Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Water Systems
Virtual INPLT Training & Assessment

Session 3
Tuesday – June 4th, 2024
10 am – 12:30 pm

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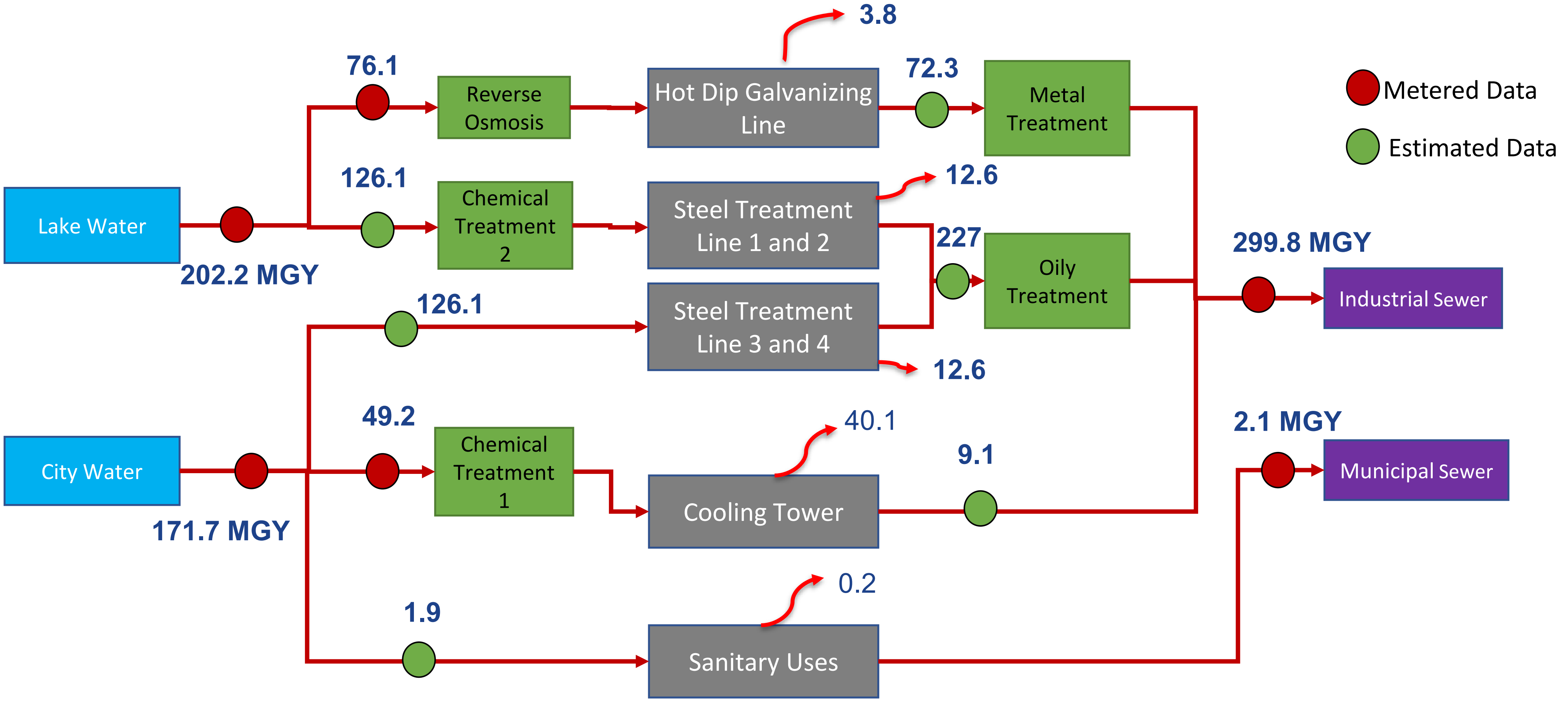
Water Virtual Training Agenda

- **Week 1 (June 16th) – Introduction to Industrial Water Assessment**
- **Week 2 (June 23rd) – Understanding System Level Water use**
- **Week 3 (June 30th) – True Cost of Water**
- **Week 4 (July 7th) – Plant Water Profiler Working Session**
- **Week 5 (July 14th) – Identifying Water Savings Opportunity**
- **Week 6 (July 21th) – Virtual Water Treasure Hunt**
- **Week 7 (July 28th) – Estimating Water Savings Opportunities**
- **Week 8 (Aug 4th) – Industrial Water System VINPLT Wrap-up Presentations**

Review – Day 1 and 2

- Water Risks
- Industrial Water Assessment
  - Step 1 - Water Baselining
  - Step 2 - True Cost of Water
  - Step 3 - Identifying water savings opportunities
- Water Baselining
  - Plant Water Flow diagram
  - Data Collection (system level and facility level)

Example Facility – Water Baseline



Agenda – Session THREE

- Today's Content:
  - Typical True Cost Components
  - Water Quality and Treatment
  - Data to collect
  - True cost exercise
- Roundtable - review of assignment
- Kahoot Quiz Game
- Q&A

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Day 3 – True Cost of Water

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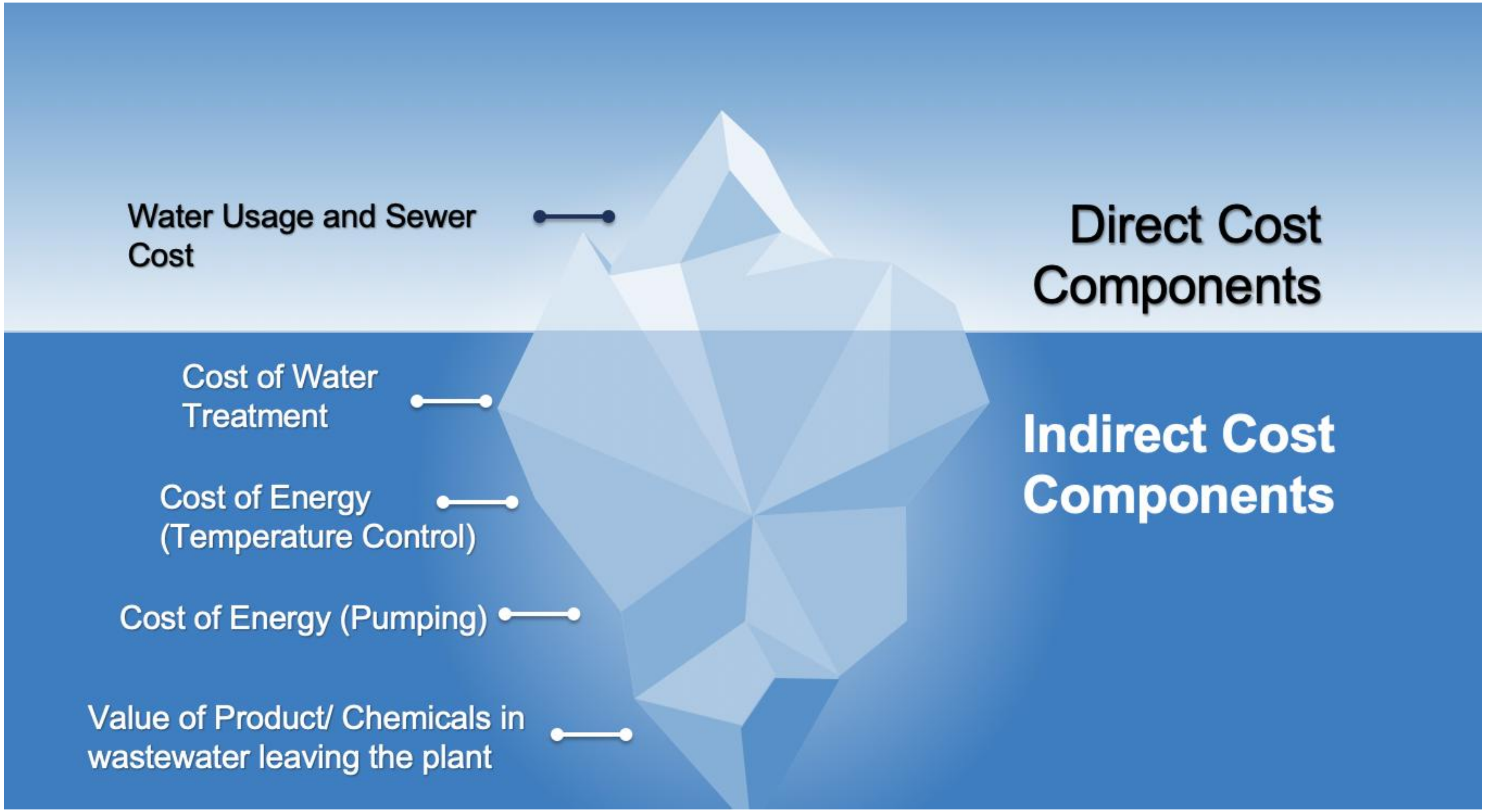
What is true cost of water?

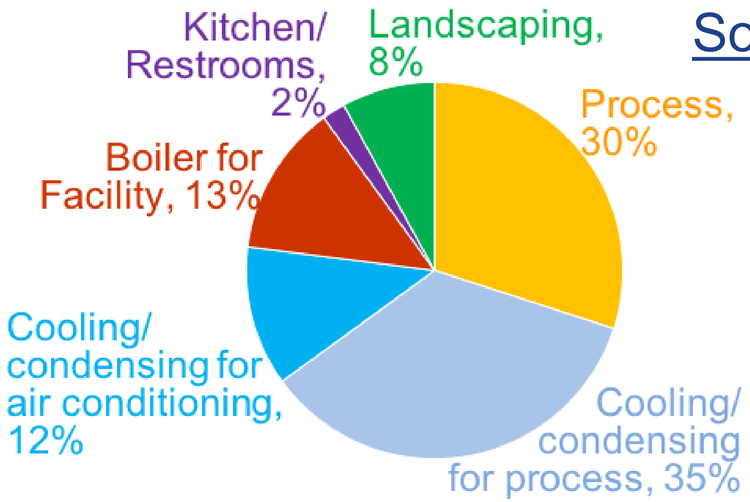


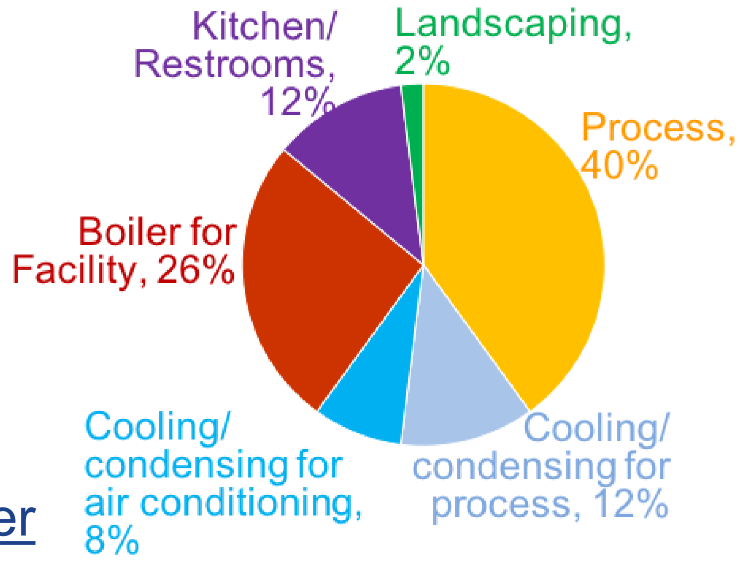
Why true cost of water?

Significance to the facility

- Reveals hidden costs of using water
- Identifies water use-intensive versus cost-intensive systems to help prioritize measures
- Helps estimate the actual cost savings from water efficiency projects, thereby prioritize and justify them

Source water intake



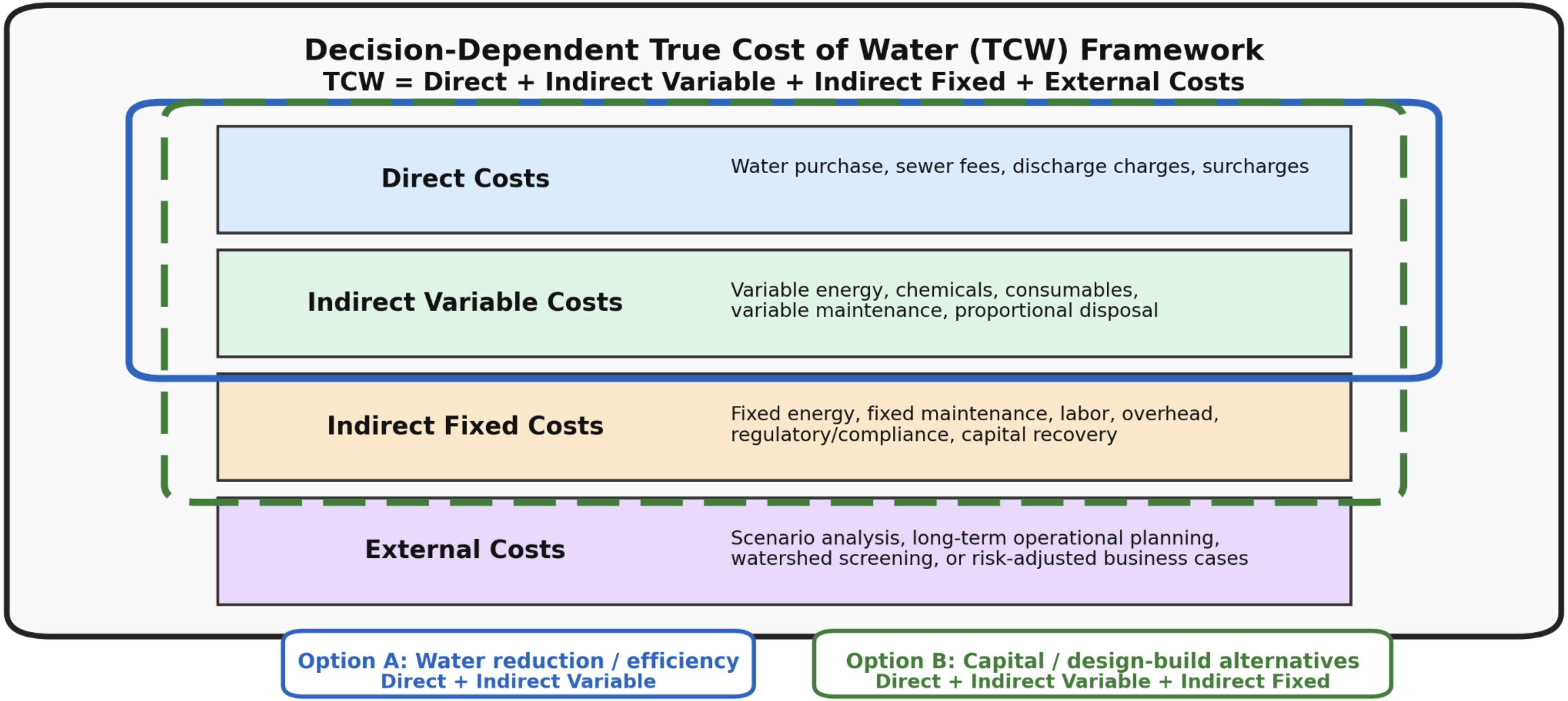


True cost of water

Typical True Cost Components

1. Direct costs (Municipal water intake and Wastewater disposal)
2. Cost of pumping (and other motor energy)
3. Cost of water and wastewater treatment
4. Cost of heat energy in wastewater

Items 2–4: Indirect Variable Cost and Indirect Fixed Cost


Decision-Dependent True Cost of Water (TCW) Framework
TCW = Direct + Indirect Variable + Indirect Fixed + External Costs
Direct Costs
Water purchase, sewer fees, discharge charges, surcharges
Indirect Variable Costs
Variable energy, chemicals, consumables, variable maintenance, proportional disposal
Indirect Fixed Costs
Fixed energy, fixed maintenance, labor, overhead, regulatory/compliance, capital recovery
External Costs
Scenario analysis, long-term operational planning, watershed screening, or risk-adjusted business cases
Option A: Water reduction / efficiency
Direct + Indirect Variable
Option B: Capital / design-build alternatives
Direct + Indirect Variable + Indirect Fixed

Indirect variable costs

Cost element	Definition	Examples	Typical allocation basis
Variable energy costs	Energy costs that change with water volume, flow rate, runtime, temperature requirement, or treatment intensity.	Pumping electricity, boiler fuel for water heating, chiller/cooling energy tied to water use, energy for reverse osmosis/filtration, variable wastewater treatment energy.	kWh or fuel per gallon, pump horsepower/runtime, heating/cooling load, treatment equipment runtime.
Chemicals and consumables	Costs that scale with water treatment, wastewater treatment, water quality, or operating load.	Coagulants, flocculants, pH adjustment chemicals, corrosion inhibitors, biocides, antiscalants, softening salts, filters, membranes, ion-exchange resin, activated carbon.	Chemical dose per gallon, dose per contaminant load, replacement frequency, process records, or treatment runtime.
Variable treatment and disposal	Costs that scale with water volume, wastewater volume, contaminant concentration, or off-site disposal quantity.	Flow-based wastewater treatment, sludge handling proportional to load, hauled wastewater, spent bath disposal, hazardous wastewater disposal, off-site treatment.	Wastewater volume, sludge generation, contaminant load, hauled volume, disposal manifests, or vendor invoices.
Variable maintenance	Maintenance costs that increase or decrease with equipment runtime, water throughput, fouling, scaling, solids loading, or wastewater load.	Membrane/filter cleaning, pump or seal replacement driven by runtime, tank cleanouts driven by loading, cooling tower maintenance tied to cycles/blowdown, wastewater treatment maintenance tied to load.	Runtime, flow volume, contaminant load, work orders, maintenance frequency, or vendor service records.

Fixed energy costs	**Energy costs that persist within normal operating ranges and do not vary directly with short-term or marginal changes in water use.**	**Base-load energy for continuously operating pumps, recirculation systems, treatment skids, controls, standby equipment, minimum cooling/chiller loop operation, base wastewater aeration.**	**Equipment responsibility, operating schedule, base-load estimate, system ownership, or allocation across served processes.**
Fixed maintenance	Maintenance costs required to keep water-related systems operational regardless of short-term changes in water volume.	Preventive maintenance, inspections, calibration, service retainers, annual maintenance contracts, baseline cooling tower maintenance, boiler water system maintenance, wastewater system upkeep.	System responsibility, maintenance records, annual operation & maintenance budgets, equipment ownership, or process responsibility.
Labor and overhead	Labor, supervision, and overhead required to operate, monitor, maintain, and manage water and wastewater systems.	Operator labor, maintenance staff time, utility management, EHS support, engineering support, data management, internal reporting, overhead allocation.	Labor hours, operator logs, staff estimates, system responsibility, number of supported processes, or facility overhead allocation rules.
Regulatory and compliance costs	Costs required to meet monitoring, reporting, permitting, and compliance obligations; folded into indirect fixed costs because they generally support ongoing authorization to operate and discharge.	Sampling and analysis, permit management, discharge monitoring reports, compliance audits, environmental staff time, laboratory fees, regulatory reporting, permit renewals, noncompliance risk management.	Permit requirements, sampling frequency, regulated streams, discharge points, compliance program cost, or process responsibility.
Capital recovery and depreciation	Annualized cost of existing or proposed water-related capital assets when evaluating long-term alternatives.	Treatment systems, RO/DI systems, cooling towers, wastewater treatment upgrades, reuse piping, tanks, pumps, controls, monitoring systems, pretreatment systems, closed-loop reuse infrastructure.	Annualized capital cost, depreciation schedule, capital recovery factor, asset utilization, system responsibility, or process served.

Indirect fixed costs	**Fixed energy costs**	**Energy costs that persist within normal operating ranges and do not vary directly with short-term or marginal changes in water use.**	**Base-load energy for continuously operating pumps, recirculation systems, treatment skids, controls, standby equipment, minimum cooling/chiller loop operation, base wastewater aeration.**	**Equipment responsibility, operating schedule, base-load estimate, system ownership, or allocation across served processes.**	**Include for capital improvement, design/build alternatives, lifecycle comparison, or full system burden analysis. Usually exclude from marginal water-efficiency screening.**
External costs	Expanded valuation costs	Broader costs or risks linked to water use, discharge, watershed context, municipal system impacts, and business continuity.	Water scarcity disruption risk, production interruption risk, reputational impacts, receiving-water impacts, municipal wastewater capacity impacts, watershed stress, community impacts, environmental externalities	Scenario analysis, risk scoring, avoided downtime, watershed risk indicators, municipal impact estimates, avoided production loss, or monetized externalities where defensible.	Include only when the analysis boundary explicitly includes long-term reliability planning, municipal impact, watershed risk, societal cost, or strategic value.

Direct Costs (Municipal Water Intake and Wastewater Disposal)

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Direct Costs

1. Municipal water intake
   - Potable
   - Non-potable
2. Wastewater disposal
   - Domestic sewer
   - Industrial sewer
   - Stormwater sewer
3. Third-party wastewater disposal services
   - Transportation, treatment and disposal.

Municipal Water and Wastewater Cost : Utility Bills

The municipal water intake and sewer can be separate or combined bills

Typically, includes two components:

1. Usage charge: based on the amount of water use and wastewater discharge
   - **Typically, different rates for residential and commercial/industrial customers**

2. Fixed charge
   - **Meter Fees -** capacity charge based on the meter size
     - Industrial: 2”, 3”, 4”, 6”, 8”, 10”, 12”, 16”
   - **Storm Drain Fees -** standard fixed cost or based on the area of impervious ground surface
   - **Fire Line Fees -** for customers with private fire protection lines

*Industrial sewer rate structure can have additional components that are discussed later

Municipal Water and Wastewater Rate Structure: Example

Customer Charge (by Water MeterSize)	Water Service Charge	Wastewater Service Charge
2"	$70.80	$113.00
3"	$141.60	$229.00
4"	$221.25	$362.00
6"	$442.50	$720.00
8"	$708.00	$1,160.00

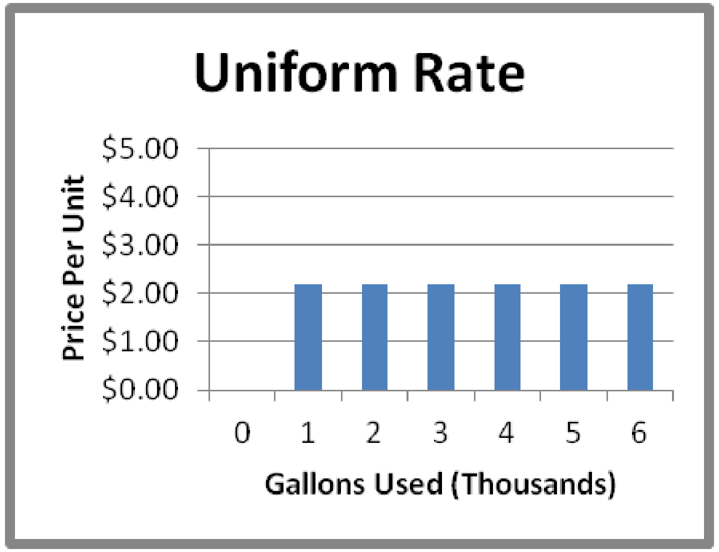
Industrial

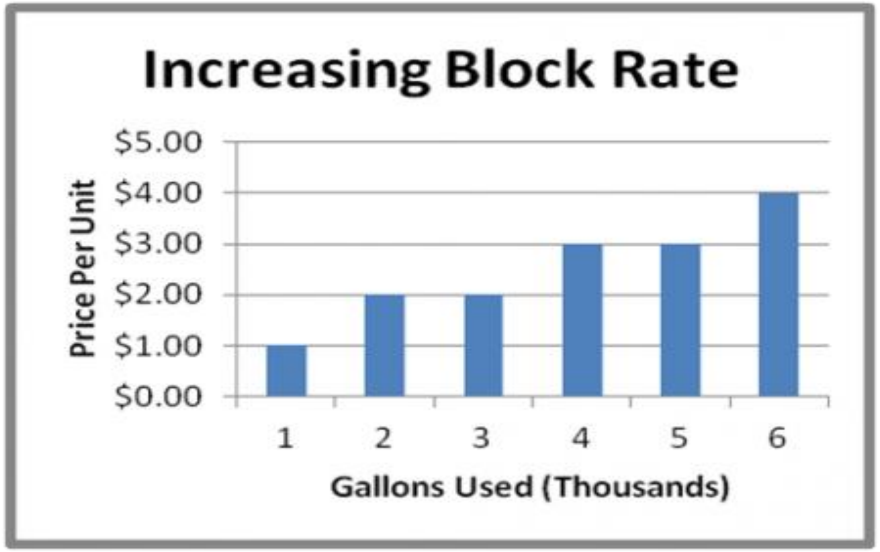
Consumption Charge	Water (in dollars)	Wastewater (in dollars)	Water & Wastewater (dollar total)
(per 100cubic feet of metered water)	$2.60	$2.38	$4.98

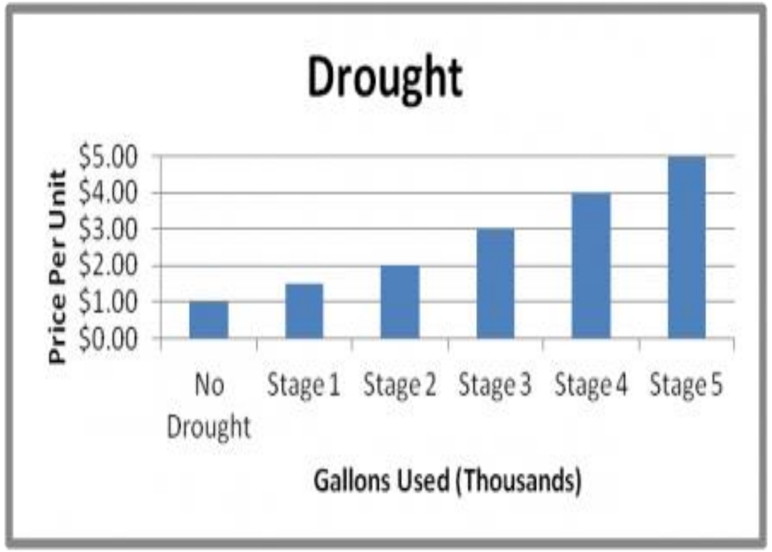
Note: Here wastewater is not metered separately; wastewater charges are based on the water usage

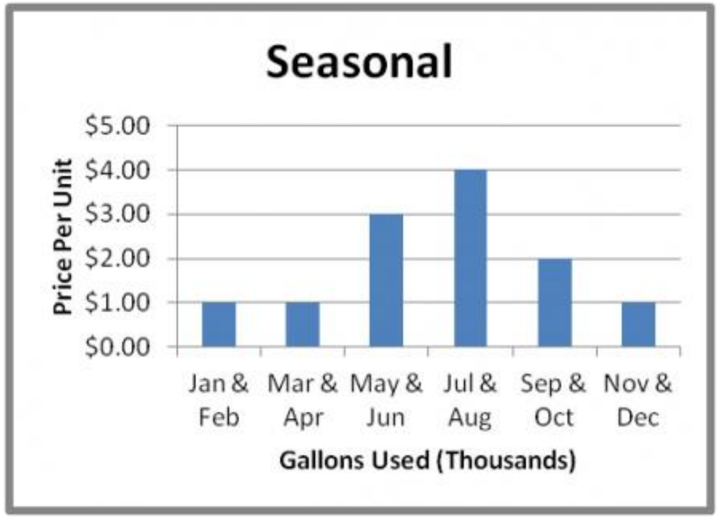
https://danvilleutilities.com/water/water-rates/industrial-water-rates.html

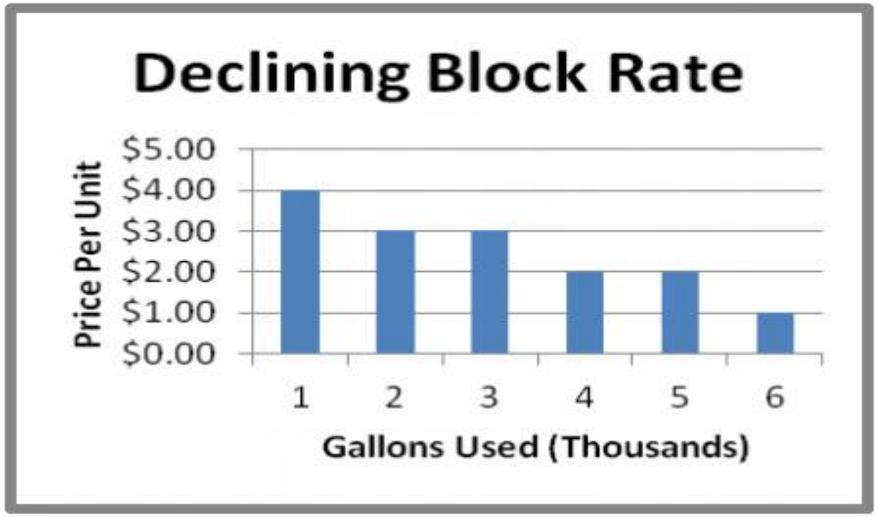
Municipal Water Rates: Usage Rate Types

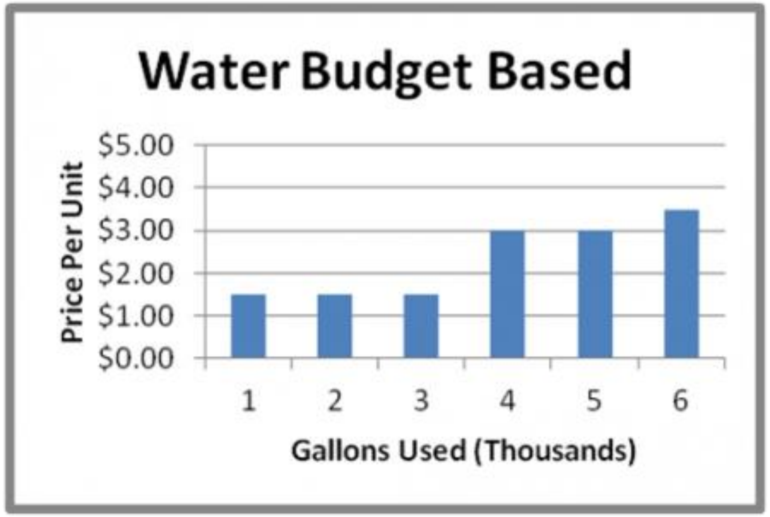












Industrial Sewer – Rate Structure

Industries with Metered Water Supplies

- Estimated wastewater (= water demand times % of water collected/ treated)
- Collection and treatment cost in $/million gallon

Industries with Unmetered Water Supplies

A **flat monthly sewer rate** based upon

- Type of industrial process
- Annualized cost of sewerage facilities in $/million gallon, derived from
  - Capital cost
  - Annual operation and maintenance cost

Surcharging based on wastewater constituent

Contaminant	Surcharge Rate
Flow	$6.50 per 1,000 gal.
BOD	$0.42 per pound
Suspended Solids	$0.50 per pound
Total Nitrogen	$1.37 per pound
Fats, Oils and Grease (FOG)	$0.50 per pound
Silver	Non-Compatible
Zinc	Non-Compatible
Phthalates	Non-Compatible
Phosphorous	$6.87 per pound

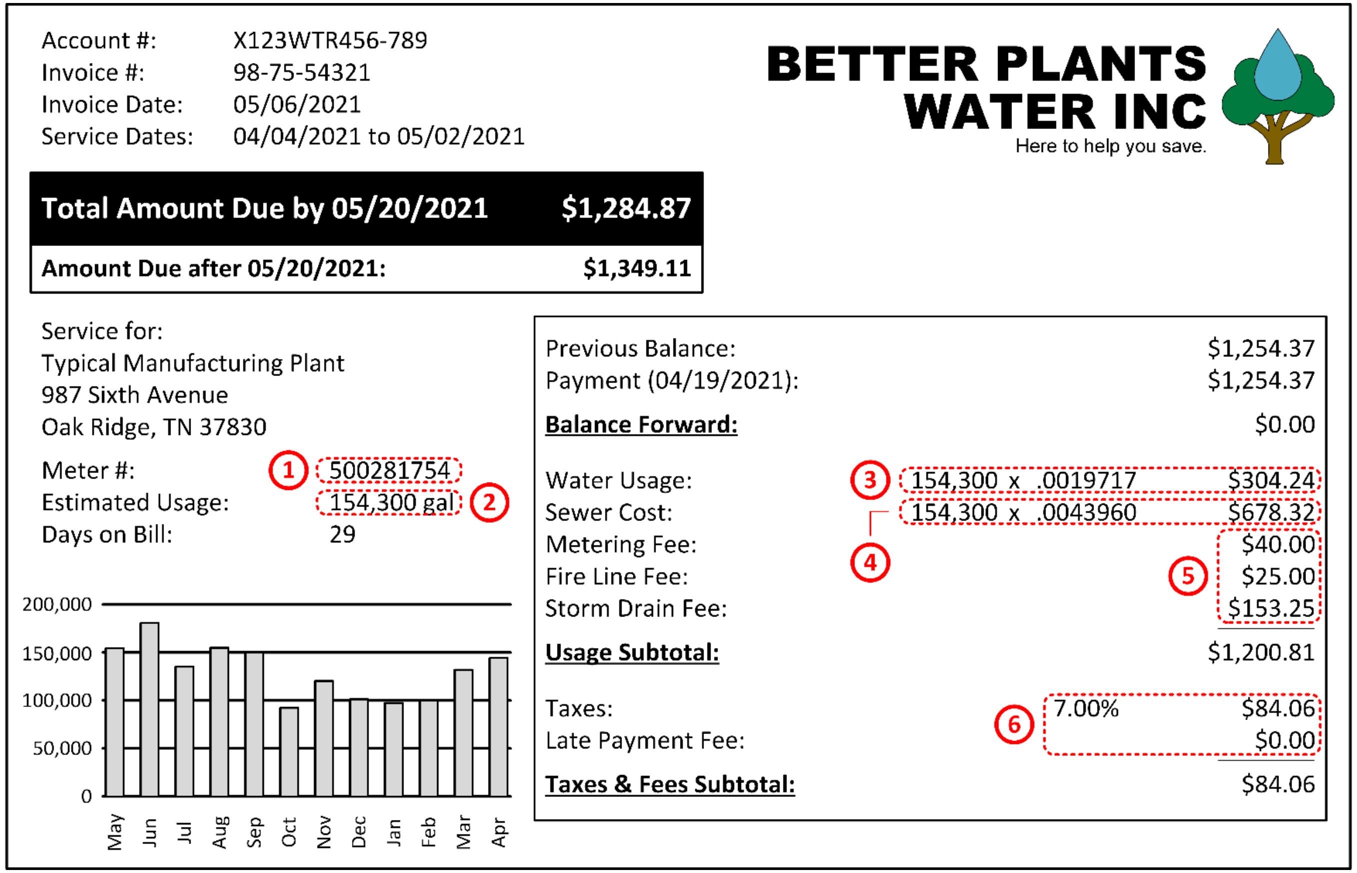
https://www.codepublishing.com/CA/Holtville/html/Holtville13/Holtville1316.html

https://www.aub.org/for-my-business/commercial-customer-service/commercialindustrial-rate-information/commercialindustrial-wastewater-rates

Utility Bill Example

Example utility bill with key information highlighted,
(1) Meter number,
(2) Meter reading,
(3) Usage charge,
(4) Sewer Charge,
(5) Fixed charge Miscellaneous Fees,
(6) Taxes and Late Fee

Note: the water usage and sewer cost are different given different rate structures



Account #:	X123WTR456-789
Invoice #:	98-75-54321
Invoice Date:	05/06/2021
Service Dates:	04/04/2021 to 05/02/2021

BETTER PLANTS WATER INC
Here to help you save.

Total Amount Due by 05/20/2021	**$1,284.87**
Amount Due after 05/20/2021:	**$1,349.11**

Service for:
Typical Manufacturing Plant
987 Sixth Avenue
Oak Ridge, TN 37830

Meter #:	(1)	500281754
Estimated Usage:	(2)	154,300 gal
Days on Bill:		29

Previous Balance:			$1,254.37
Payment (04/19/2021):			$1,254.37
Balance Forward:			$0.00
Water Usage:	(3)	154,300 x .0019717	$304.24
Sewer Cost:	(4)	154,300 x .0043960	$678.32
Metering Fee:	(5)		$40.00
Fire Line Fee:	(5)		$25.00
Storm Drain Fee:	(5)		$153.25
Usage Subtotal:			$1,200.81
Taxes:	(6)	7.00%	$84.06
Late Payment Fee:	(6)		$0.00
Taxes & Fees Subtotal:			$84.06

Municipal Water and Wastewater Rates: Multiple Rates

If multiple water meters are in the facility, water rates may be different depending on

- Utility provider
- Meter size
- Usage
- Quality of supplied water
  - Potable water
  - Non-potable water
  - Reclaimed or recycled water

Within a facility, wastewater rates and rate structure may be different for

- sanitary sewer,
- stormwater sewer,
- industrial sewer

*City may require **stormwater be discharged to an industrial sewer** if possibility to pick up industrial pollutants.*

It is important to consider the water intakes/discharges separately in the water baseline if they cost significantly different

http://www.cvwd.org/385/Nonpotable-Water-Rates

Third-party Wastewater Disposal

Typically seen in facilities that produce specialized contaminates that cannot be sent to local municipal

Examples:

- Water with hazardous materials
- Battery wash water,
- Tank cleaning wastewater,
- Specialized industrial process wastewater

The direct cost component will include the **treatment cost** as well as the **cost to transport** the wastewater to the receiving/processing facility

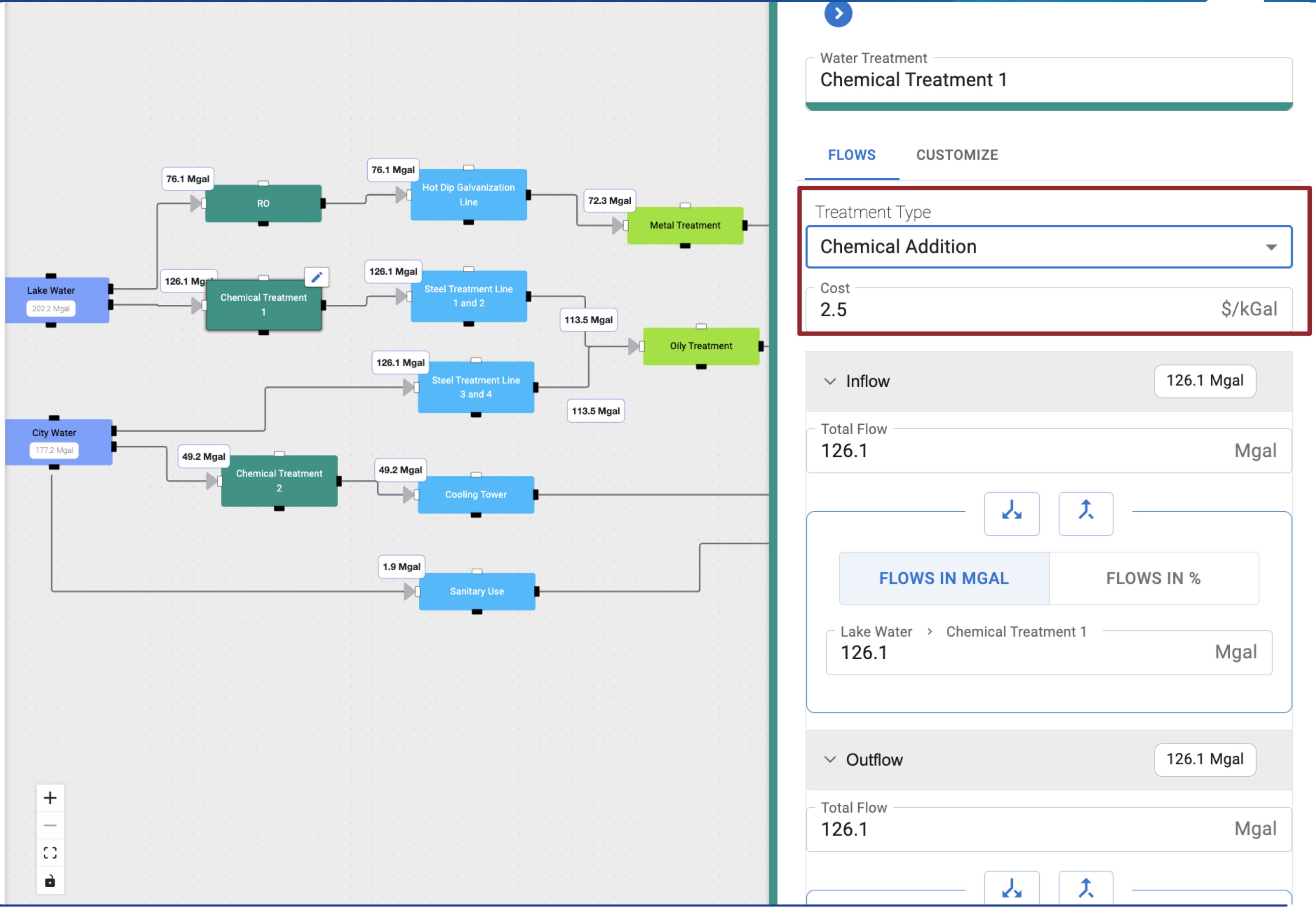
A holding tank stores wastewater from various sources until it is pumped out and hauled to a receiving/processing facility.

https://www.wrijax.com/Services/Transportation-Services/
https://www.iec-nj.com/wastewater-hauling/

MEASUR Tool and Utility Cost

MEASUR uses a blended cost to calculate results - only the annual average cost of utility is needed per kgal for water.

While, the seasonal variations and other nuances of cost structure is not considered in MEASUR, knowing how the facility is billed is still important to know.



Polling Question 1

What is the blended usage cost for intake water?

1.) $5.3 per kgal
2.) $6.8 per kgal
3.) $14.6 per kgal
4.) $4.1 per kgal

Water Supply Services
Your water, our priority.

Billing Summary

Billing Date:	9/04/2020	Amount Due:	$7,688.26
Due Date:	9/18/2020	After Due Date:	$8,072.67

Account Information

Account Number:	AB123W987-654
Invoice Number:	29-08-789321
Customer Name:	Fine Factories Inc.
Service Address:	123 Four Street Huntington, WV 25701
Current Meter Reading:	648,844
Previous Meter Reading:	124,544
Usage:	524,300 gal
Meter Read Date:	8/31/2020
Days on Bill:	31

Questions or comments? We're available 24/7 at:
betterbuildingssolutioncenter.energy.gov/better-plants/program-information

Account Summary

Previous Amount:		$7,153.58
Payment 08/12/2020:		-$7,153.58
Balance Forward:		$0.00
Meter Fee:		$760.76
Fire Line Fee:		$37.25
Storm Drain Fee:		$57.32
Usage Cost:	524,300 gal	$3,582.64
Sewer Cost:	524,300 gal	$2,815.11
Sales Tax (6.00%):		$435.18
Current Charges:		$7,688.26
Amount Due:		**$7,688.26**

Indirect Cost
(Pumping, water and wastewater treatment, heat energy)

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Pumps – Motor driven Systems

- Source water intake:
  - Pumping Groundwater
  - Pumping Surface water
- Process
  - Booster Pressure pump
  - Recirculation pumps
- Cooling and condensing system
  - Make-up water pumps
  - Water recirculation pumps
  - Cooling Tower Fans
- Boiler/Steam system
  - Make-up water pumps
  - Boiler Feedwater pumps
  - Condensate Return pumps
  - Other auxiliary services

Outside of these stand-alone motors, there is energy considered as part of water treatment as well

Pumps and Fans: Cooling Tower

- Cooling tower recirculation pumps
- Cooling Tower fan
- Make-up water pumps

Pumps and Fans: Boiler/Steam Systems

- Boiler Feedwater pumps
- Condensate Return pumps
- Make-up water pumps
- Auxiliary fans

Costs for pumping and motor energy

Total Energy Use(kwh/year) = $kW_{full\ load}$ * Load Factor * Hours of Operation per Year

1. Motor nameplate data

   Calculation using rated horsepower

   - *$kW_{full\ load}$ = 0.746 * Horsepower / Efficiency*

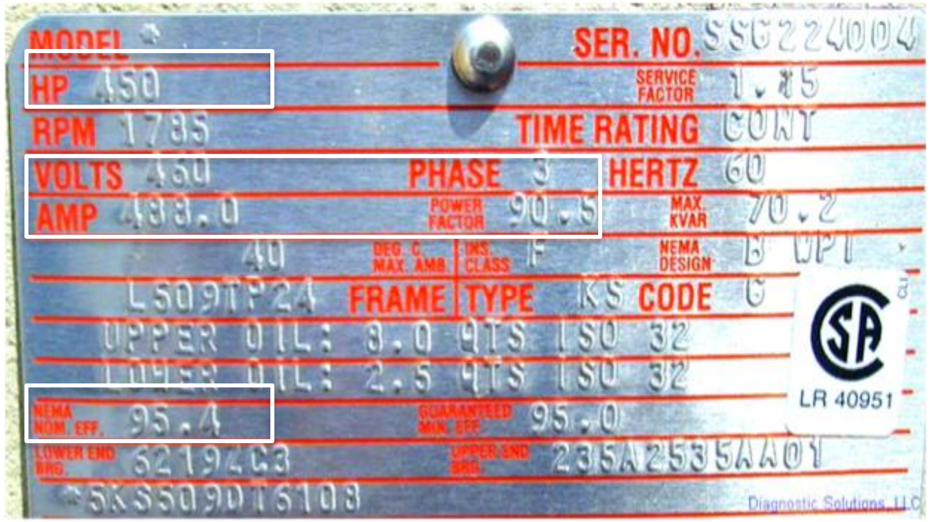
   Calculation using rated full load amps

   If single-phase motor

   - *kW = Volts x Amps x Power Factor / 1000*

   If 3-phase motor

   - *kW = Volts x Amps x Power Factor x √3 / 1000*



2. Operational details
   - Hours of Operation per Year
   - Load Factor (i.e., average load/peak load)

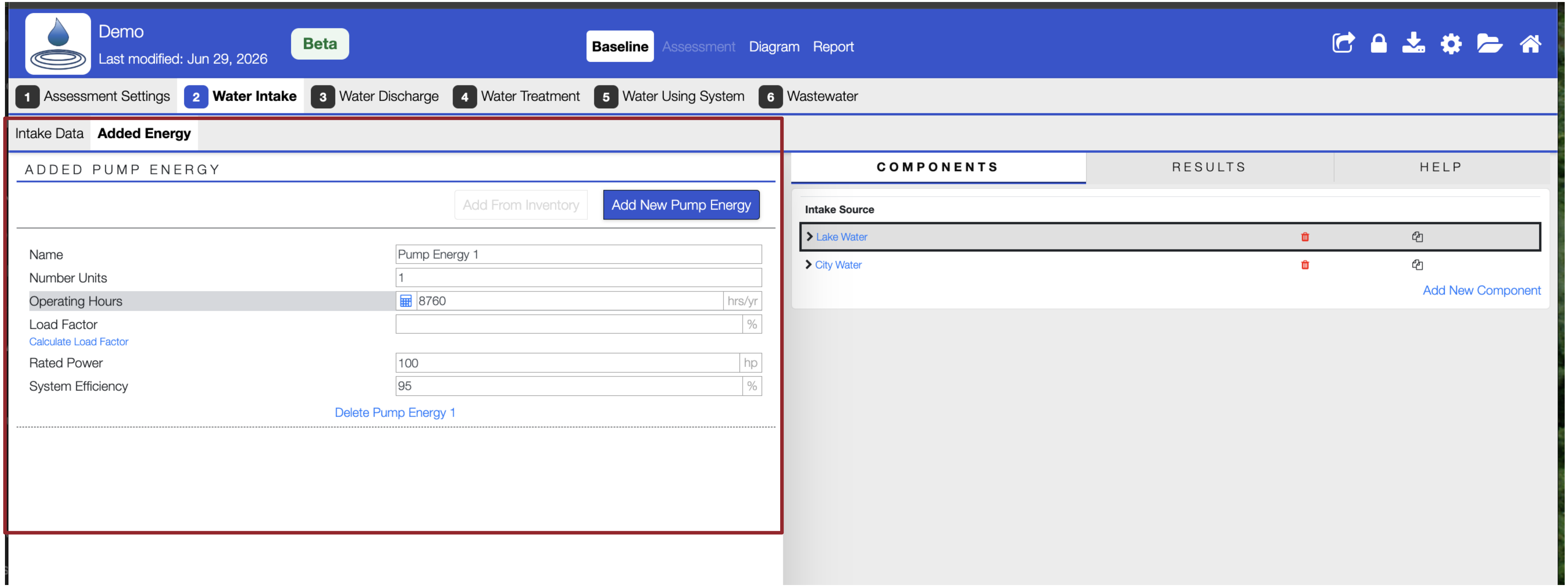
Digital Multimeters

- Multimeters can be used to get the instantaneous current, energy and power
- Limited logging capability and used primarily for spot measurements
- Load factor can be estimated accurately

Run time Loggers

- Used to collect the run time of a motor system over a period
- Simple to setup and use and provides the operating hours of a system

Pumps and Motor Energy in Measur Tool



Select the system the electric energy applies to and enter power, load factor and hours of operation to calculate energy

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A small fraction of the motor population is responsible for most of the energy consumption

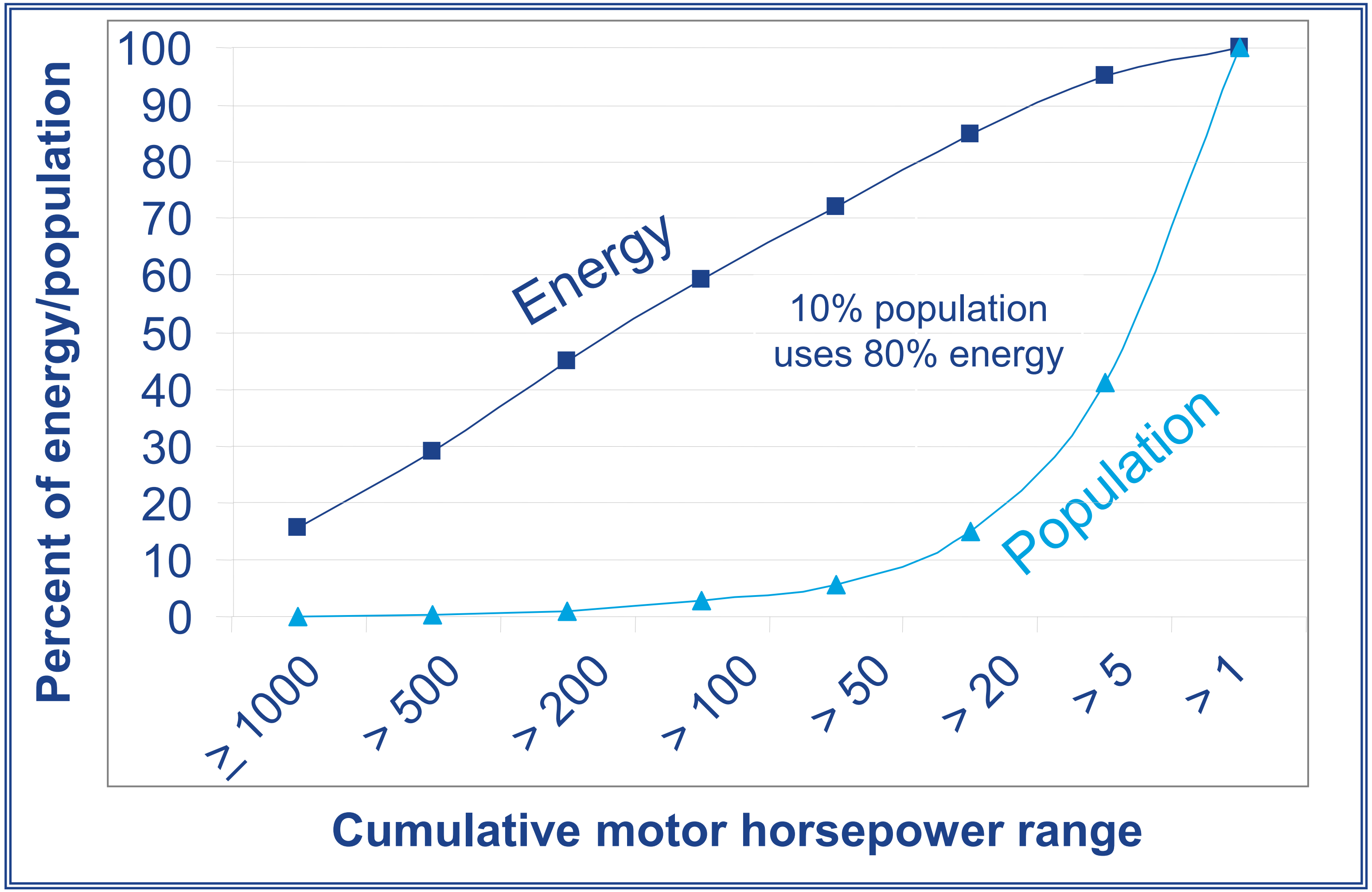
Focus on the relatively big stuff that runs a lot.

These are typically
- Intake pump station
- Cooling tower recirculation systems
- Plant wide circulation pumps

Facilities inventory can be used if kept updated

System drawing might not have the most updated and accurate information

Secondary pumps can be ignored



Note the descending order (left to right)

Water and Wastewater Treatment

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Purpose of Water Treatment

Process Requirements: Certain industries require highly purified water for their processes

Regulatory Compliance: Many industries must treat wastewater to meet local environmental regulations before discharging it into public sewers or natural bodies of water.

Recycling and Reuse: Treating water efficiently allows for recycling within the plant, which reduces the total intake of fresh water and lowers operational costs.

Water and Wastewater Treatment

- Water Treatment: Treatment done to intake water prior to use in facility
  - Treatment method is driven by **process needs** and **quality of makeup water**
  - Surface water intakes can be of varying hardness and contain dissolved solids not appropriate for use
  - Typically done by chemicals and/or membrane filtrations systems

- Wastewater Treatment: Treatment done after being used in facility operations
  - Treatment method is driven by **process contaminates** and **discharge requirements.**
  - The water can pick up various contaminates (depending on the product) which need to be removed before discharge or being recycles for other operation.
  - Can be multiple different treatment steps in succession

Characteristics Water Quality

Hardness

- **Source of hardness:** Calcium and magnesium ions
- **Impact**: Hard water can form scale on equipment and pipes
- **Treatment:** Ion exchange (water softeners), lime softening, scale inhibitors like phosphonates

Conductivity

- **Source of conductivity:** Dissolved ions and salts
- **Impact**: Increases corrosion and can degrade water quality for process and effectiveness of demineralization processes like reverse osmosis or deionization.
- **Treatment**: Reverse osmosis, deionization, corrosion inhibitors

pH

- **Source of pH:** Acids and bases
- **Impact:** pH levels outside the neutral range can be corrosive, affect the solubility of metal ions, and impact other treatment processes.
- **Treatment:** Chemical neutralization using acids (like hydrochloric or sulfuric acid) or bases (like sodium hydroxide)

Other Water Quality Characterization

Parameter	Contributing Contaminant	Impact	Unit of Measurement	Treatment Technology
Hardness	Calcium, magnesium ions	Scale formation on equipment and pipes	mg/L as CaCO3	Ion exchange, lime softening, scale inhibitors (e.g., phosphonates)
Conductivity (TDS)	Dissolved ions	Enhances corrosivity, affects processes	µS/cm	Reverse osmosis, deionization, corrosion inhibitors
pH	Acids, bases	Can lead to corrosion or scaling	pH scale	Acid/base neutralization, corrosion inhibitors
Specific Ions (Chloride, Sulfate, Fluoride)	Natural sources, industrial discharges, water treatment chemicals	Corrosion, toxicity, taste issues	mg/L	Reverse osmosis, ion exchange, activated alumina, corrosion inhibitors
Heavy Metals	Industrial discharges, mining runoff	Toxicity, bioaccumulation	mg/L or µg/L	Chemical precipitation (ferric chlorides), ion exchange, Adsorption (activated carbon)
Total Suspended Solids (TSS)	Soil, organic matter, oil and grease	Clogs filters, harms aquatic life	mg/L	Filtration, sedimentation, chemical flocculation

Other Water Quality Characterization

Parameter	Contributing Contaminant	Impact	Unit of Measurement	Treatment Technology
Turbidity	Suspended solids, soil, organic matter, oil and grease	Blocks light, carries pollutants	NTU	Filtration, sedimentation, flocculation
Biochemical Oxygen Demand (BOD)	Organic matter, food waste, oil and grease	Indicates potential oxygen depletion	mg/L	Activated sludge, trickling filters
Chemical Oxygen Demand (COD)	Organic and inorganic pollutants, oil and grease	High pollution levels, treatment challenges	mg/L	Chemical oxidation, biological processes
Nutrients (Nitrogen, Phosphorus)	Agricultural runoff, wastewater, fertilizers	Causes eutrophication and algal blooms	mg/L	Biological nutrient removal, chemical precipitation
Toxic Organic Compounds	Pesticides, solvents, industrial chemicals	Hazardous to health and environment	mg/L or µg/L	Advanced oxidation, activated carbon, bioremediation

Water Treatment: for Cooling Tower

Make-up to boilers and cooling tower is treated to ensure efficiency, maximize equipment life, reduce maintenance costs and maintain levels of operational performance.

Cooling tower contaminants can include chlorides, hardness, iron, biological materials, silica, sulfates, TDS, and or TSS.

Treatment Requirement

- Scale Inhibition
- Corrosion Inhibition
- Antifouling with Biocides and Algaecides
- pH adjustment
- Antifoaming
- Prevent agglomeration of solids and disperse organic debris

In addition to chemical treatment, water softeners (ion exchange) can be used to reduce hardness of cooling tower water.

https://www.r2j.com/cooling-tower-water-treatment-chemicals/

Water Treatment: for Cooling Tower

Scale Inhibitors:
•**Examples**: Phosphonates, polyphosphates, and polymaleic acid.
•**Purpose**: These chemicals prevent the precipitation of mineral salts that can lead to scale formation. They function by interfering with the crystal formation process, keeping minerals dissolved in the water.

Corrosion Inhibitors:
•**Examples**: Zinc, phosphates, molybdates etc.
•**Purpose**: Corrosion inhibitors form a protective film on the surface of metals to protect against the corrosive effects of oxygen, chlorides, and other corrosive agents in the water.

Biocides and Algaecides
Examples. Such as chlorine, bromine, chlorine dioxide, copper sulfate etc.
Purpose: Biocides control microbial growth, including bacteria, algae, and fungi, which can cause biofouling and lead to reduced heat transfer efficiency and increased corrosion rates.

Emerging and Alternative Water Treatment for Cooling Tower

Electrolysis based water treatment

Electrolysis based water treatment

Photo by Gregg Tomberlin, NREL

https://betterbuildingssolutioncenter.energy.gov/

Water Treatment: for Boiler/Steam System

Boiler makeup feeds can include dissolved, suspended solids and inorganic matter such as iron, copper, calcium, magnesium, aluminum and dissolved gases.

Level of treatment depends on the boiler operation pressure. Common methods and technologies used to treat boiler feedwater include

Treatment Requirement

- Scale Inhibition
- Corrosion Inhibition
- Remove residual oxygen (Oxygen Scavengers)
- Condensate Line Protection
- Antifouling with Biocides and Algaecides
- pH adjustment (Alkalinity Builders)
- Antifoaming
- Prevent agglomeration of solids

In addition to chemical treatment, RO and membrane filtrations can be used to reduce hardness of cooling tower water.

https://sensorex.com/blog/2019/12/03/common-chemicals-in-boiler-water-treatment/

Water Treatment: for Process

Process water can be Direct (contact) or Indirect (non-contact).

Indirect Water – Doesn't need much treatment except to avoid scaling/corrosion in pipes

Direct Contact Water - Different degrees of treatment might be needed based specific to the process needs

Water treatment technologies used in process water are determined by,

- **Purity Levels**: Different processes demand different levels of water purity (hardness, TDS, conductivity etc.) and. some processes may be sensitive to specific contaminants
- **Variability and contaminants in available source water**
- **Economic Factors :** Cost of Treatment Technologies and water Recycling Needs
- **Operational Efficiency -** Process Integration and Maintenance and Downturn:
- **Environmental Impact -** Sustainability Practices and Waste Reduction Goals:

Industrial Water Quality Requirements – Examples

Food industries:

- **Process**: Cooking, Ingredient incorporation
- **Water Quality Needs**: Safe for consumption, free from harmful bacteria and high levels of salts/minerals that can affect taste
- **Treatment Used**: Filtration, UV disinfection, reverse osmosis, carbon filtration, and chlorination.

Metals Processing Industry:

- **Process**: Fabrication processes, including metal finishing, plating, and washing.
- **Water Quality Needs**: High purity, low metal concentration, controlled pH.
- **Treatment Used**: Ion Exchange, RO, Chemical Treatment,

Pharmaceutical:

- **Process**: Manufacture of medications and injectables.
- **Water Quality Needs**: Extremely high purity, free from bacteria, toxins, particulates, and organic impurities.
- **Treatment Used**: Ultrafiltration, reverse osmosis, electro deionization, UV sterilization, and ultra-pure water systems.

Textiles:

- **Process**: Dyeing, washing, and finishing of fabrics.
- **Water Quality Needs**: Free from iron and other heavy metals that can stain fabrics, and controlled hardness to avoid scale in heat exchangers.
- **Treatment Used**: Softening by ion exchange, filtration, and sedimentation to remove suspended solids,

Automotive:

- **Process**: Component manufacturing, painting, and coating.
- **Water Quality Needs**: High-quality water for paint and coating applications to prevent defects
- **Treatment Used**: Deionization, reverse osmosis, and filtration to control particulates and dissolved solids.

Industrial Wastewater: Contaminants by Industry

Food industries:

- Organic particulate and waste matter.
- Synthetic compounds like antibiotics and growth hormones (animal slaughter)

Pulp & Paper:

- Acids, chlorine, chloroform, dioxins, hydrocarbons and phenols in wastewater from bleaching
- Presence of lignin and lignin derivates

Metals Processing Industry:

- Metal contaminates from surface treatments
- Waste products like ammonia and cyanide in cooling water
- Oil and grease contaminates in processes require water as a coolant and lubricant

Textiles:

- Chemical products like bleach and dyes.

Automotive:

- Grease, paints and solvent in wastewater are common

Pharmaceutical:

- Residual and nonresidue drug waste

Water and Wastewater Treatment: Example Processes

Chemical Treatment

- Oil/Water Separation
- Neutralization
- Chemical Treatment of Cooling Tower Makeup Water
- Lime Softening
- Chlorination, Ozonation

Physical Treatment

- Screening and Grit Removal
- Flotation, Dissolved Air Flotation
- Sand Filtration, Bag Filtration, Cartridge Filtration
- Granular Activated Carbon Adsorption (GAC)
- UV Filtration
- Ion Exchange Softening
- Membrane Filtration

Physio-Chemical Water Treatment

- Coagulation – Flocculation – Sedimentation
- Clarification (Settling, Sedimentation)

Biological treatment

- Membrane Bioreactor (MBR)
- Activated Sludge / Aerobic Lagoon
- Anaerobic Lagoon
- Biological Nutrient Removal (BNR)

Thermal treatment

- Evaporation
- Distillation/rectification

Common Wastewater Systems – Examples

Aeration System

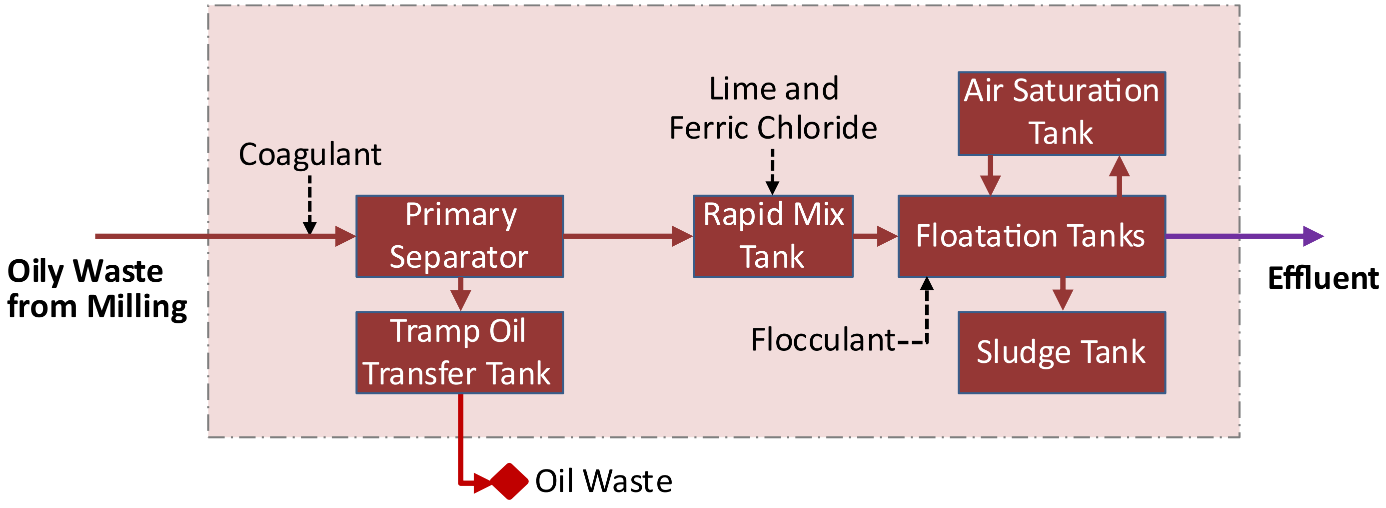
Settling/Separation tanks (chemical treatment)

Clarifiers

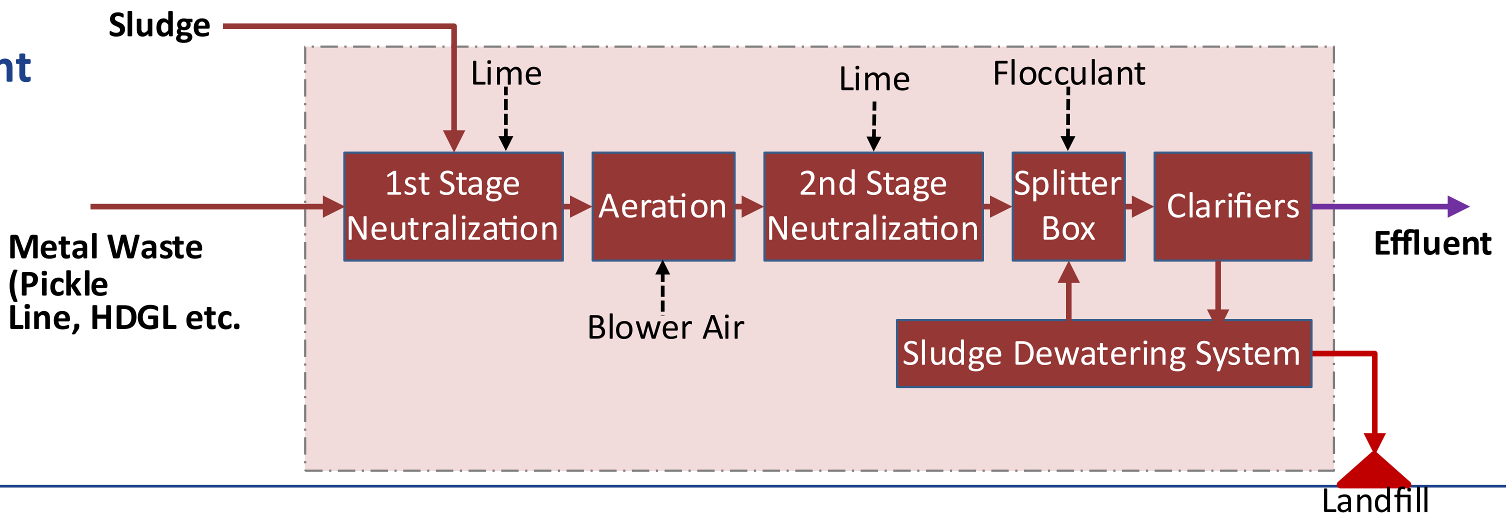
PH Neutralization Systems

Wastewater Treatment Trains in Iron and Steel

Typical Oily Waste Treatment



Typical Metal Waste Treatment



Cost of Water and Wastewater

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Estimating Cost of Water and Wastewater treatment

For each water and wastewater treatment process:

If maintained by the facility

- Cost of water (or wastewater) treatment ($/year) = Sum of unit cost of treatment process ($/kGal)
  - Cost of chemicals (variable)
  - Cost of energy (fixed and variable)
  - Cost of operation (replacements, maintenance) (fixed and variable)
  - Annualized cost of equipment installation (fixed)

If maintained through a third-party service (depending on contract terms - mostly fixed**)**

- Cost of water (or wastewater) treatment ($/year) = Annual total amount paid to the third-party

Chemical treatment

Most used in industries and can be used to treat for various contaminates.

Typical Water Treatment

- Scale and corrosion inhibitors – Boiler and cooling tower makeup

Typical Wastewater Treatment

- Neutralizing – Ph control
- Precipitating out heavy metals - Treatment of metals and toxic materials

Typical cost components:

- Cost of chemicals - (variable)
- Cost of electricity use - (typically fixed)
  - Feeder pumps
  - Water circulation
- Labor cost for testing chemical levels - (fixed)
- Maintenance of equipment - (fixed)

Chemical treatment with automated monitoring and control

Physical treatment

Suited for removing solids contaminants via clarifiers , oils and grease with separators or deionization with filtration

Example treatment processes

- Screening, skimming
- Filtration
- Clarifiers/ Sedimentation

Typical Cost Components:

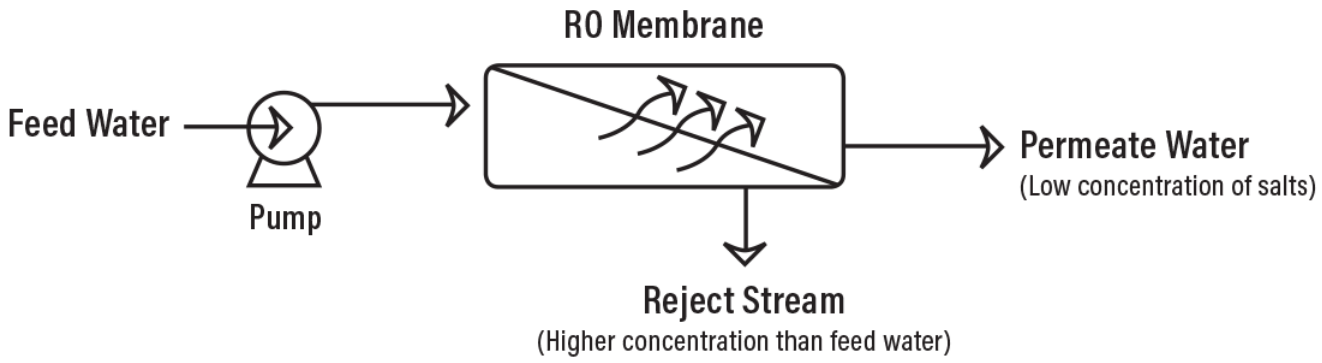
- Electricity to operate mechanical equipment
- Pumping energy
- Maintenance (membrane cleaning)
- Recuring replacement cost

Clarifiers - Example of Physical Treatment

Settling tanks built with mechanical means for continuous removal of solids being deposited by sedimentation

Physical treatment: RO and Membrane filtration System

Water is demineralized or deionized by pushing it under pressure through a semi-permeable Reverse Osmosis Membrane.



Typical cost components:

- Electricity to operate pumps (variable)
- Chemicals for pretreatment and membrane cleaning
- Media replacement (variable)

Deionization to remove unwanted ions

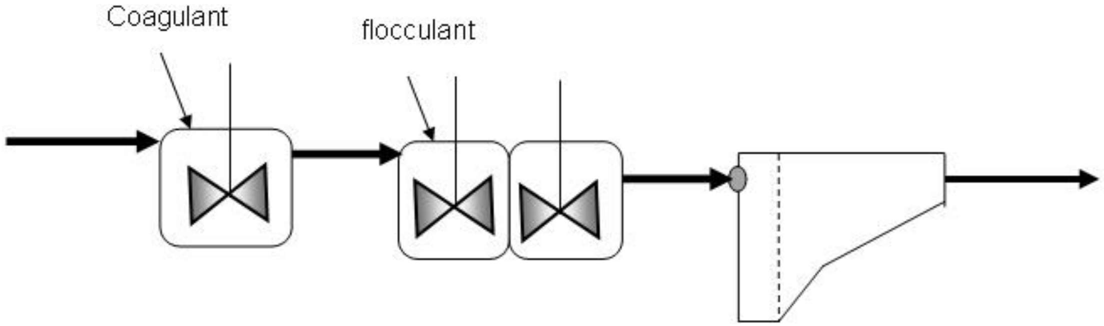
Physio-chemical treatment: Coagulation with Sedimentation

Involves using chemicals which can modify physical state of colloidal particles making them more stable and coagulable for further treatment or filtration purposes.

- Coagulation (Coagulant + rapid mixing)
- Flocculation (Flocculant + slow-mixing)

Typical cost components::

- Cost of chemicals
- Cost of Pumping
- Cost of motor energy for mixing
- Maintenance and replacement cost



Coagulation – Flocculation -- Sedimentation

Aerobic treatment

Air is added into wastewater to allow aerobic bio-degradation of the pollutant components.

Typical cost components:

- Electricity for air blowers/ compressed air/ mechanical agitators
- Pumping
- Operations and maintenance

https://gsps-eng.com/aerators-wastewater.html

Thermal treatment of wastewater

Thermal separation process are any technology that involves high temperatures in its treatment.
E.g. Evaporation, distillation/rectification etc.

Its best suited when,

- Wastewater ingredients, dry substance contents, pH value or particle size changes frequently
- Wastewater is highly concentrated

Example manufacturing processes

- Wastewater from Industrial Laundries
- Toxic wastewater from Chemical Production Process
- Wastewater from the production of wood fiber boards

Multi effect Evaporation Plant

True Cost Components

- Heat input (electricity or fossil-fuel)
- Mechanical energy input
- Other (maintenance)

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https://www.gea.com/en/binaries/wastewater-industry-concentration-membrane-filtration-gea_tcm11-34902.pdf

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True Cost Components
4. Cost of Heat Energy in Wastewater Leaving the Plant

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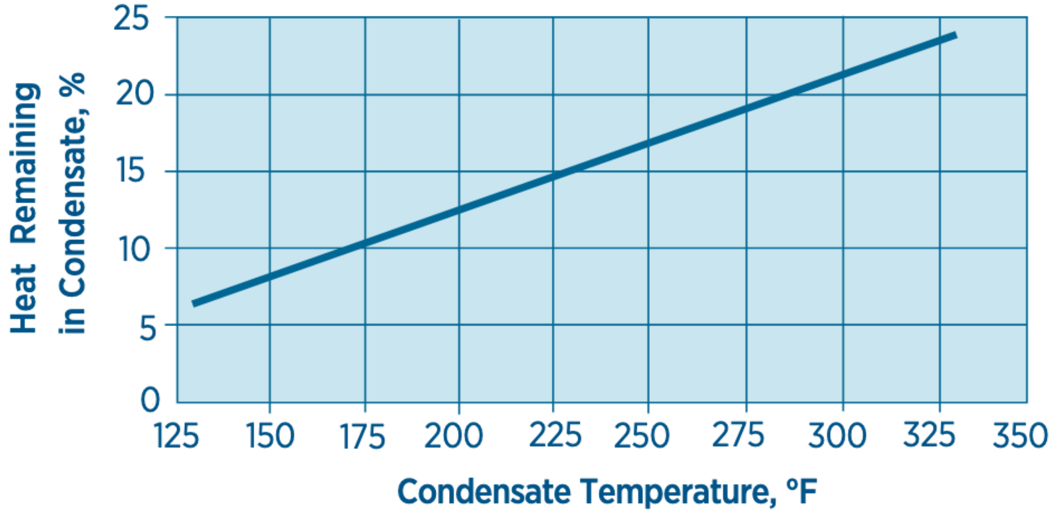
High Temperature Wastewater Sources

Energy lost in the form of heat in the discharge stream can add to the true cost

Typical areas of heat loss

- Boiler blowdown (212 ºF at atmospheric pressure)
- Condensate (130-225 ºF)
- Processes cleaning/sanitizing

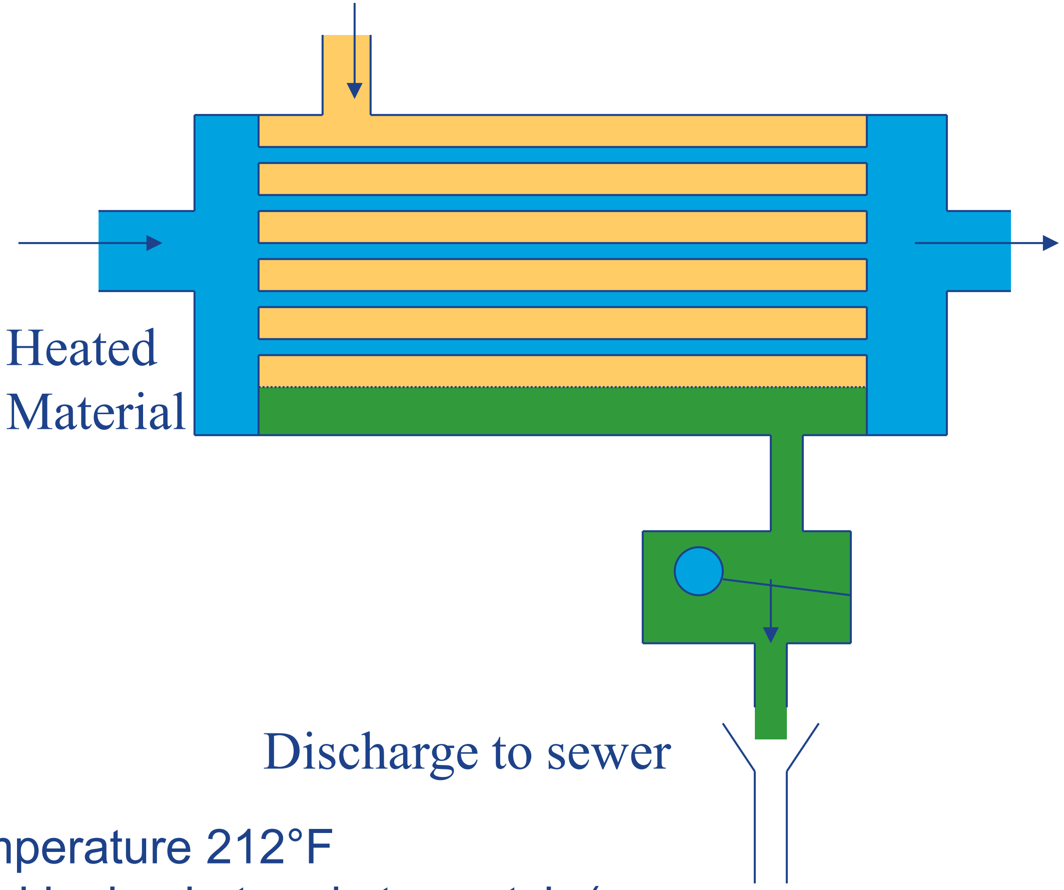
If lesser water is used, the energy (and cost) associated with heating it can be reduced



https://www.energy.gov/sites/prod/files/2014/05/f16/steam8_boiler.pdf

High Temperature Wastewater Sources: Condensate

- Condensate exits a process heat exchanger as a saturated liquid
- The condensate temperature provides an indication of the energy loss associated with the condensate return system



Measured condensate temperature 212°F
Condensate flow measured by bucket and stopwatch (mass and energy balance is also a common method)

Estimating cost of heat energy in wastewater

Data to collect

- For high temperature wastewater leaving the facility:
  - Quantity (MGal/year)
  - Temperature of wastewater
- Temperature of source water intake
- Water heating efficiency (e.g., ~0.78 for typical combustion system)
- Cost of heating fuel ($/MMBtu);

$$\text{Cost of Heat Energy in Wastewater (\$/year)} = \frac{\text{Volume * Density * Specific Heat * Temperature rise}}{\text{Water Heating Efficiency}} \times \text{Cost of Heating Fuel}$$

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True Cost of Water: Wrap Up

Cost of municipal water intake and wastewater disposal

- **Volume** of purchased water, sewer discharge and third-party disposal
- Unit costs of municipal water, sewer and third-party disposal

Costs for pumping and motor energy

- Pump and motor specifications and operation
- Unit cost of electricity

Cost of water and wastewater treatment

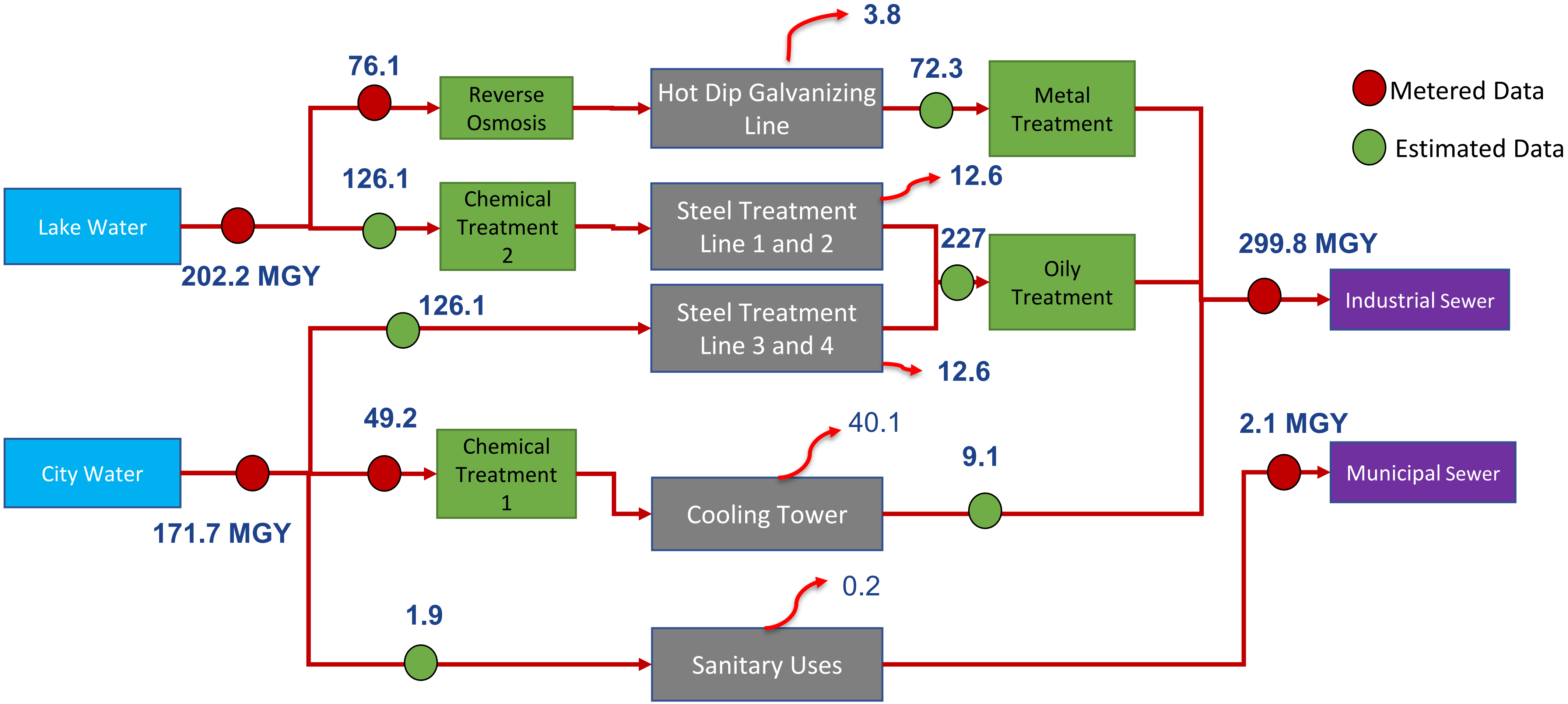
- Volume of water and wastewater treated
- Unit costs of water & wastewater treatment (To be calculated)

Cost of unused heat energy in wastewater

- Volume of high temperature wastewater leaving the facility
- Temperature of incoming water and high temperature wastewater leaving the facility
- Unit cost of water heating fuel

True Cost of Water – Exercise

Example Facility – With Data (Session 2)

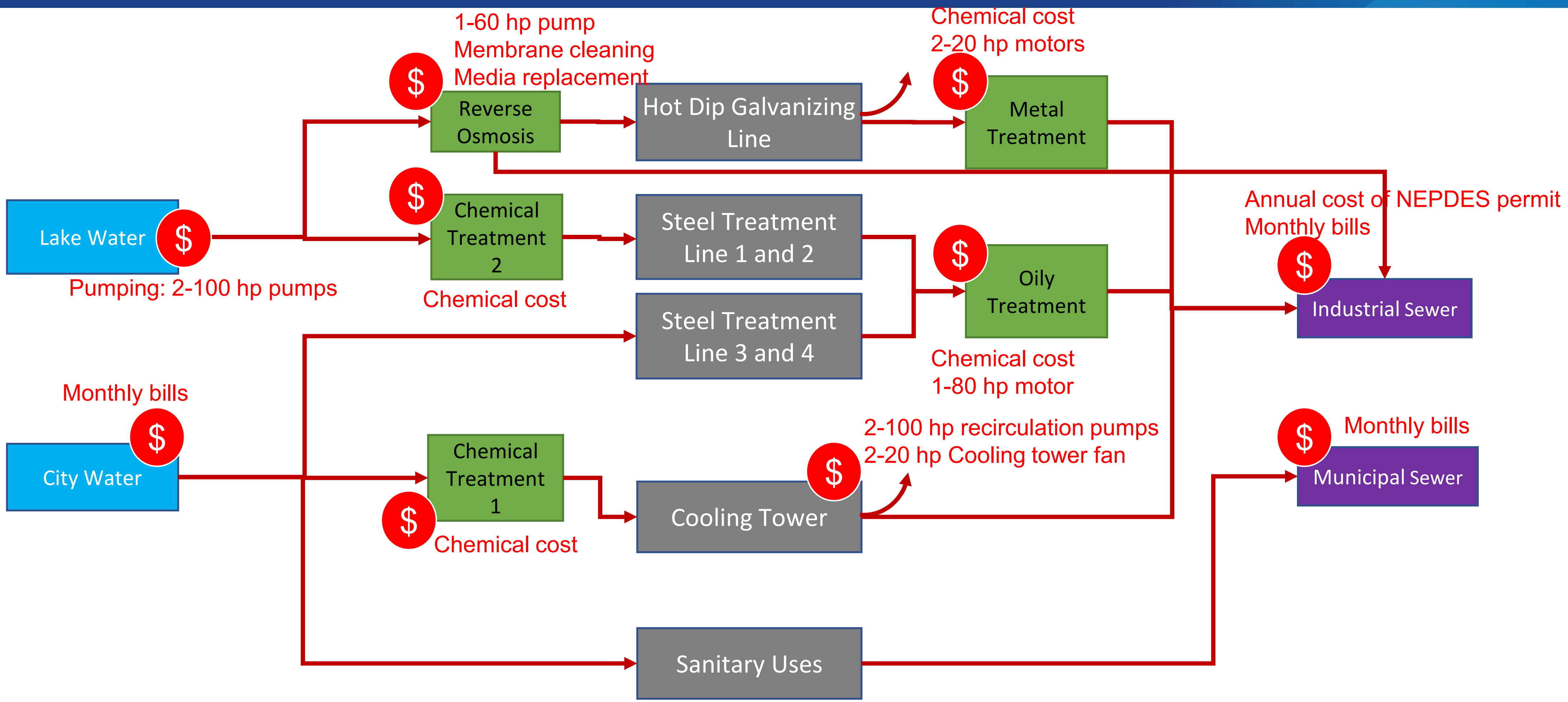


True Cost Exercise: Plant information

Following information has been collected from our example facility

- Utility bills for city water, sewer and electricity.
- Chemicals added from vendor
  - Cooling tower
  - RO system
  - Oily Waste
  - Metal Removal
- Nameplate data and run hours
  - Main Lake water Pump station
  - Cooling Tower System – Fans and pumps
  - RO System
  - Equipment's in Metal and Oily Removal

Identify True Cost Components



Utility Costs

- City water cost: $104.65/month fixed charge and $1.71/kGal usage charge

  City Water cost = (104.65*12) /(171.7*1000) + 1.71 = 1.72/kGal

- Domestic sewer cost: $18.22/month fixed charge and $1.14/kGal volume charge

  Domestic Sewer cost = (18.22*12) /(2.1*1000) + 1.14 = 1.24/kGal

- Industrial sewer cost: Variable monthly charge based on peak flow rate; sum of monthly bills = $588,000

  Industrial Sewer cost = 598000/(299.8*1000) = $2/kGal

- **Electricity cost: $0.05/kWh**

Pumping Cost - Calculation

What is the cost of operating 2 recirculation pumps (100 hp, 80% efficiency, load factor = 0.7) 24hours a day throughout the year? Note: 1 hp is 0.746 kw ; Average electricity cost is $0.05/kWh

Total Energy Use(kwh/year) = kW * Load Factor * Hours of Operation per Year

kW = hp *0.746/ efficiency ; Cost/year = kwh/year * $/kwh

Pump energy use = (0.746*2*100*0.7/0.8)*8760 = 1,143,618 kWh/year

Pump electricity cost = $0.05/kWh * 1,143,618 kWh/year = $57,181/year

Pumping cost

Lake water:

- 2 recirculation pumps (100 hp, 80% efficiency, load factor = 0.7)
  - Pump energy use = (0.746*2*100*0.7/0.8)*8760 = 1,143,618 kWh/year
  - Pump electricity cost = $0.05/kWh * 1,143,618 kWh/year = $57,181/year

Cooling tower:

- 2 recirculation pumps (100 hp, 80% efficiency, load factor = 0.7)
  - Pump energy use = (0.746*2*100*0.7/0.8)*8760 = 1,143,618 kWh/year
  - Pump electricity cost = $0.05/kWh * 1,143,618 kWh/year = $57,181/year
- 2 cooling tower fans (20 hp, 80% efficiency, load factor = 0.7)
  - Motor energy use = (0.746*2*20*0.7/0.8)*8760 = 228,724 kWh/year
  - Motor electricity cost = $0.05/kWh * 228,724 kWh/year = $11,436/year
- Total electricity cost: $68,617

Water Treatment Cost

- **Chemical Treatment 1 for cooling tower**
  - Volume of water to be treated = 49.2 MGY
  - Chemical cost ($800/month) = 12*800 = $9600
  - Unit cost = 9600/(49.2*1000) = $0.195/kGal

- **Chemical Treatment 2 for steel treatment lines 1&2**
  - Volume of water to be treated = 126.1 MGY
  - Chemical cost ($1200/month) = 12*1200 = $14,400
  - Unit cost = 14400/(126.1*1000) = $0.114/kGal

Water Treatment Cost – RO System

- **RO System (Vantage® M84R036) operates throughout the year and has a pump motor that is 60 HP, 80% efficiency, load factor = 0.9**
  - Pump energy use = (0.746*60*0.9/0.8)*8760 = 441,110 kWh/year
  - Pump electricity cost = $0.05/kWh * 441,110 kWh/year = $22,056/year
- **Membrane cleaning costs $200 and is done 4 times a year)**
  - 200 x 4 = $800/year
- **The media is replaced semiannually and costs $1,000**
  - 2 x 1000 = $2,000/year
- Total cost = $24,856/year
- Unit cost = 24856/(76.1*1000) = $0.33/kGal

System Cutsheets can be used along with nameplate data as appropriate

Operating hours can be estimated or metered using runtime loggers

Membrane replacements and other operational cost can be got from Logs

SPECIFICATIONS

	Flow Rate Specifications GPM Nominal (m³/hr)						Customer Connection Specifications			Utility Requirements***			
Model No**	Product*	Feed	Reject	Vessel Staging	Membrane Vessel	Membrane Quantity	Feed	Product	Reject	High Voltage Service	High Voltage FLA	Pump HP	Approx Shipping Weight lb (kg)
M84R024	107 (24.3)	143 (32.5)	36 (8.7)	3:2:1	4	24	3″	3″	2″	480 VAC 3ph	67	50	5576 (2529)
M84R036	160 (36.3)	215 (48.8)	53 (12.0)	4:3:2	4	36	4″	4″	2″	480 VAC 3ph	79	60	6115 (2774)
M84R048	214 (48.6)	285 (64.7)	71 (16.1)	6:4:2	4	48	4″	4″	2″	480 VAC 3ph	79	60	6465 (2932)

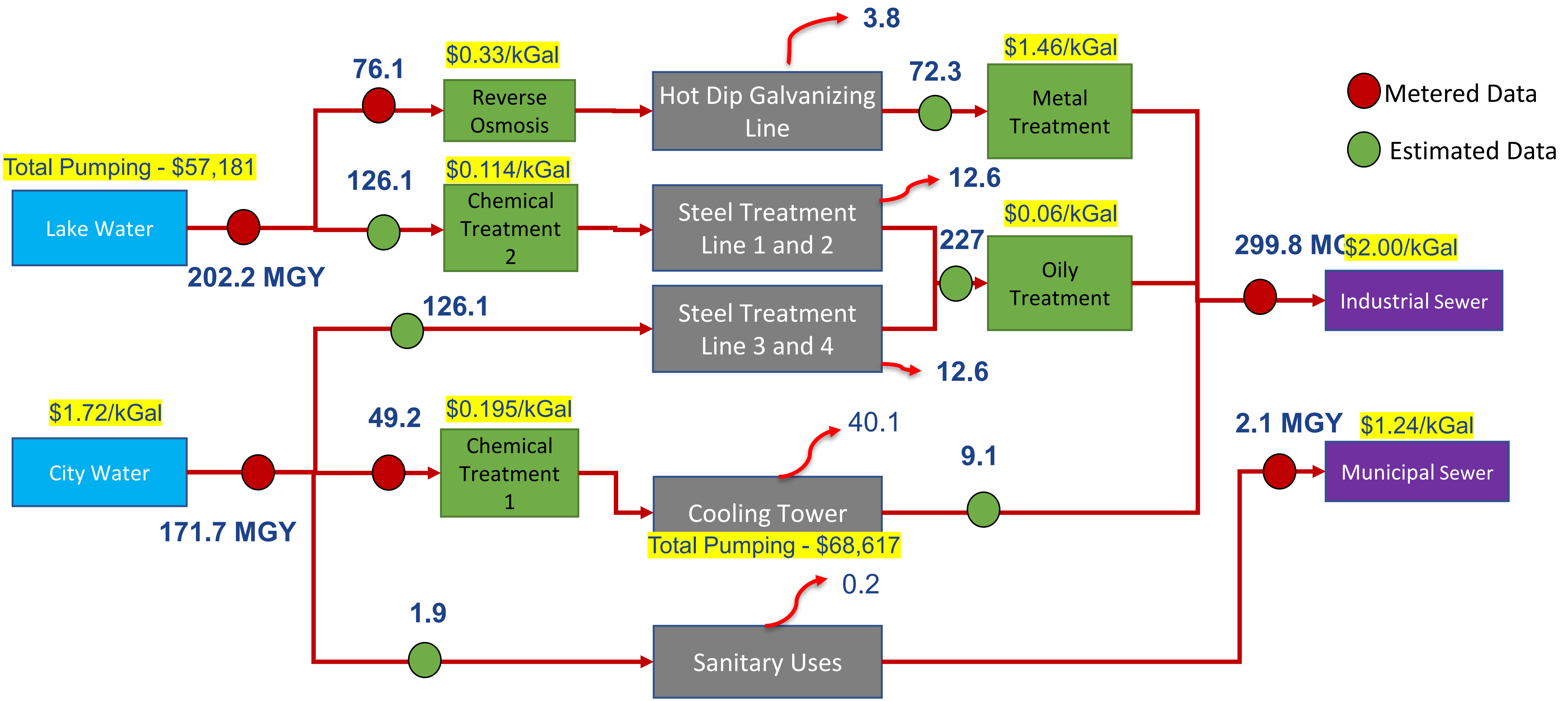
* Product flow rates are based on a flux rate of 16 GFD and equipment design parameters listed below. Product flow rates may not be appropriate for other feed waters.
** The 8 designates 8″ housing, the 4 designates 4 elements in length, and the -R0XX designates the number of membranes.
*** Additional voltage options are available. Refer to equipment specifications.

Wastewater Treatment Cost

- **Metal wastewater treatment -** 2 motors (20 hp, 80% efficiency, load factor = 0.70)
  - Chemical cost = $15,000 annual
  - Motor energy use = (0.746*2*20*0.7/0.8)*8760 = 228,724 kWh/year
  - Pump electricity cost = $0.05/kWh * 228,724 kWh/year = $11,436/year
  - Total cost = $26,436
  - Unit cost = 26436/(18.1*1000) = $1.46/kGal

- **Oily wastewater treatment -** 1 motors (80 hp, 80% efficiency, load factor = 0.7)
  - Chemical cost = $8,000 annual
  - Motor energy use = (0.746*80*0.7/0.8)*8760 = 114,362 kWh/year
  - Pump electricity cost = $0.05/kWh * 228,724 kWh/year = $5,718/year
  - Total cost = $13718
  - Unit cost = 13718/(227*1000) = $0.06/kGal

Example Facility – With Data (Session 2)



True cost of water: facility wide

	Unit cost $/kGal	MGY	Total
City water	$ 1.72	171.7	$ 295,324
RO system	$ 0.33	19	$ 6,270
	$ 0.20	49.2	$ 9,594
	$ 0.11	126.1	$ 14,375
	$ 1.46	18.1	$ 26,426
	$ 0.06	227	$ 13,620
Cooling tower pumps and fans			$ 68,617
Lake water			$ 57181
Industrial sewer	$ 2.00	299.8	$ 599,600
Sanitary sewer	$ 4.24	2.1	$ 8,904
True cost of water			**$ 1,099,911**
Direct costs			**$ 903,828**
Ratio			**1.22**

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Polling Question 2

What do you consider to be the most important cost components of water to know for your facility?

1.) Only direct Cost
2.) Direct cost and indirect variable cost
3.) Direct and Indirect (variable and fixed)
4.) All direct and variable cost + external cost

MEASUR Demo

Roundtable Discussions

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Homework #3

1. Collect the necessary facility level and system data needed to determine true cost for the facility