Energy Performance Analysis for Wastewater Treatment Plants

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Better Buildings, Better Plants

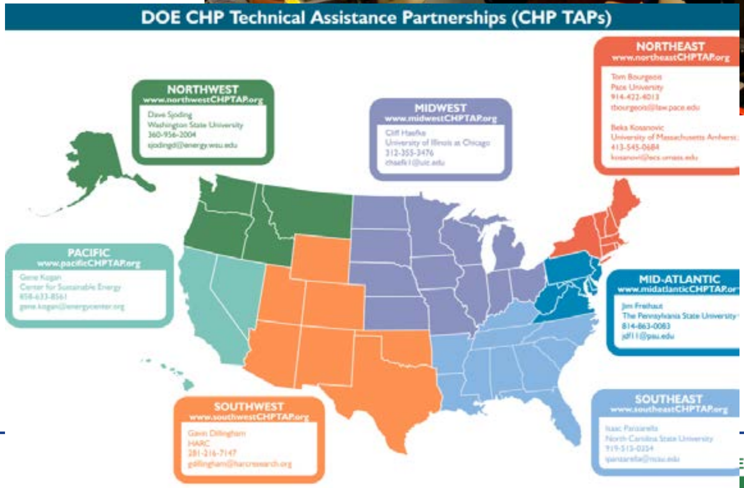
- **Better Plants** Program is a key component of the DOE's **Better Buildings Initiative**, which seeks to improve the energy efficiency of residential, commercial and **industrial** buildings
- Through Better Plants:
  - Set **long-term efficiency goals (25%)**
  - Receive **technical assistance, networking 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**



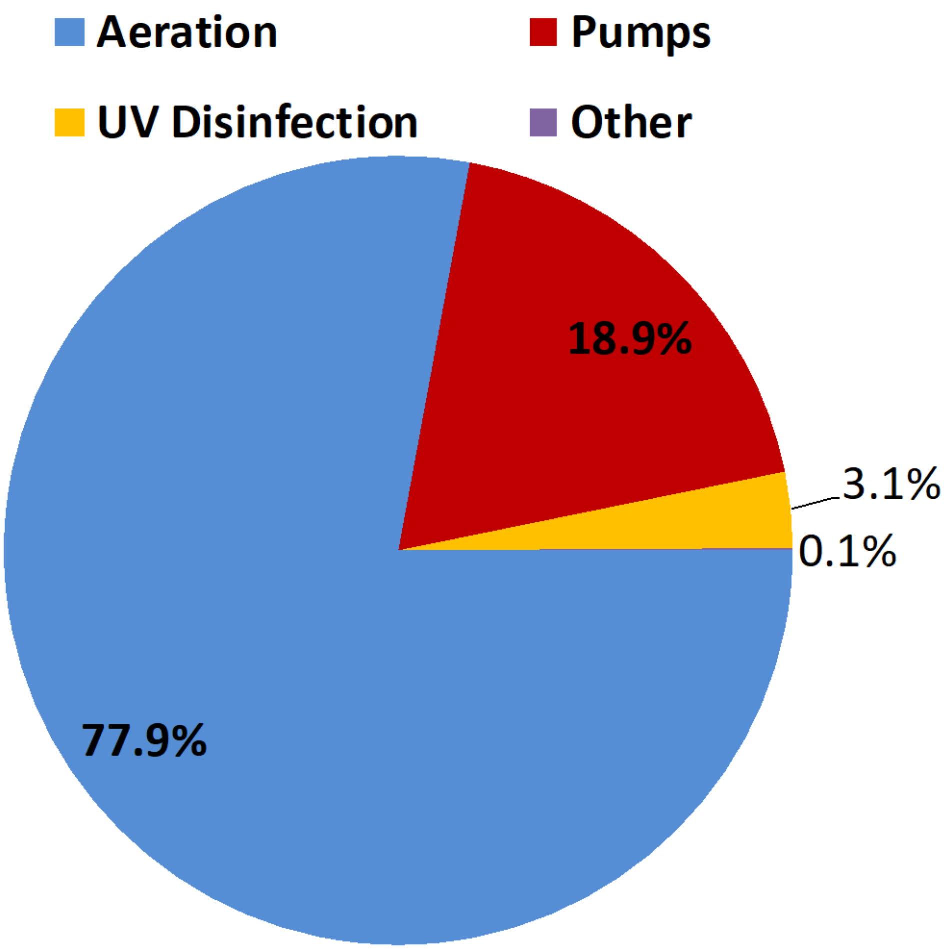
Wastewater Treatment Plants - Energy Intensive!

- **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)

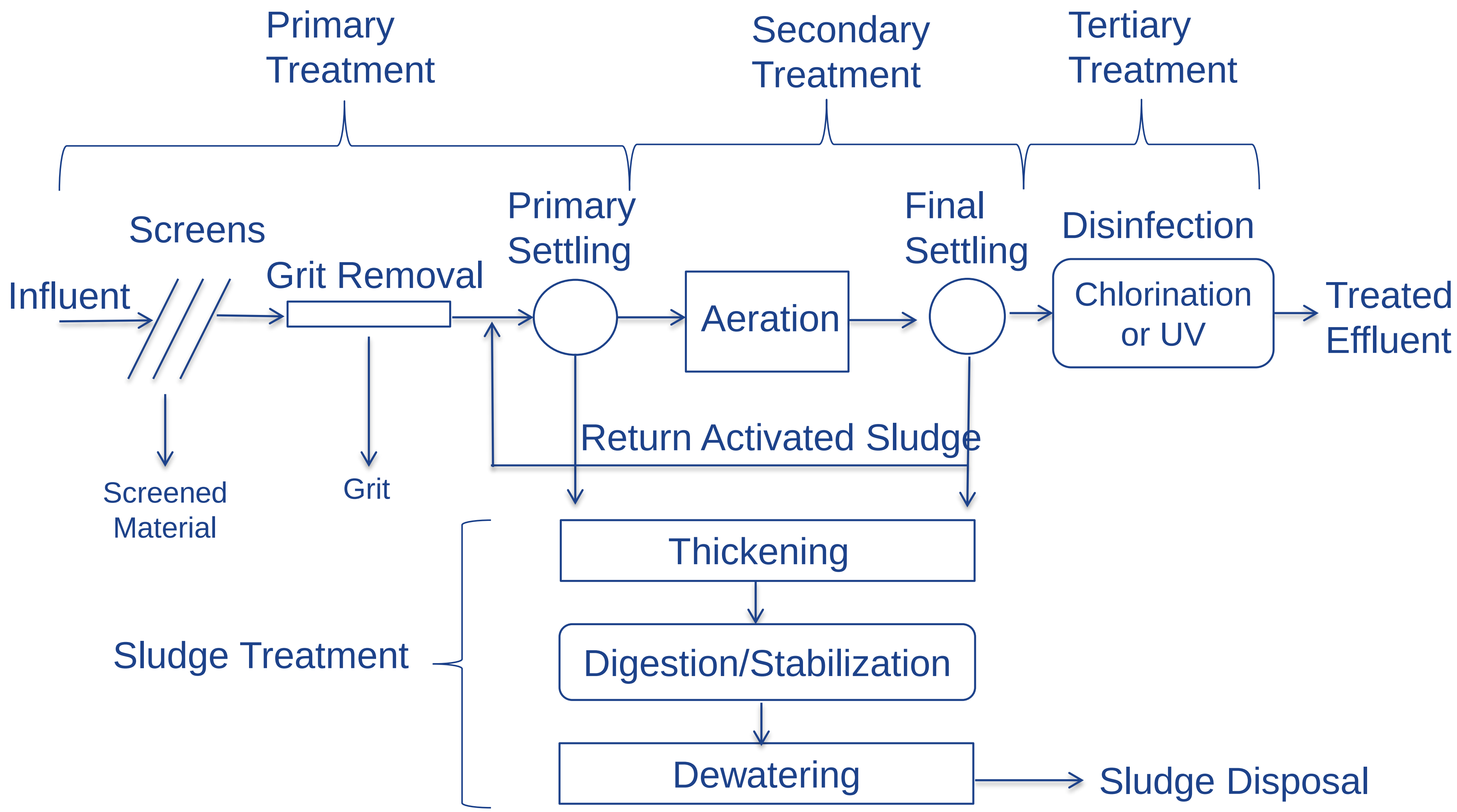
Typical WWTP Electricity Use Distribution

- **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

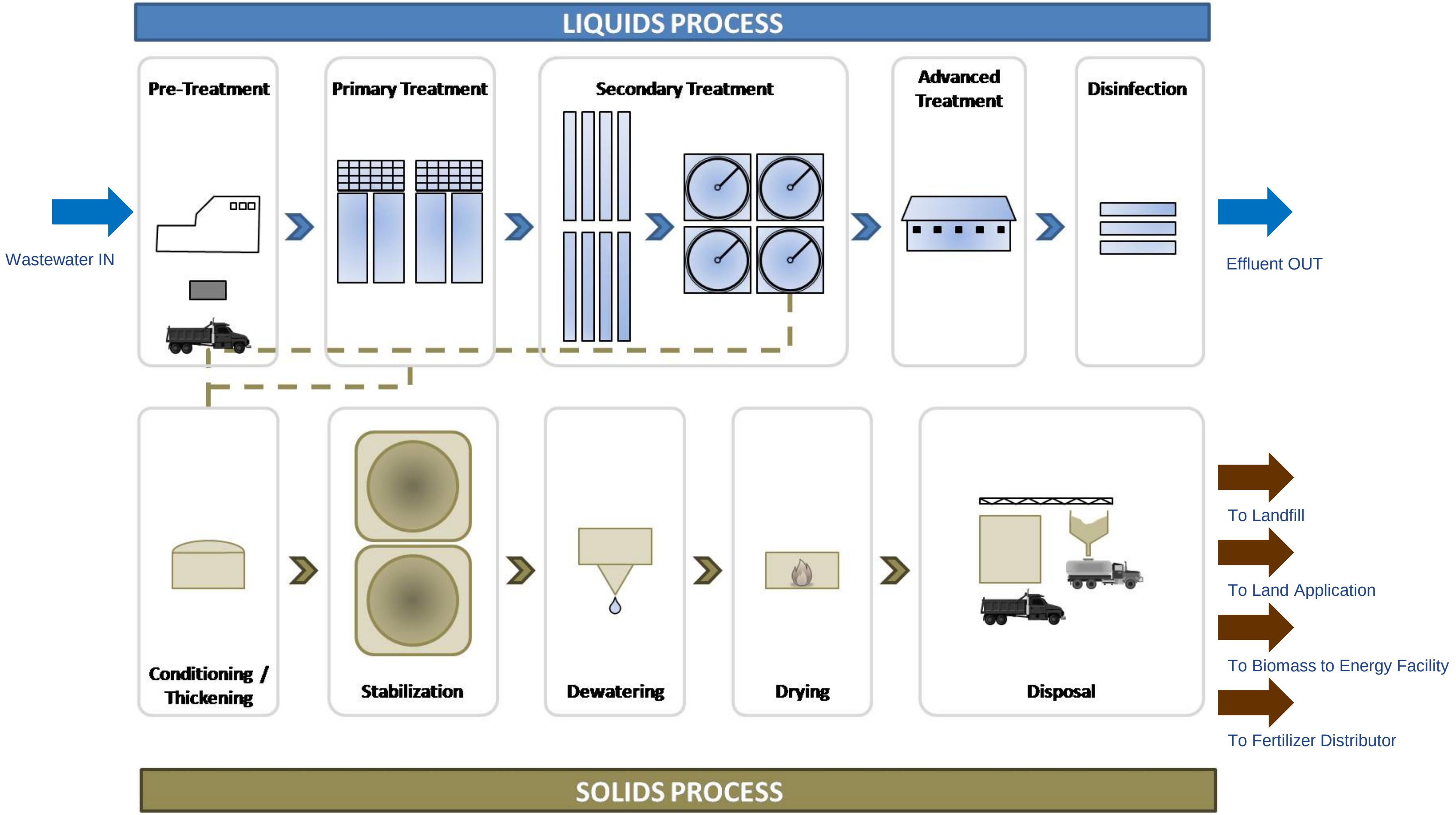


Source*: Malcolm Pirnie, the Water Division of ARCADIS (2011). "Typical Energy Usage Patterns in U.S. Wastewater Treatment Plants."*

WWT Process Overview



WWTP Process Overview



Main Challenges for Baselining & 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?

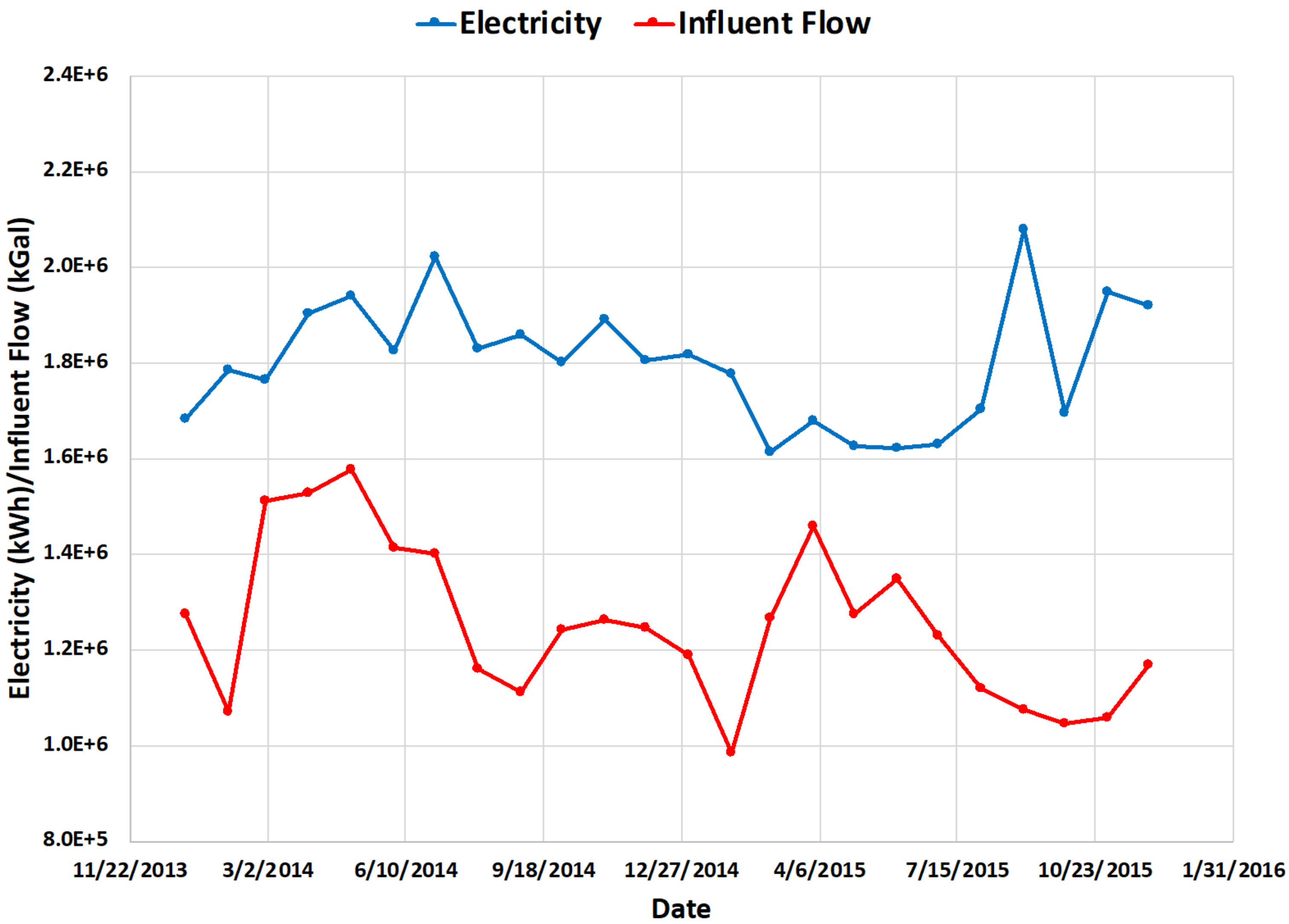
Partial Load Data for Some WWTP Partners

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	**181%**
Grand Rapids Water Resource Recovery Facility	Grand Rapids Plant	60.9	32.6	**87%**
Charleston Water System	Charleston Plant	33.1	20.4	**62%**
Ithaca Area Wastewater Treatment Facility	Ithaca Plant	8.7	5.4	**61%**
Massachusetts Water Resources Authority	Boston Plant	364	234	**56%**
Western Lake Superior Sanitary District	Duluth Plant	43	32	**34%**
Kent County Department of Public Works	Milford Plant	13.9	11.3	**23%**

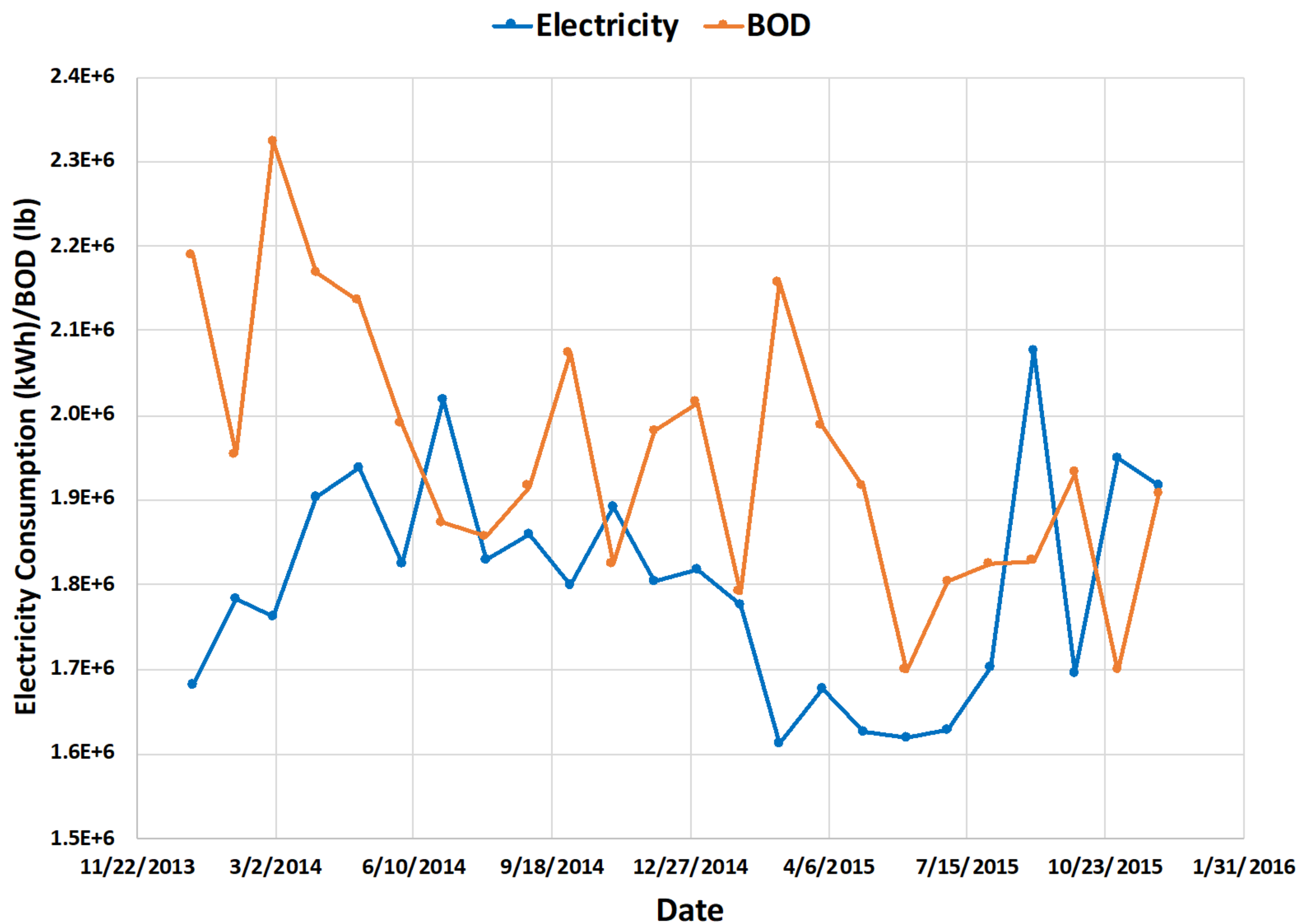
Partial Load Data for Some WWTP Partners

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%**

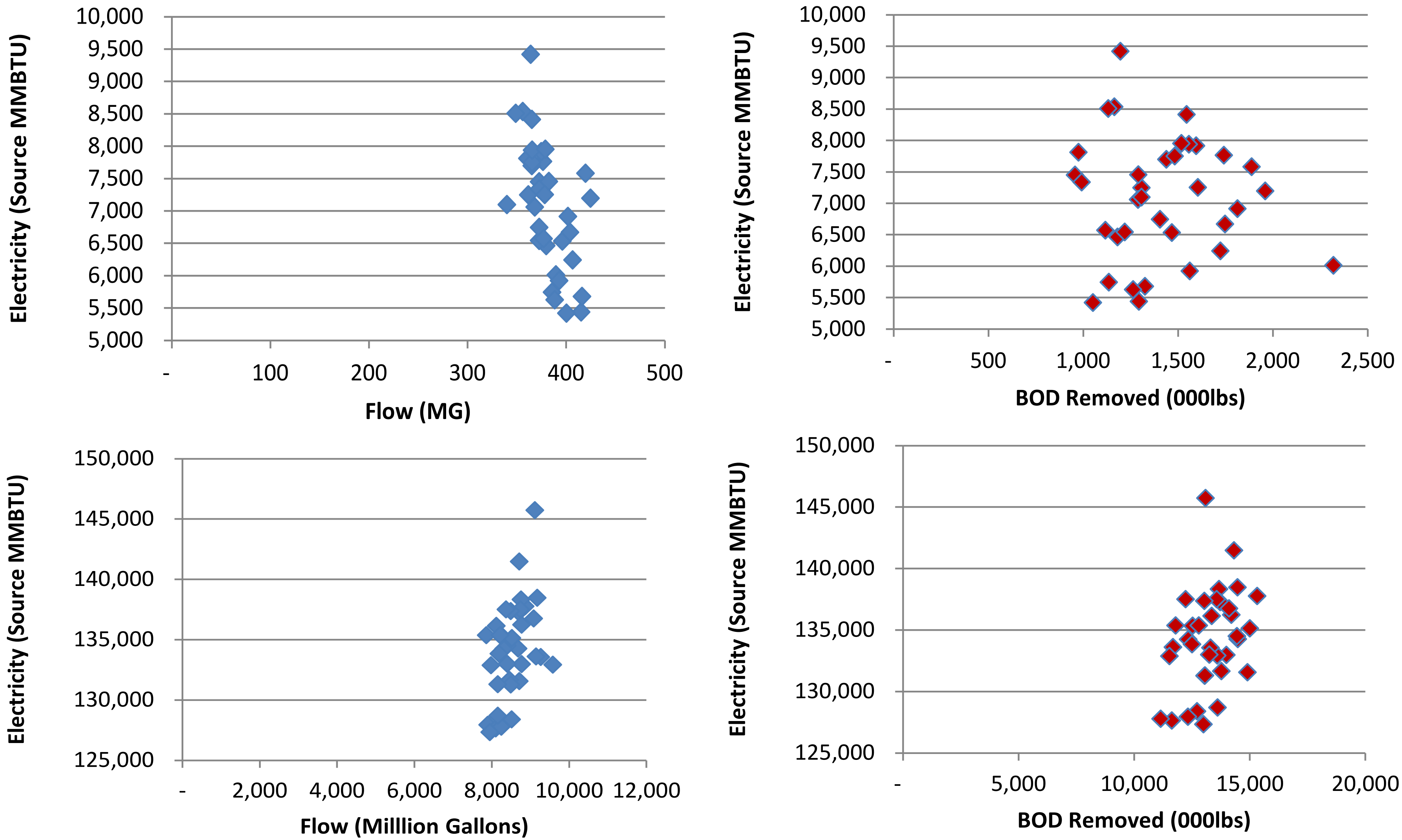
Data Review for One Partner



Data Review for One Partner



Electricity vs Flow and BOD for Two Partners



Main Challenges

- Where to draw the boundary?
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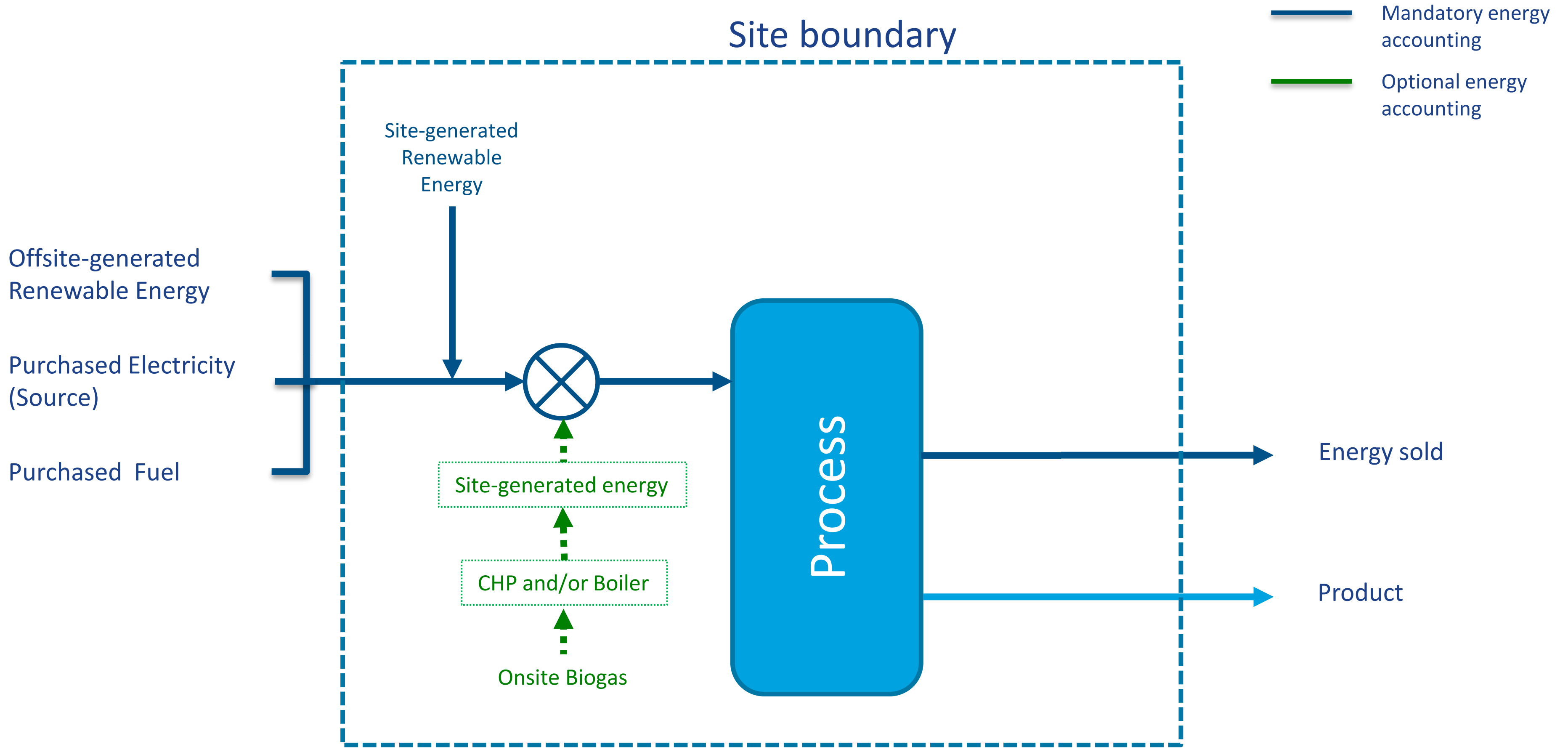
Better Plants Boundary Definition Considerations



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

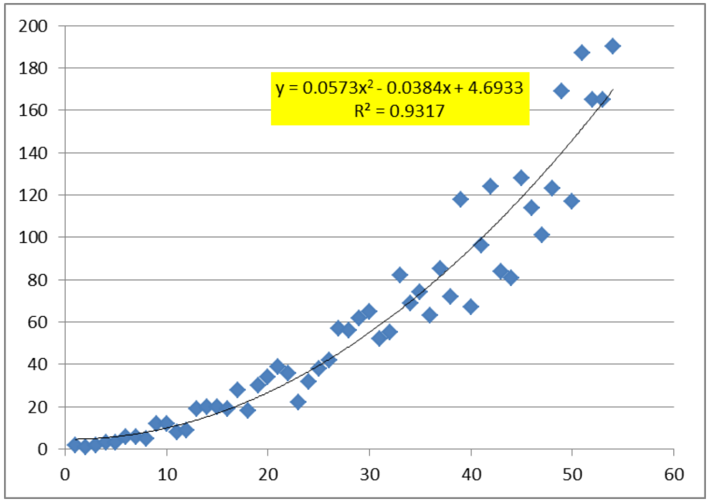
	Regression-based Approach	Facility-level Approach	Corporate-level Approach
1	Define the boundary	Define the boundary	Define the boundary
2	Choose a baseline year	Choose a baseline year	Choose a baseline year
3	Determine relevant variables affecting energy consumption at each facility	Decide on the energy 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 Baselining and Tracking Guidance, US DOE, January 2015.

Regression Based Approach

What is a regression?

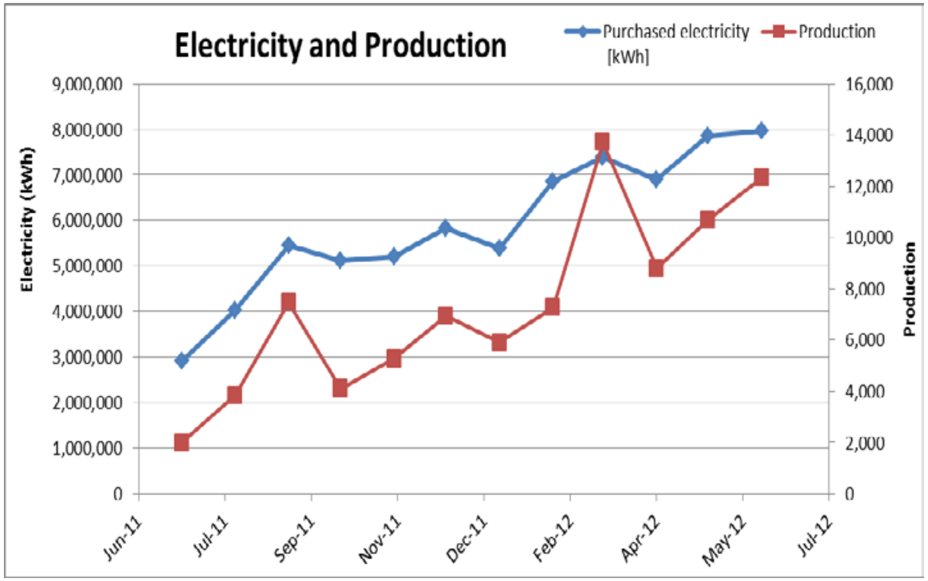
- **Statistical analysis** that models a plant's energy consumption
- **EnPI 5.0** tool

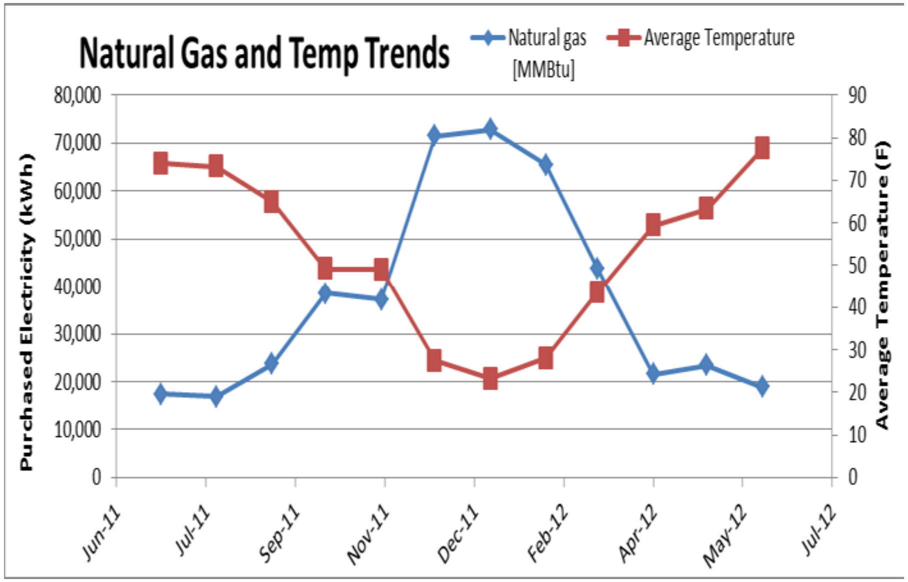


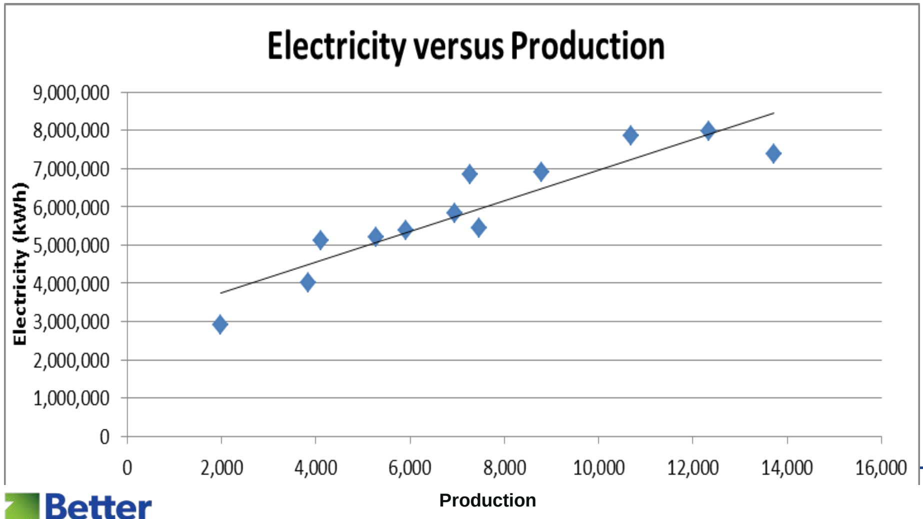
Why is regression better?

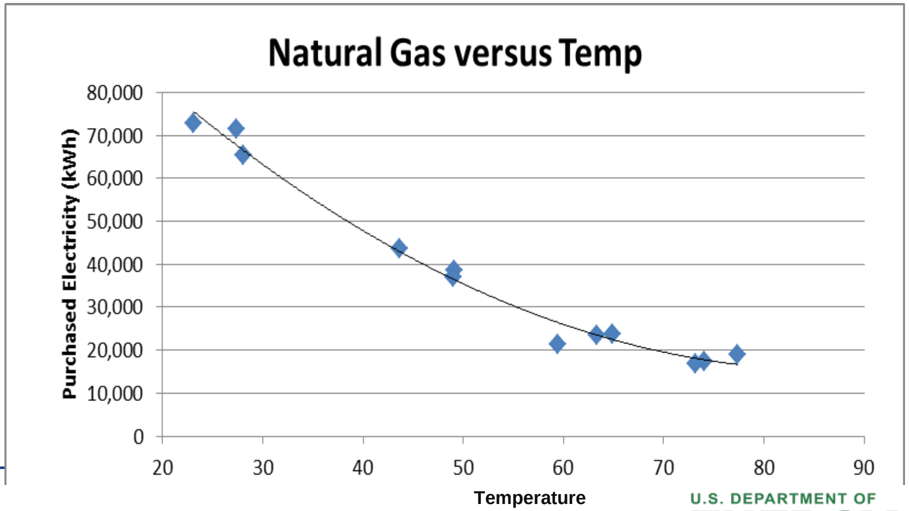
- Accounts for energy fluctuations due to changes on **flow, BOD, weather,** etc.
- Uncovers **insights on factors** that impact energy use that are not apparent
- Can **validate energy savings**

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 R	Model p-V	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				

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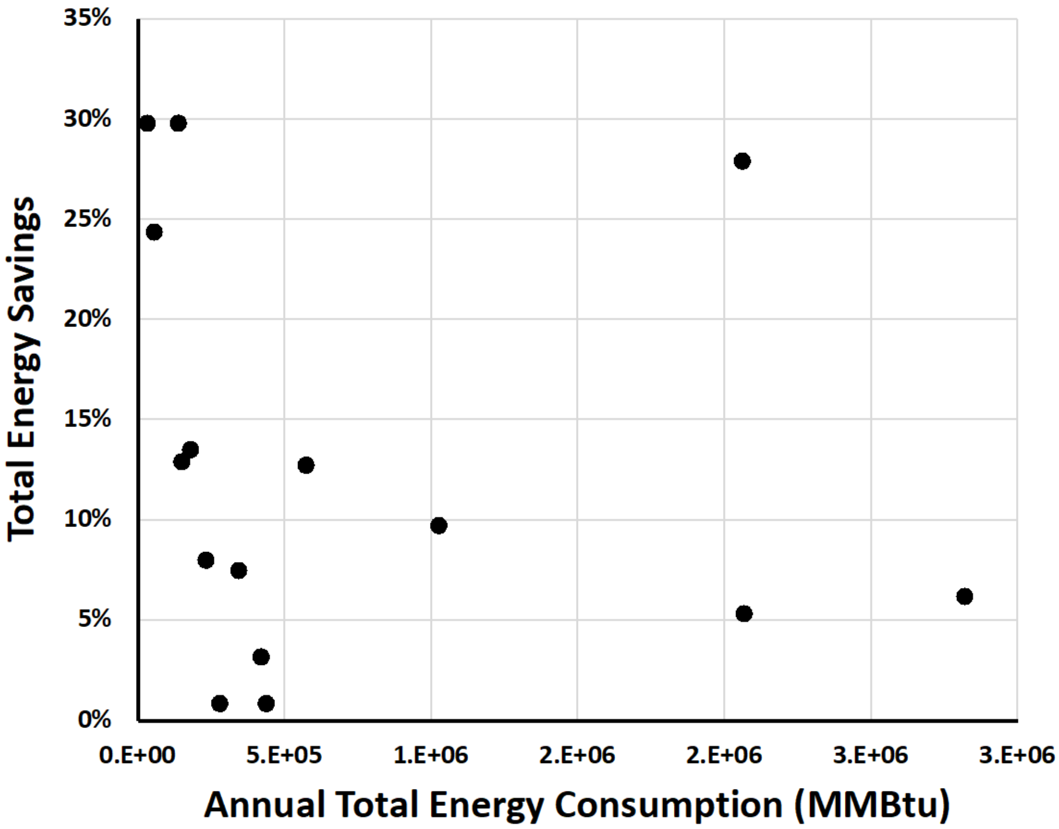
EnPI Models Selection

- 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 **R²** > **0.5**
- **Engineering** validity
  - Included **variables**
  - **Coefficients** of variables
  - **Intercepts**

M	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 Phosphor	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 Suspendec	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

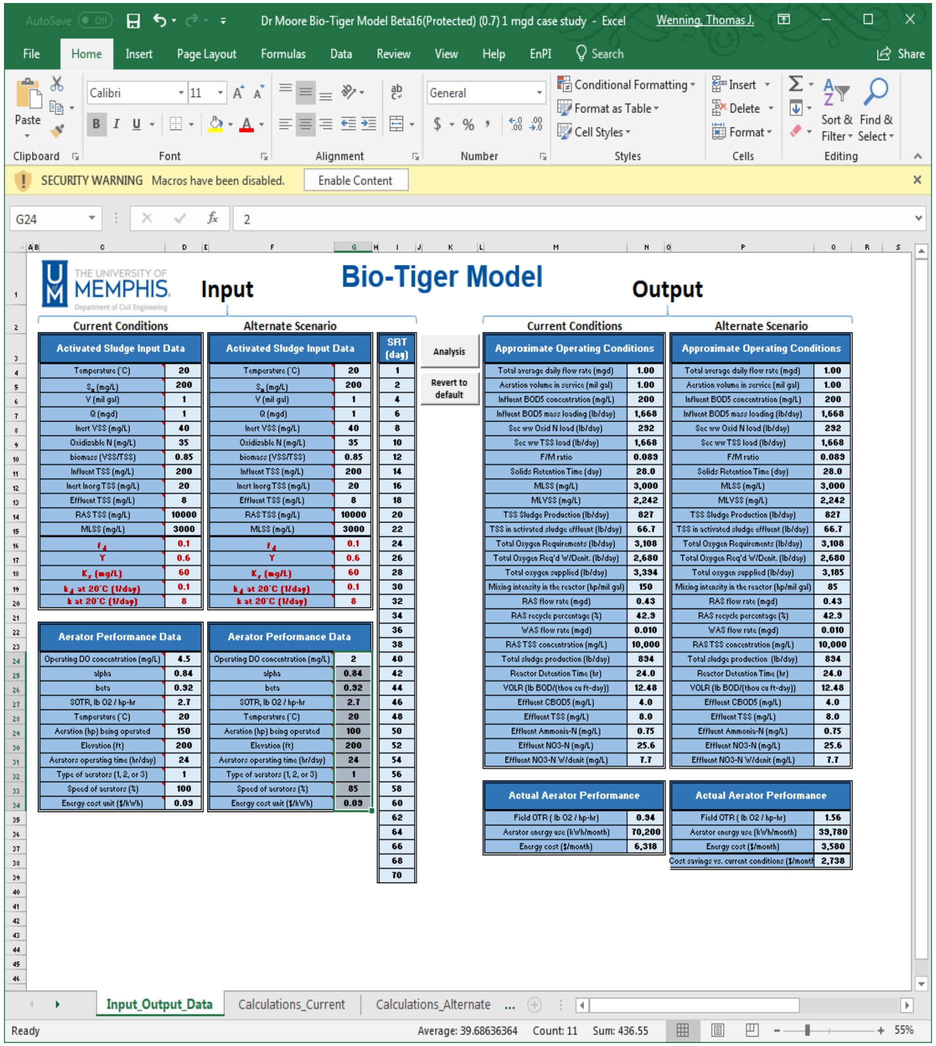


What are the Better Plants WWTP Goal Achievers Doing??

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

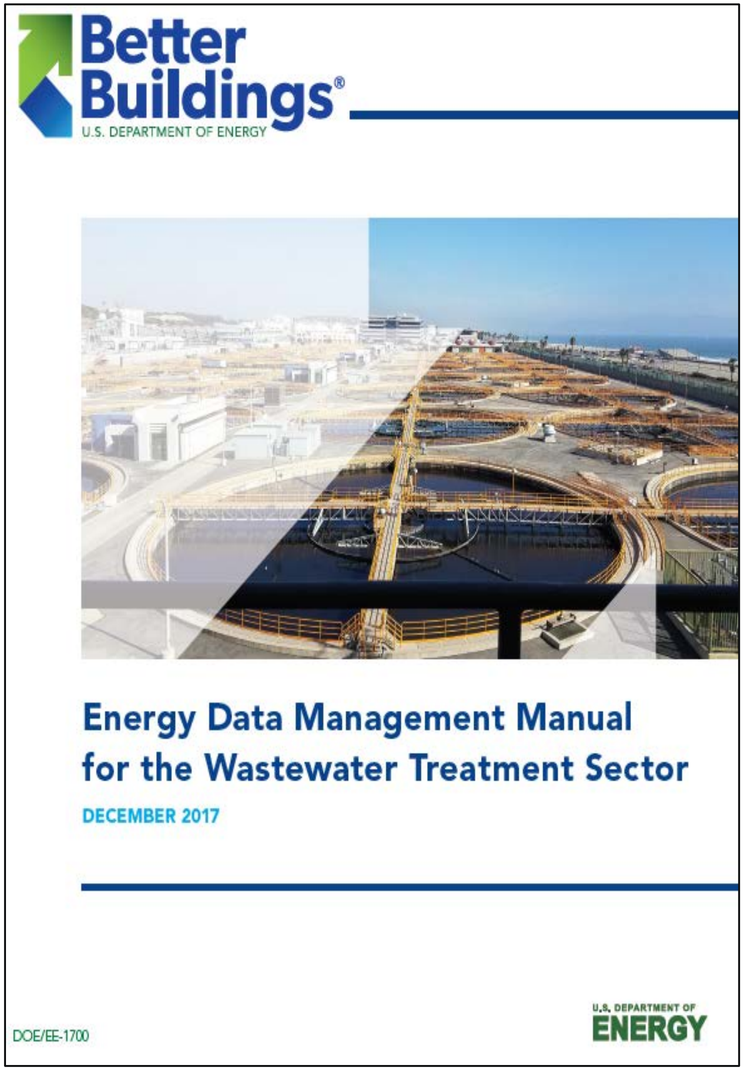
For Super-Advanced Users: Bio-kinetic Modeling

- **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



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
- **Energy Efficiency Strategies** for Municipal Wastewater Treatment Facilities
  - https://www.nrel.gov/docs/fy12osti/53341.pdf



Questions?