Laboratory/Literature-Library-Details.page?id=50335

⁶ Samples collected at the facility and tested at Dr. Ruihong Zhang'UC Davis Bioenergy Laboratory, 10/2012.

⁷ Amón, R., T. Wong, D. Kazama, M. Maulhardt, *Draft California Tomato Processing Facility: Pump System Assessment.* CaliforniaEnergy Commission, 2012, CIFAR, UC Davis.

The Case Study will present WEi calculations for the well water supply system and the wastewater discharge system. Researchers also collected data to account for the energy intensity of fan systems utilized in cooling towers. The side bar shows the embedded energy extracted by sand filters.

The following sections provide base-line data that is used to estimate the energy conservation potential from capturing tomato water. Every gallon of tomato water recovered is one less gallon pumped from wells, cooled in cooling towers or discharged as wastewater.

Well Water Pumping Energy Intensity

Table 4 provides data from the North and South wells to calculate the WEi of pumping ground water resources at this facility. An overall WEi of 2.1 kWh per every 1,000 gallons of water pumped was determined. Given that the North and South wells are operating at different plant efficiency (OPE) ratios the WEi of the North well is much higher.

Sand Filter Energy Intensity:

All fresh water used at the facility is treated with sand filters. Researchers calculated the loss of embedded energy during filtration at 10.25 psi for the JPX-650-V model and a loss of 10.14 psi for the JPX-1160-V sand filter.

Supply -Side Well Pump Energy Intensity	Water G/2250h	kWh	kWh/1000G	G/kWh
North Well	189,297,000.00	456,232.50	2.4101	414.91
South Well	168,000,000.00	291,240.00	1.7336	576.84
Both Wells	357,297,000.00	747,472.50	2.0920	478.01

Table 4. Water Energy Intensity of Fresh Water Supply

The Pump ESA calculates the overall WEi by using the following formulas:

(1) WEi = 747,472, (kWh) / 357,297,000 (Gal) = 0.0021 (kWh/Gal)

(2) 0.0021 (kWh/Gal) x 1,000 gals/ 1,000 gals = 2.1 kWh/1000Gal.

Wastewater Pumping Energy Intensity

Wastewater is collected throughout the facility to the In-Plant Pump Delivery system and then pumped to the Central Wastewater system. Additional wastewater is gravity-fed from the aerated flume ponds. From this location wastewater is pumped to adjacent agricultural fields. All these locations are regarded as the Wastewater WEN Point.

Table 5 shows the overall water energy intensity of the wastewater WEN Point. The WEi is calculated at 0.42 kWh for every 1,000 gallons of wastewater pumped.

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

Table 5. Wastewater System Energy Intensity

The Pump ESA calculates the overall WEi by using the following formulas:

(1) WEi = 140,155, (kWh) / 337,500,000 (Gal) = 0.00042 (kWh/Gal)

(2) 0.00042 (kWh/Gal) x 1,000 gals / 1,000 gals = 0.42 kWh/1000Gal.

The following section of this Case Study will utilize the WEi for water supply (2.1 kWh/1000Gal) and wastewater (0.42 kWh) systems to estimate the electricity savings potential from recovering tomato water.

Recovering 70 Million Gallons of Tomato Water per Season

Section IV provided calculations to estimate the technical potential to recover over 50 million gallons of tomato water. Section V also identified over 20 million gallons of tomato water that are already recovered but not used as boiler feedwater. Combining these sources provides the technical potential to recover 70 million gallons of tomato water during a 2,250 hours production season.

This Case Study assumes that the facility will recover the tomato water. The following sections illustrate the water energy nexus (WEN) relationship from achieving water conservation efforts. Electricity savings will result from reduced well water pumping, reduced fan cooling tower use, reduced in-plant wastewater pumping, and also offers the potential to recover tomato water heat energy. However, the Case Study does not provide a complete WEN relationship because it does not calculate the potential energy expenditure to recover, store and deliver recovered tomato water to new end use locations. Further research is required.

The following formulas are used to estimate electricity conservation by reducing well water pumping by 70 million gallons.

(1) 70,000,000 (gallons per season) / 1,000 Gal x 2.1 (kWh water energy intensity of pumping 1,000 gallons of well water)

= 147,000 kWh

(2) $147,000 \text{ kWh} \times 0.15/\text{kWh} = $22,050.$

The following formulas are used to estimate electricity conservation by reducing wastewater pumping by 70 million gallons.

(1) 70,000,000 (gallons per season) / 1,000 Gal x 0.41 (kWh water energy intensity of pumping 1,000 gallons of wastewater)

= 28,700 kWh

(2) $28,700 \text{ kWh} \times 0.15/\text{kWh} = $4,305$.

Combining the savings from the well water and wastewater pumping systems shows that there is technical potential to eliminate the use of 175,700 kWh of electricity while accruing \$26,355 in cash flow for the facility. Although the Case Study takes into account the potential to reduce WEi by improving the well water and the wastewater pumping system efficiencies, it does not calculate a new base line.

The Pump ESA report provides targeted recommendations to improve overall pumping plant efficiency in the North Well and at the wastewater discharge pumping station. After the repair or replacement of pumps is accomplished, new pump efficiency calculations should be conducted to establish a new WEi base line. Using the WEi metric will show the improvements accrued from lowering kWh consumption.

Tomato Water Cooling Tower Load Reduction Technical Potential

Additional electricity savings can be accrued by not delivering 70 million gallons of tomato water to the cooling towers. Currently this amount of tomato water is cooled from 160° F to 78° F by the cooling towers. At a flow rate of 31,111 gallons per hour, tomato water contributes 21 MMBTU per hour to the cooling load. Using the following formula:

(1) $Q = mc_p\Delta T$ Where: m = 31,111 gal/hr. x 8.33 lb/gal = 259,155 lb/hr $c_p = 1 \text{ Btu/lb}^{-0} \text{ F}$ $\Delta T = 160^{0-}78^{0} = 82^{0} \text{ F}$ Q = 259,155 lb/hr (m) x 1 (c_p) x 82⁰ F (ΔT) = 21,250,680 Btu/hr. To calculate the equivalent electricity savings from this cooling load we use the following formulas:

- (1) 21,250,680 (BTU/hr) / 12,000 (Btu/Ton) = 1,771 Tons.
- (2) 1,771 (Tons) x 0.06 (Cooling Tower Heat Rejection Efficiency) = 105 kW
- (3) 105 (kW) x 2,250 (season hours) = 236,800 kWh.
- (4) 236,800 x 0.15 (\$/kWh) = \$35,520

There is the technical potential to reduce electricity use by 236,800 kWh and save \$35,520 annually by not delivering tomato water to the cooling towers. In addition to the electricity savings, there is also the technical potential to recover thermal energy by capturing excess heat from tomato water. Using the following formula:

- (1) 160° F (tomato water incoming temperature) 90° F (tomato water outgoing temperature) = 70° F (potential heat energy recovered, Δ T)
- (2) 70° F x 31,111 gal/hr (flow rate) x 8.33 lb/gl = 18,140,824 BTU/hr
- (3) 18,140,824 (BTU/hr) x 2,250 (season hours) = 40,816,854,225 BTU/season
- (4) 40,816,854,225 (BTU/season)

Assuming that 70[°] F from each of the 70 million gallons of tomato water can be extracted by the heat exchangers, there is a technical potential to recover over 40,817 MMBtu of energy. This energy can be assumed to replace natural gas fuel used to produce steam and heat. Carbon credits⁸ can be accumulated under the California Air Resources Board Cap and Trade program, mandated by AB 32 (Statutes of 2006)⁹; further enhancing the facility's potential to achieve resource sustainability goals.

To calculate the amount of money that could be saved from the recovered heat depends on the final use. If the facility can utilize the recovered energy to displace steam there is a technical potential to save \$235,298, by using the following formula:

- (1) 40,817 MMBtu / 0.85 (% boiler efficiency¹⁰) = 48,020 MMBtu (natural gas equivalent)
- (2) 48,020 MMBtu x 4.90 (\$/MMBtu) = \$235,298

VIII. Benefits from Recovered Tomato Water

There is the technical potential to recover 70 million gallons of tomato water at this facility; with the potential to reduce electricity consumption by 442,600 kWh and generate over 40,000 MMBtu of energy. Table 7 also shows that the theoretical recovery of heat from tomato water to

offset steam production can save \$235,289 in Natural Gas costs. Adding electricity savings from pumps and cooling tower load adds \$66,390 to annual cash flow.

⁸ EPA Carbon Content Coefficient 14.47 kg C/ MMBtu, <u>http://www.epa.gov/cpd/pdf/brochure.pdf</u>

⁹ CARB, <u>http://www.arb.ca.gov/cc/capandtrade/guidance/chapter2.pdf</u>

¹⁰ Amón, R., T. Wong, D. Kazama, M. Maulhardt, Draft California Tomato Processing Facility: Steam System Assessment. California Energy Commission, 2012, CIFAR.

Avoided Energy	kWh Savings	\$ Savings
Well Water	176,400	22,050
Wastewater	29,400	4,305
Cooling Towers	236,800	35,520
Total	442,600	61,875
Recovered Energy	MMBtu	\$4.90 MMBtu
Tomato Water Heat	40,817	235,298

Direct energy savings are generated from reduced pumping and reduced cooling tower fan use. Thermal energy is captured from excess heat. Indirect energy savings occur from the avoidance of "parasitic" losses that occur when water is filtered, pumped to a holding tank, or when passing through a valve.

Summary

Although the Case Study does not calculate the cost to recover and use tomato water, it shows significant cost savings potential to motivate company management to further evaluate the opportunity to achieve water and energy conservation. The Case Study recommends improving overall pumping plant efficiency and recalculating potential electric benefits. The electric power savings from the cooling towers will remain the same, as well as the amount of heat recovered from tomato water.

Additional sustainability benefits result from the preservation of ground water resources, the reduction in wastewater organic loads discharged on land, and the commensurate air pollution reduction benefits. This facility has the opportunity to reduce the Water Energy intensity (WEi) of processing tomatoes. The facility should be rewarded for adopting these Industrial Best Practices.

Similar tomato processing facility managers are encouraged to utilize Industrial BPs to conduct energy and water system assessments; to measure current performance conditions and establish resource use metrics. This is particularly true for companies that are committed to adopting long-term sustainability principles.

Other companies may be required to adopt Industrial BPs to further reduce green house gas (GHG) pollution emissions. Particularly at California-based food companies that produce 25,000 or more metric tons of carbon dioxide per year. These companies are required to participate in the California Air Resources Board Cap and Trade program¹¹ mandated by AB 32 (Statutes of 2006). Investing physical capital to comply with climate change regulations is a new cost of production that didn't previously exist. Companies will need to evaluate the cost of adopting resource efficiency measures by accounting for environmental and social factors.

¹¹CARB, <u>http://www.arb.ca.gov/cc/capandtrade/guidance/chapter2.pdf</u>