



# Energy Performance Analysis for Wastewater Treatment Plants

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The 40<sup>th</sup> IETC  
Jun 13 2018

# Better Buildings, Better Plants

- **Better Plants** Program is a key component of the DOE's **Better Buildings Initiative**, which seeks to improve the energy efficiency of residential, commercial and **industrial** buildings
- Through Better Plants:
  - Set **long-term efficiency goals (25%)**
  - Receive **technical assistance, networking platforms** and **recognition opportunities**
- Manufacturers have two opportunities to engage in Better Plants:
  - Broader-based **Program** level
  - Higher-level **Challenge** level



# Better Plants: Water/Wastewater Treatment Sector Participation

## Accomplishments

# of Partners	25
Number of Plants	~170
% of US Mfg. Energy Footprint	0.1%

## Reported Savings

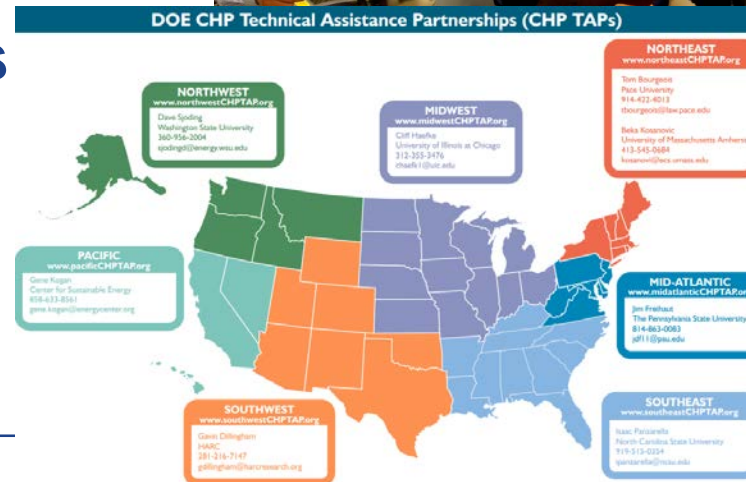
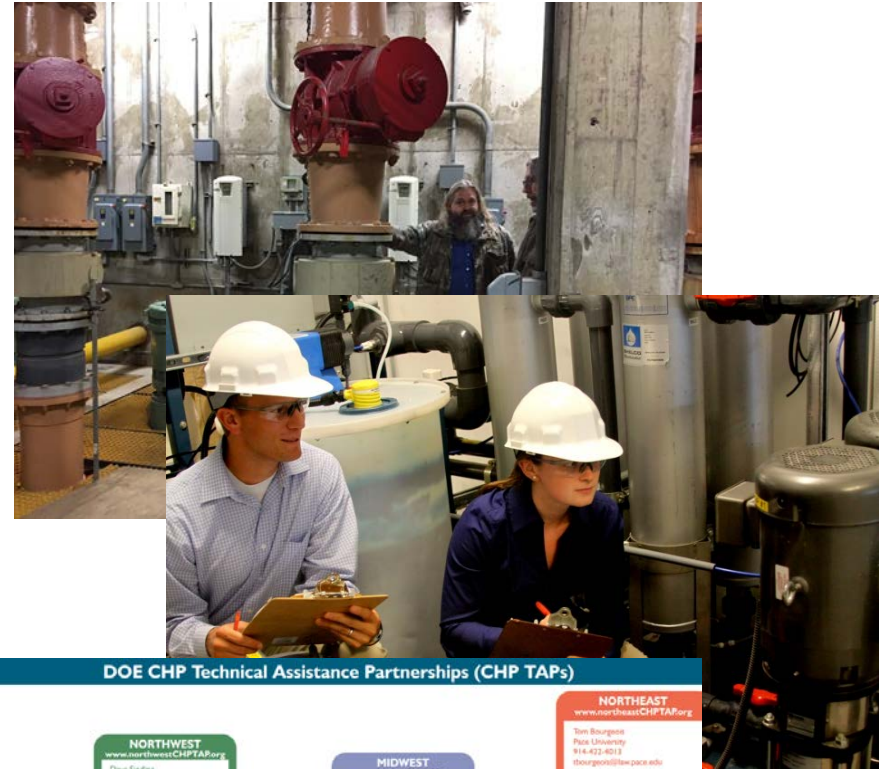
Cumulative Energy Savings	1 TBtu
Cumulative Cost Savings	\$4.3M
Cumulative GHG Savings	25k MT
Average Annual Energy Savings	2.2%





# Better Plants Technical Supports for Water/WWTP

- In-Plant Training on **Water/WWTP**
- In-Plant Training on **Pumping**
- **IAC Energy Assessments**
- **CHP Deployment Technical Assistance**
- **Energy Performance Analysis**
- **Software Tools**
- **Best Practices Sharing**



# Wastewater Treatment Plants - Energy Intensive!

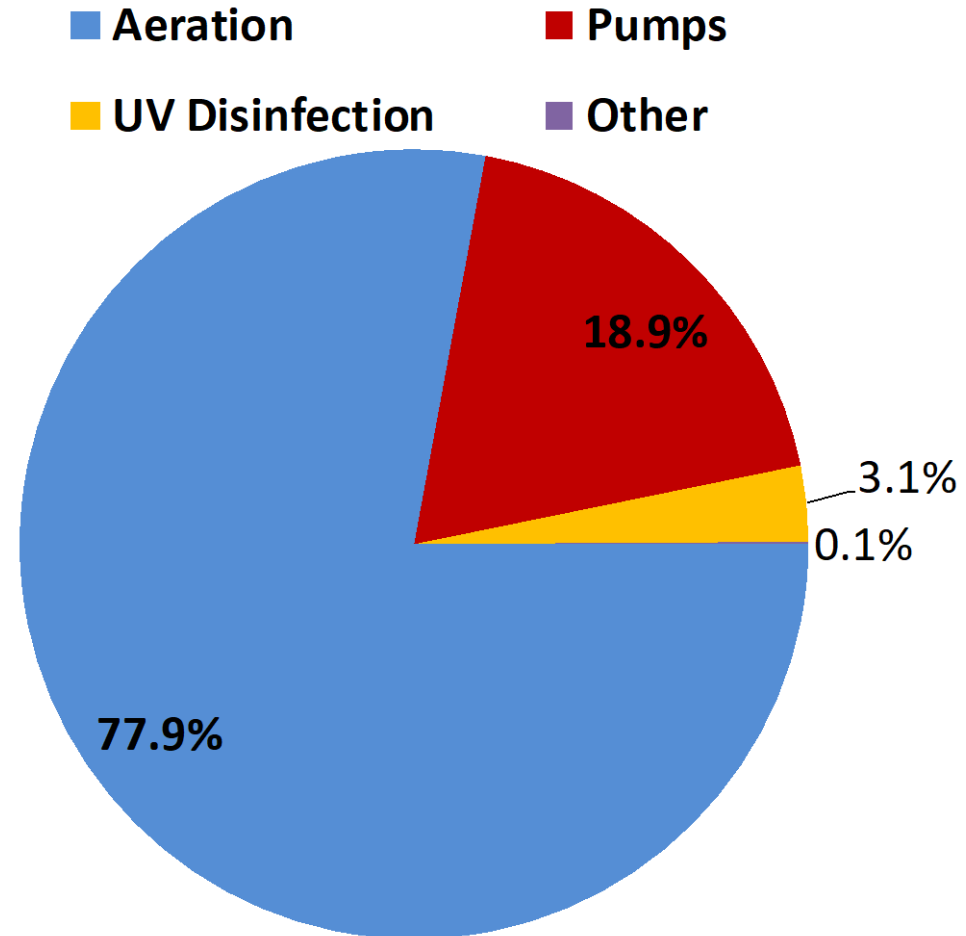
- **4%** of U.S. Electricity
- **\$4B** Annual Energy Cost
- **35%** of Typical U.S. Municipal Energy Budgets
- **25% - 40%** of Operational Cost is **Energy**



*Source: US Environmental Protection Agency (EPA)*

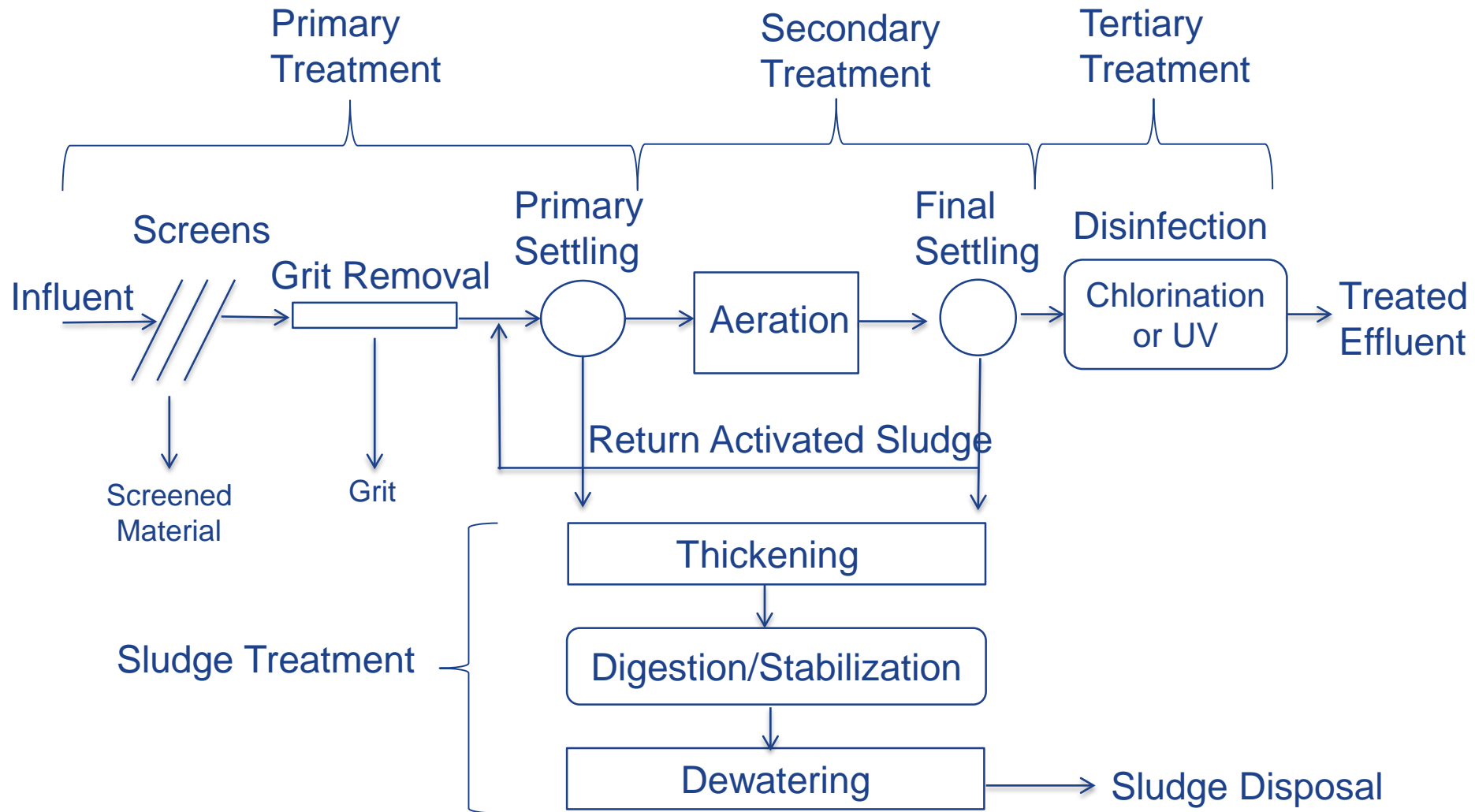
# Typical WWTP Electricity Use Distribution

- **Primary uses** of energy are **pumping** and **aeration**
- **Aeration mixes air (oxygen)** with wastewater to **remove BOD**, and tie the energy consumption to **BOD removal**
- **Pumps** are used to **move wastewater** through treatment plant, and thus tie energy consumption to water flow rate
- **Water Flow Rate** and **BOD removal** are reasonable energy intensity variables

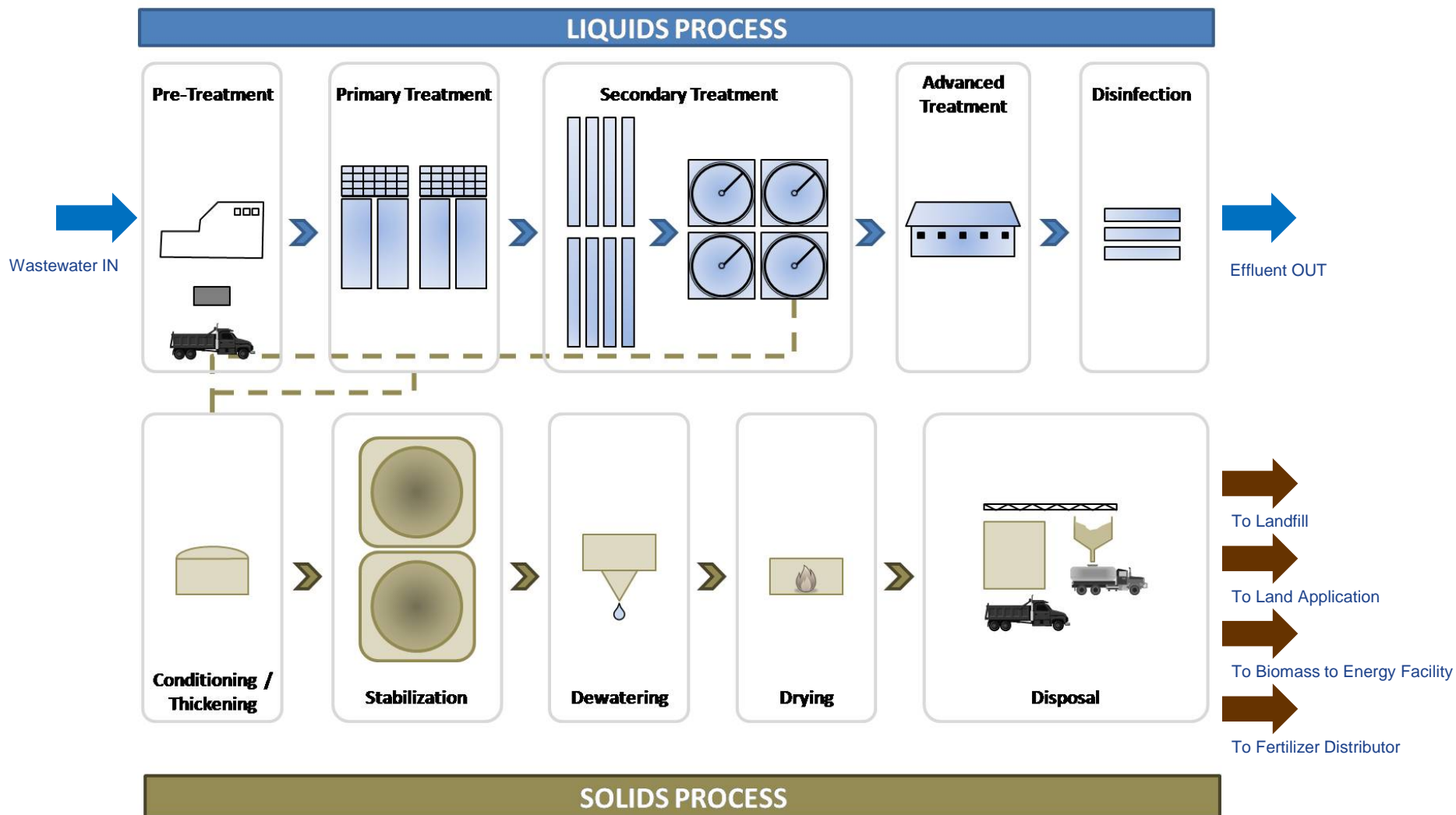


*Source: Malcolm Pirnie, the Water Division of ARCADIS (2011). "Typical Energy Usage Patterns in U.S. Wastewater Treatment Plants."*

# WWT Process Overview



# WWTP Process Overview





# Main Challenges for Baselineing & Benchmarking

- Where to draw the boundary?
- What should we use as the key indicator?
  - Flow
  - Biochemical Oxygen Demand (BOD)
- Also – what about the variation in flow?

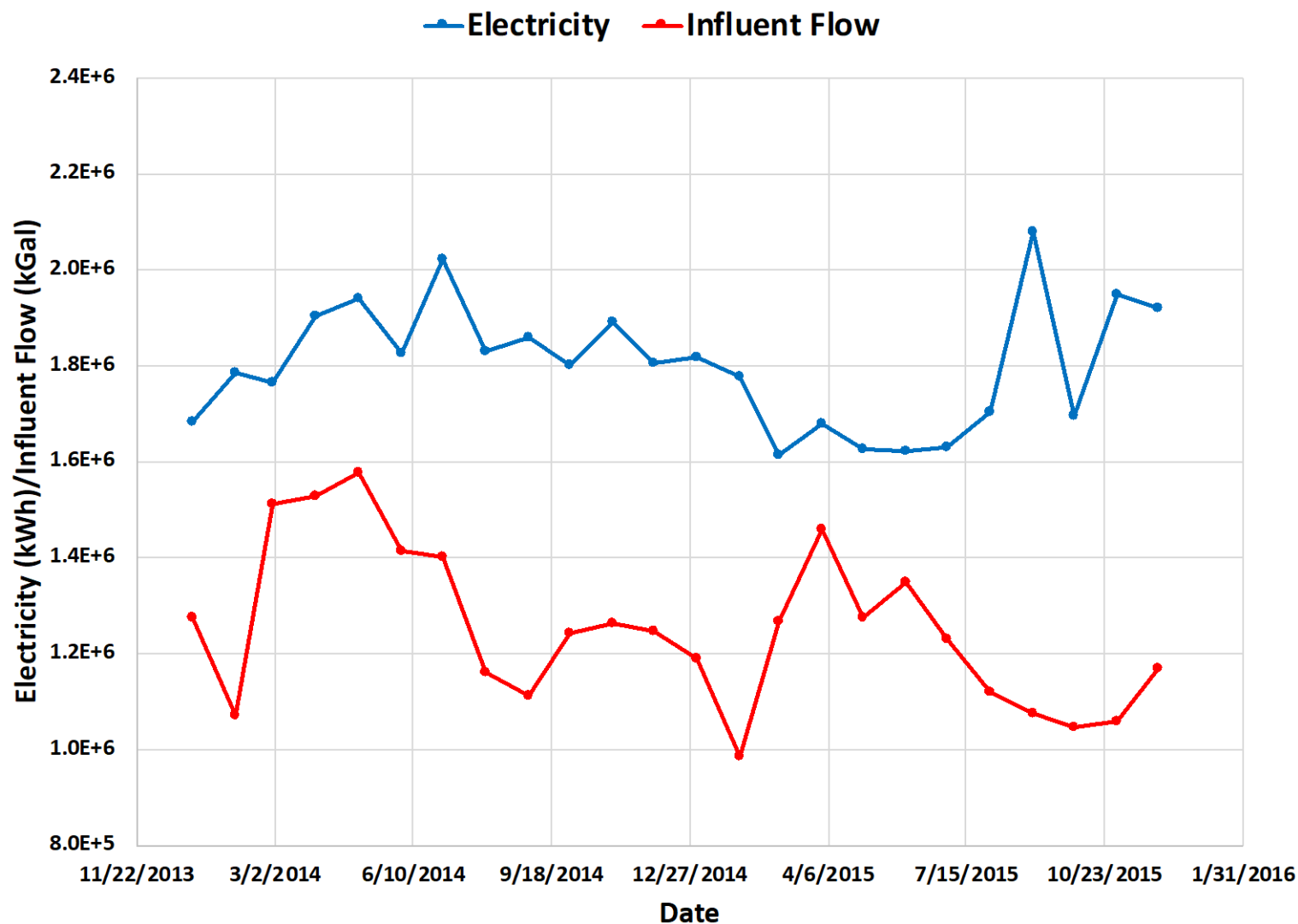
# Partial Load Data for Some WWTP Partners

Partner	Plant	Flow (MGD)		
		2016 Max Monthly Daily Average	2016 Min Monthly Daily Average	Max/Min Ratio
Alexandria Renew Enterprises	Alexandria Plant	69	24.5	<b>181%</b>
Grand Rapids Water Resource Recovery Facility	Grand Rapids Plant	60.9	32.6	<b>87%</b>
Charleston Water System	Charleston Plant	33.1	20.4	<b>62%</b>
Ithaca Area Wastewater Treatment Facility	Ithaca Plant	8.7	5.4	<b>61%</b>
Massachusetts Water Resources Authority	Boston Plant	364	234	<b>56%</b>
Western Lake Superior Sanitary District	Duluth Plant	43	32	<b>34%</b>
Kent County Department of Public Works	Milford Plant	13.9	11.3	<b>23%</b>

# Partial Load Data for Some WWTP Partners

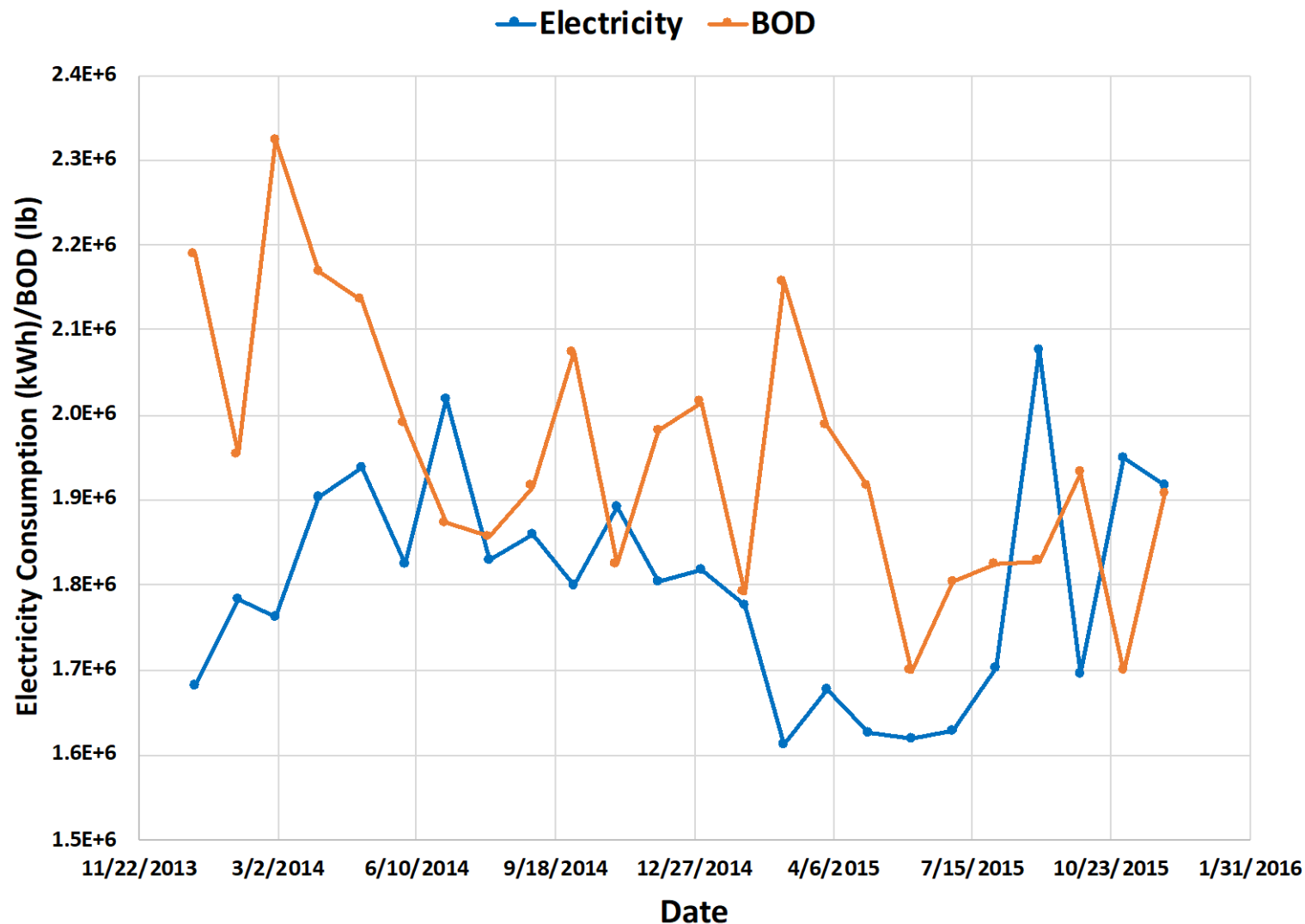
Partner	Plant	BOD (lb./MG)		
		2016 Max Monthly Daily Average	2016 Min Monthly Daily Average	Max/Min Ratio
Alexandria Renew Enterprises	Alexandria Plant	4,158	777	435%
Grand Rapids Water Resource Recovery Facility	Grand Rapids Plant	2,058	1,049	96%
Charleston Water System	Charleston Plant	273	143	91%
Ithaca Area Wastewater Treatment Facility	Ithaca Plant	1,612	902	79%
Western Lake Superior Sanitary District	Duluth Plant	1,838	1,084	70%
Massachusetts Water Resources Authority	Boston Plant	1,895	1,261	50%
Kent County Department of Public Works	Milford Plant	2,399	1,610	49%

# Data Review for One Partner

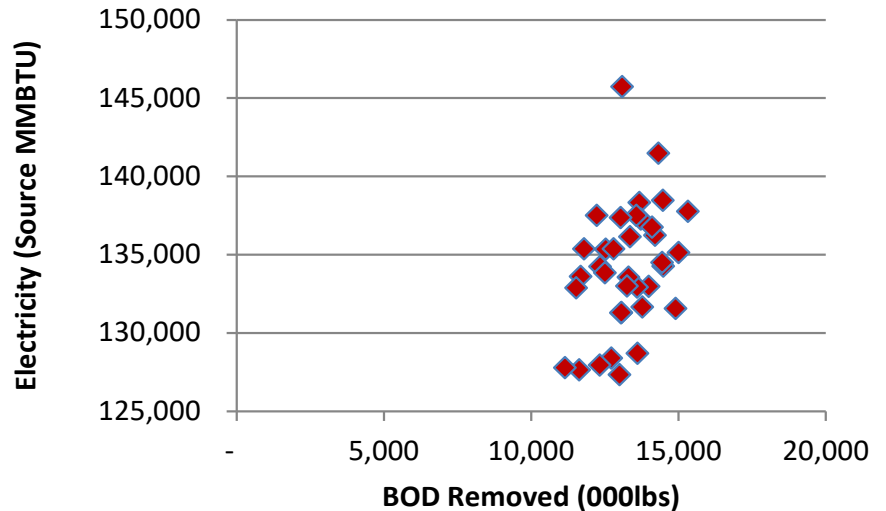
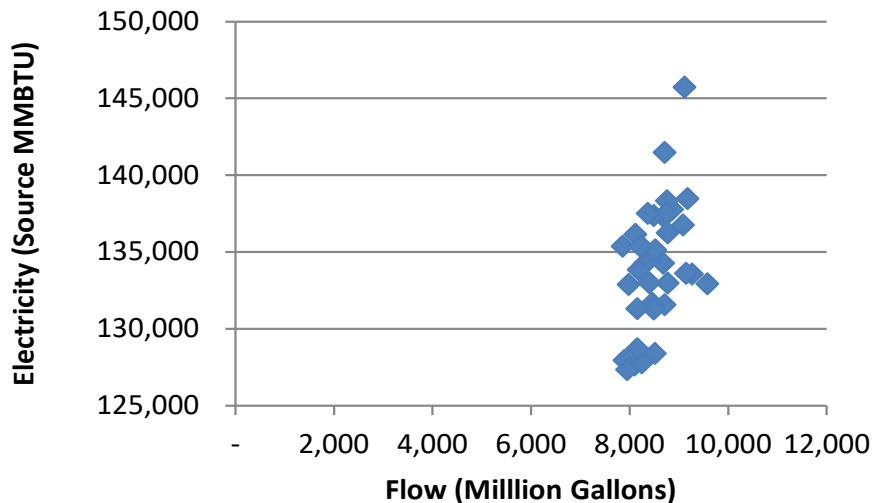
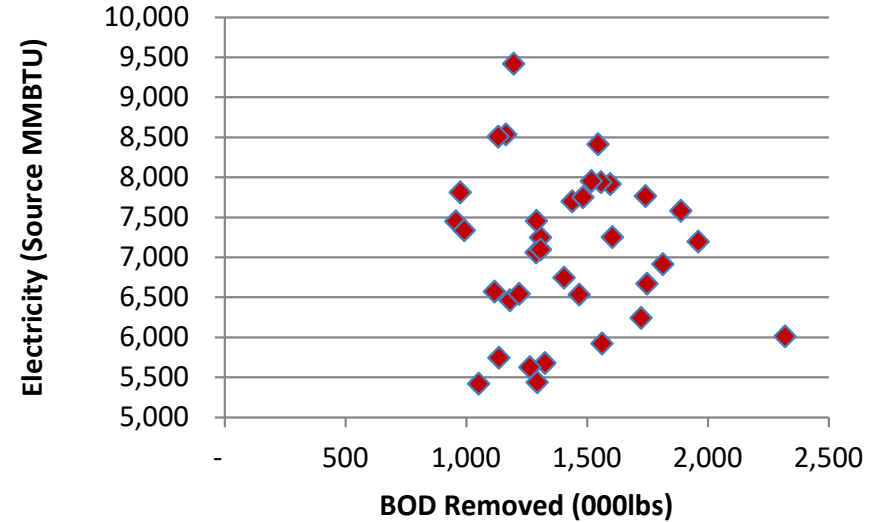
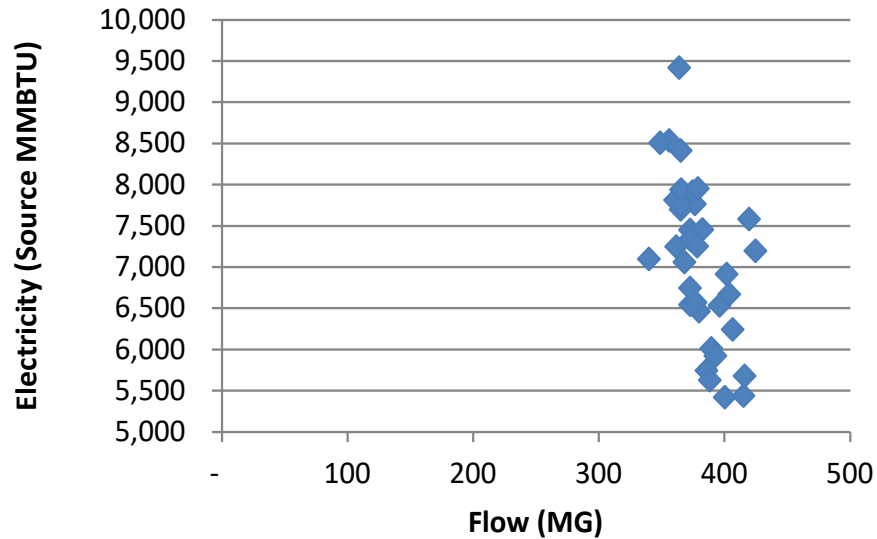




# Data Review for One Partner



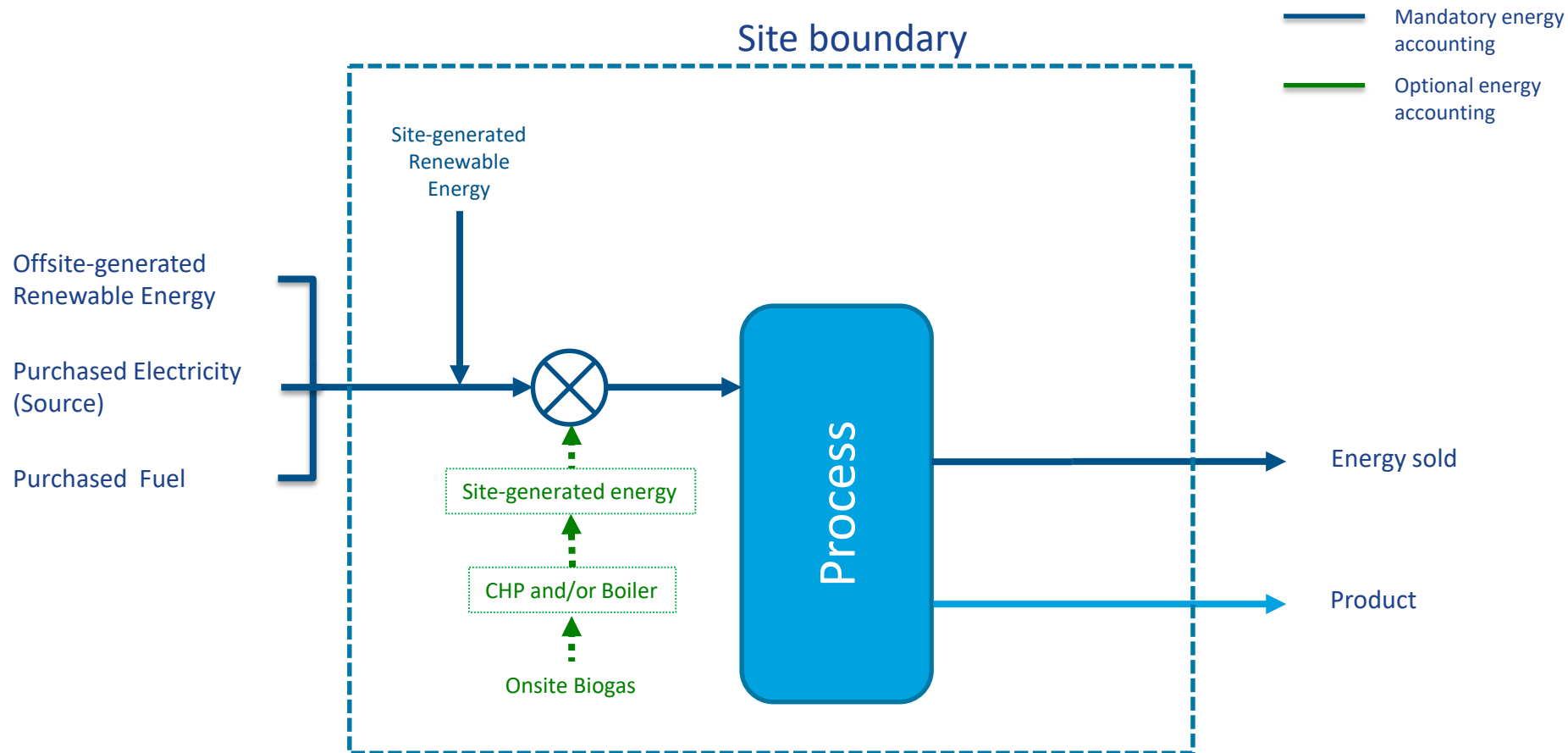
# Electricity vs Flow and BOD for Two Partners



# Main Challenges

- Where to draw the boundary?
- What should we use as the key indicator?
  - Flow
  - Biological Oxygen Demand (BOD)
- Also – what about that variation in flow?

# Better Plants Boundary Definition Considerations





# Baselining and Benchmarking – 3 Main Approaches



Increasing  
Level of  
*Data*  
*Quality* and  
*Confidence*

- **Corporate-level approach**
  - Total corporate energy consumption divided by total production
- **Facility-level approach**
  - Each facility energy intensity performance improvement
  - Aggregate facility performance to corporate
- **Regression-based approach**
  - Create regression model

# Comparison of Better Plants Approaches

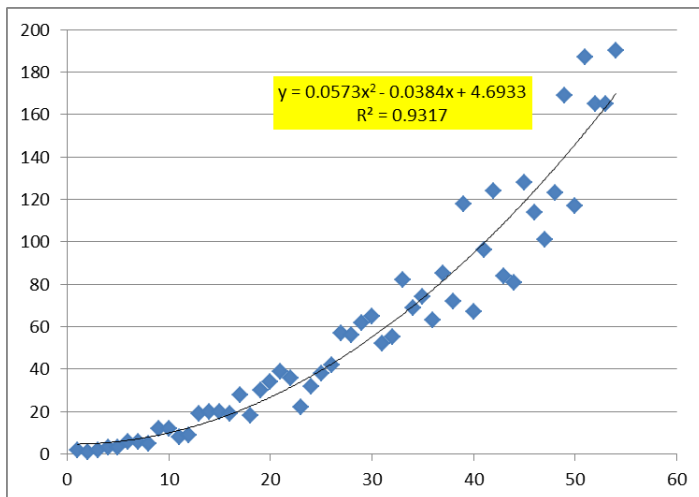
	Regression-based Approach	Facility-level Approach	Corporate-level Approach
1	Define the boundary	Define the boundary	Define the boundary
2	Choose a baseline year	Choose a baseline year	Choose a baseline year
3	Determine relevant variables affecting energy consumption at each facility	Decide on the energy intensity denominator for each facility, usually units of output	Decide on the corporate-wide energy intensity denominator, which will usually be either a standard unit of output, revenue, or some other financial metric
4	Gather data on energy consumption and relevant variables for each facility	Gather data on energy consumption and units of output for each facility	Gather data on energy consumption and whatever is being used as the corporate-wide energy intensity denominator—usually units of output, revenue, or some other financial metric
5	Use regression analysis to normalize each facility's data	Calculate energy intensity for the baseline year and the current year for each facility	Calculate energy intensity for the baseline year and the current year across the corporation
6	Calculate the change in energy intensity from the baseline year for each facility	Calculate the change in energy intensity from the baseline year for each facility	Calculate the change in energy intensity from the baseline year for the corporation
7	Aggregate the data on energy intensity change from each facility to the corporate level	Aggregate the data on energy intensity change from each facility to the corporate level	Calculate total and new energy savings
8	Calculate total and new energy savings	Calculate total and new energy savings	

Source: *Energy Intensity Baselineing and Tracking Guidance*, US DOE, January 2015.

# Regression Based Approach

## What is a regression?

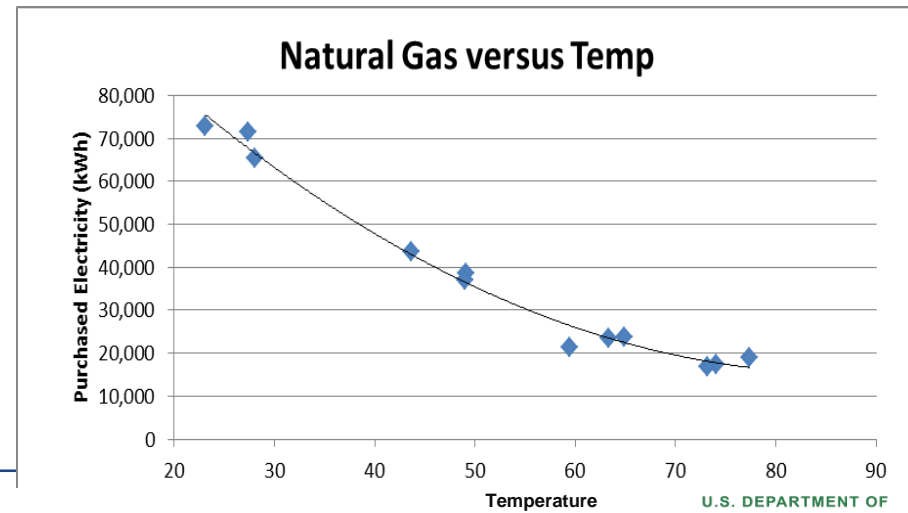
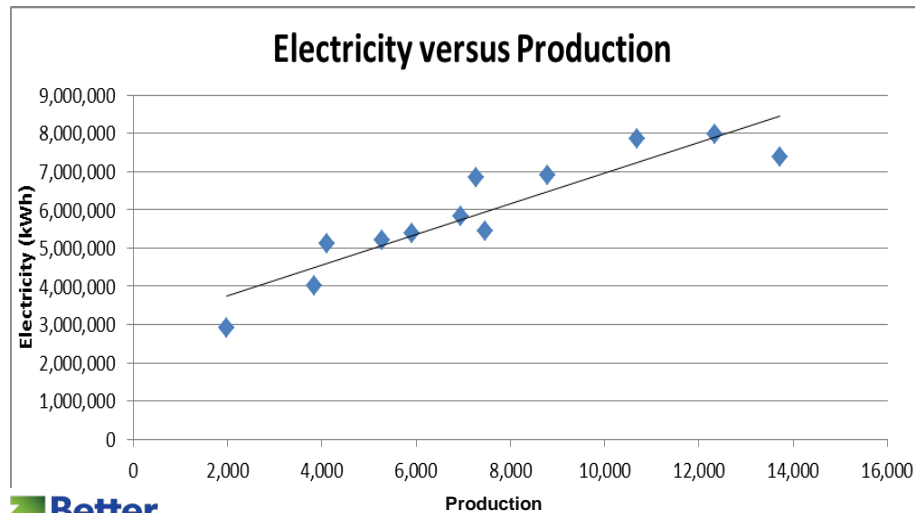
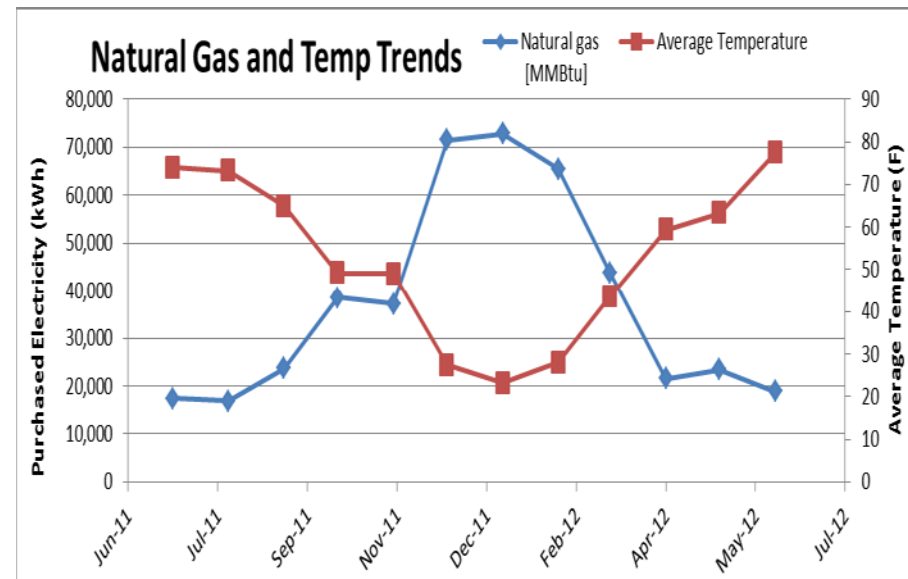
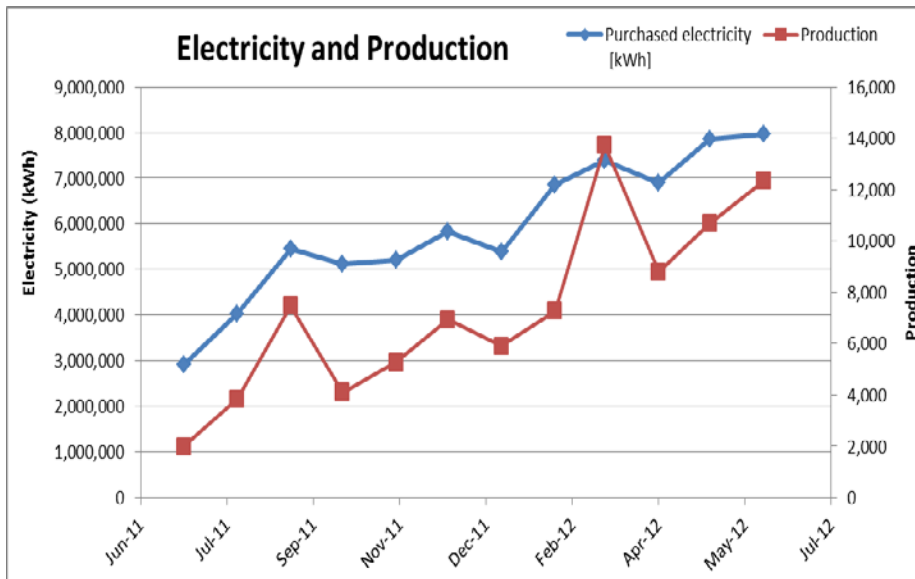
- **Statistical analysis** that models a plant's energy consumption
- **EnPI 5.0** tool



## Why is regression better?

- Accounts for energy fluctuations due to changes on **flow, BOD, weather**, etc.
- Uncovers **insights on factors** that impact energy use that are not apparent
- Can **validate energy savings**

# Regression Based Approach – Exploiting Data Trends

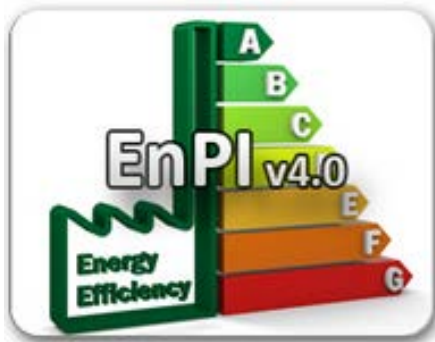




# Regression Based Approach—EnPI Tool

## EnPI Tool

- **Linear regression** model
- Energy consumption is dependent variable
- Production, weather, other factors used to explain energy consumption



## Key Attributes...

- Allows **multiple factors** to be considered
- Provides **robust estimates** of energy use
- **Simple** to use – TAMs can assist
- Can be used across multiple plants and business units

# Key Variables to Consider in Regression Models

- Influent **Flow Rate**
- **BOD** Removal
- **Weather** (HDD, CDD)
- **Chemical Composition** - Ammonia & Phosphorous
- **Rainfall**
- Influent **Temperature**
- Total Suspended **Solids**
- **Other**

Energy Use	Model is A	Variables	Variable p	R2	Adjusted	Model p	Formula
5 Natural Gas (CCF)(MMBTU)	TRUE	HDD (F)	0.0016435	0.90613062	0.852491	0.001057	(4.1327211
		IF Flow (mg)	0.1542216				
		IF Phosphor	0.0793578				
		IF Ammonia	0.1695491				
5 Total Electricity (MMBtu)	TRUE	CDD (F)	0.0143981	0.87778584	0.831956	0.000521	(4.7214802
		IF Flow (mg)	0.0001157				
		IF Phosphor	0.0005333				

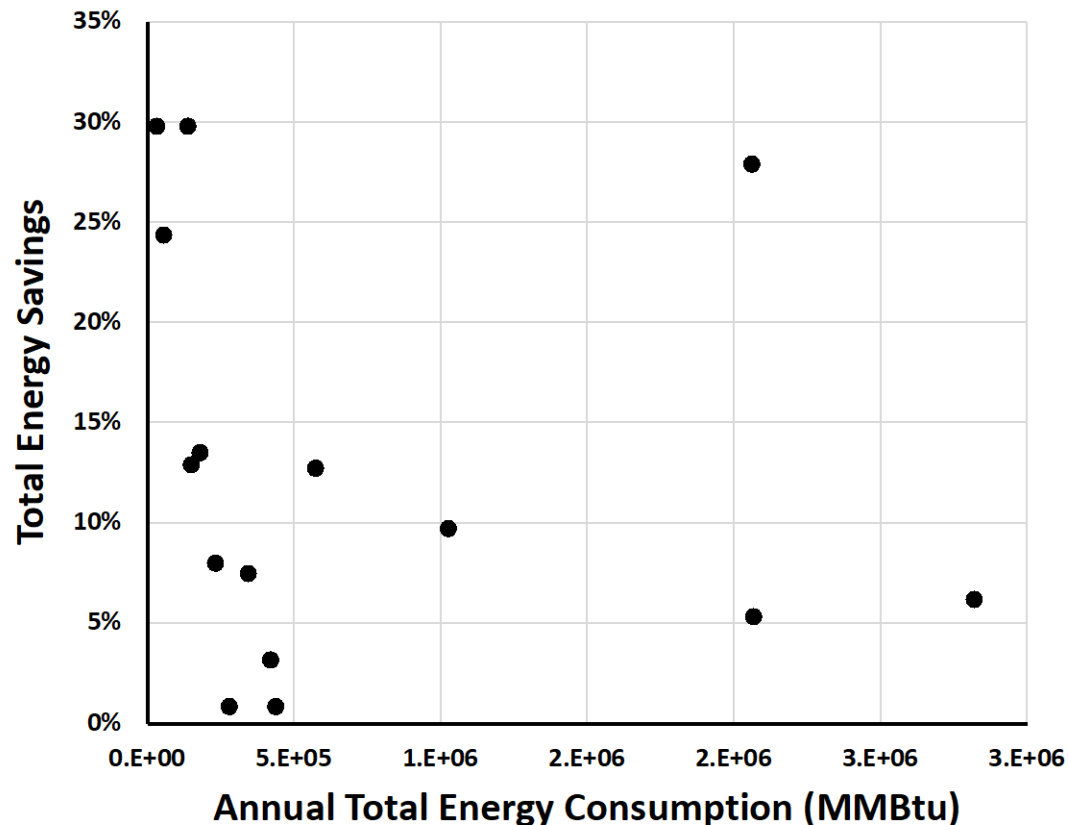
# EnPI Models Selection

- EnPI creates **many** models
- Statistical** validity
  - Model p-value < **0.1**
  - All variable p-value < **0.2**
  - At least 1 variable p-value < **0.1**
  - Adjusted **R<sup>2</sup>** > **0.5**
- Engineering** validity
  - Included **variables**
  - Coefficients** of variables
  - Intercepts**

Model	Model	Variables	Variable p-V	Adjusted R2	Model p-	Formula
32	TRUE	CDD (F)	0.0144	0.8320	0.0005	(4.7214802)
		IF Flow (mg)	0.0001			
		IF Phosphoru	0.0005			
39	TRUE	IF Flow (mg)	0.0002	0.8039	0.0010	(6.1492976)
		IF Phosphoru	0.0043			
		IF Ammonia	0.0282			
26	TRUE	HDD (F)	0.0850	0.7494	0.0025	(-1.2090213)
		IF Flow (mg)	0.0005			
		IF Phosphoru	0.0029			
40	TRUE	IF Flow (mg)	0.0006	0.7061	0.0047	(7.1092492)
		IF Suspended	0.0244			
		IF Ammonia	0.0459			
28	TRUE	HDD (F)	0.0361	0.6787	0.0066	(1.7028129)
		IF Flow (mg)	0.0012			
		IF Ammonia	0.0083			

# Summary of Better Plants WWTP Partners

- **5 Partners Use Regression Models**
- **3 Partners - 25% Energy Savings Goal Achievers**
- **10 Partners - over 10% Total Energy Savings**
- **5 Partners - over 5% Total Energy Savings**



# What are the Better Plants WWTP Goal Achievers Doing??

- Install **Combined Heat Power** systems
- Use **Biogas** for Heating
- Install **Efficient Aeration Diffusers**
- Optimize **Blowers' Operation**
- Optimize WAS and RAS **Pumps' Operation**



# For Super-Advanced Users: Bio-kinetic Modeling

- **BioTiger Modeling Tool**
  - Developed by **U of Memphis**
  - Developed through US DOE's **IAC program**
- **Active Sludge Process**
- **Fundamental Ground-up Analysis**
- Modeling based on **Monod Kinetics**
- **Excel Spreadsheet Modeling Tool**

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## Bio-Tiger Model

### Input

### Output

#### Current Conditions

Activated Sludge Input Data	
Temperature (°C)	20
$S_0$ (mg/L)	200
Y (ml/g)	1
Q (mg/d)	1
Inlet VSS (mg/L)	40
Oxidizable N (mg/L)	35
biomass (VSS/TSS)	0.85
Influent TSS (mg/L)	200
Inlet biorg TSS (mg/L)	20
Effluent TSS (mg/L)	8
RAS TSS (mg/L)	10000
MLSS (mg/L)	3000
$f_d$	0.1
Y	0.6
$K_d$ (mg/L)	0.1
$k_d$ at 20°C (1/day)	0.1
$k_d$ at 20°C (1/day)	8

#### Alternate Scenario

Activated Sludge Input Data		SRT (day)
Temperature (°C)	20	1
$S_0$ (mg/L)	200	2
Y (ml/g)	1	4
Q (mg/d)	1	6
Inlet VSS (mg/L)	40	8
Oxidizable N (mg/L)	35	10
biomass (VSS/TSS)	0.85	12
Influent TSS (mg/L)	200	14
Inlet biorg TSS (mg/L)	20	16
Effluent TSS (mg/L)	8	18
RAS TSS (mg/L)	10000	20
MLSS (mg/L)	3000	22
$f_d$	0.1	24
Y	0.6	26
$K_d$ (mg/L)	0.1	28
$k_d$ at 20°C (1/day)	0.1	30
$k_d$ at 20°C (1/day)	8	32

#### Aerator Performance Data

Operating DO concentration (mg/L)	
alpha	0.84
beta	0.32
SOTR, lb O <sub>2</sub> /hp-hr	2.7
Temperature (°C)	20
Aeration (hp) being operated	100
Elevation (ft)	200
Aerators operating time (hr/day)	24
Type of aerators (1, 2, or 3)	1
Speed of aerators (R)	100
Energy cost wk (\$/kWh)	0.03

#### Aerator Performance Data

Operating DO concentration (mg/L)		SRT (day)
alpha	0.84	42
beta	0.32	44
SOTR, lb O <sub>2</sub> /hp-hr	2.7	46
Temperature (°C)	20	48
Aeration (hp) being operated	100	50
Elevation (ft)	200	52
Aerators operating time (hr/day)	24	54
Type of aerators (1, 2, or 3)	1	56
Speed of aerators (R)	85	58
Energy cost wk (\$/kWh)	0.03	60

#### Current Conditions

Approximate Operating Conditions	
Total average daily flow rate (mgd)	1.00
Aeration volume in aeration (ml gal)	1.00
Influent BOD5 concentration (mg/L)	200
Influent BOD5 mass loading (lb/day)	1.666
Sec wve Oxid N load (lb/day)	232
Sec wve TSS load (lb/day)	1.666
F/M ratio	0.083
Solids Retention Time (day)	20.0
MLSS (mg/L)	3.000
MLVSS (mg/L)	2.242
TSS Sludge Production (lb/day)	827
TSS in activated sludge effluent (lb/day)	66.7
Total Oxygen Requirement (lb/day)	3.106
Total Oxygen Req'd w/ Wind. (lb/day)	2.680
Total oxygen supplied (lb/day)	3.354
Mixing intensity in the reactor (hp/ml gal)	150
RAS flow rate (mgd)	0.43
RAS recycle percentage (%)	42.3
VAS flow rate (mgd)	0.010
RAS TSS concentration (mg/L)	10,000
Total sludge production (lb/day)	834
Recistor Duration Time (hr)	24.0
VOLR (lb BOD/(thru cu ft-day))	12.40
Effluent CBOD5 (mg/L)	4.0
Effluent TSS (mg/L)	8.0
Effluent Ammonia-N (mg/L)	0.15
Effluent NO3-N (mg/L)	25.6
Effluent NO2-N w/indist (mg/L)	7.7

#### Alternate Scenario

Approximate Operating Conditions	
Total average daily flow rate (mgd)	1.00
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Total oxygen supplied (lb/day)	3.185
Mixing intensity in the reactor (hp/ml gal)	85
RAS flow rate (mgd)	0.43
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Actual Aerator Performance	
Field OTR (lb O <sub>2</sub> /hp-hr)	0.34
Aerator energy use (kWh/month)	70,200
Energy cost (\$/month)	6,318

Actual Aerator Performance	
Field OTR (lb O <sub>2</sub> /hp-hr)	1.56
Aerator energy use (kWh/month)	33,780
Energy cost (\$/month)	3,580

Cost savings vs. current condition: \$3,738

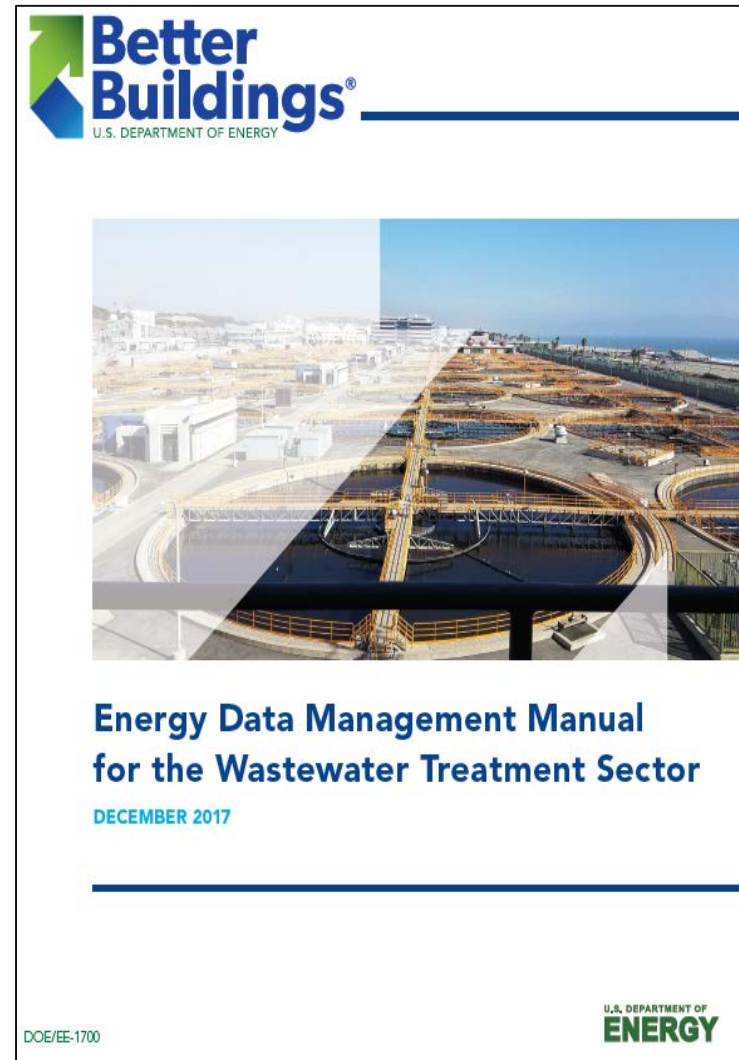
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Input\_Output\_Data Calculations\_Current Calculations\_Alternate ...



# Further Resources

- **Better Buildings Solution Center**
  - <https://betterbuildingssolutioncenter.energy.gov/>
- Quarterly Better Plants W/WW Informational **Webinar**
- **Energy Data Management Manual** for the Wastewater Treatment Sector
  - [https://www.energy.gov/sites/prod/files/2018/01/f46/WastewaterTreatmentDataGuide\\_Final\\_0118.pdf](https://www.energy.gov/sites/prod/files/2018/01/f46/WastewaterTreatmentDataGuide_Final_0118.pdf)
- **Energy Efficiency Strategies** for Municipal Wastewater Treatment Facilities
  - <https://www.nrel.gov/docs/fy12osti/53341.pdf>



# Questions?