Energy Costs and Demands in Wastewater Treatment

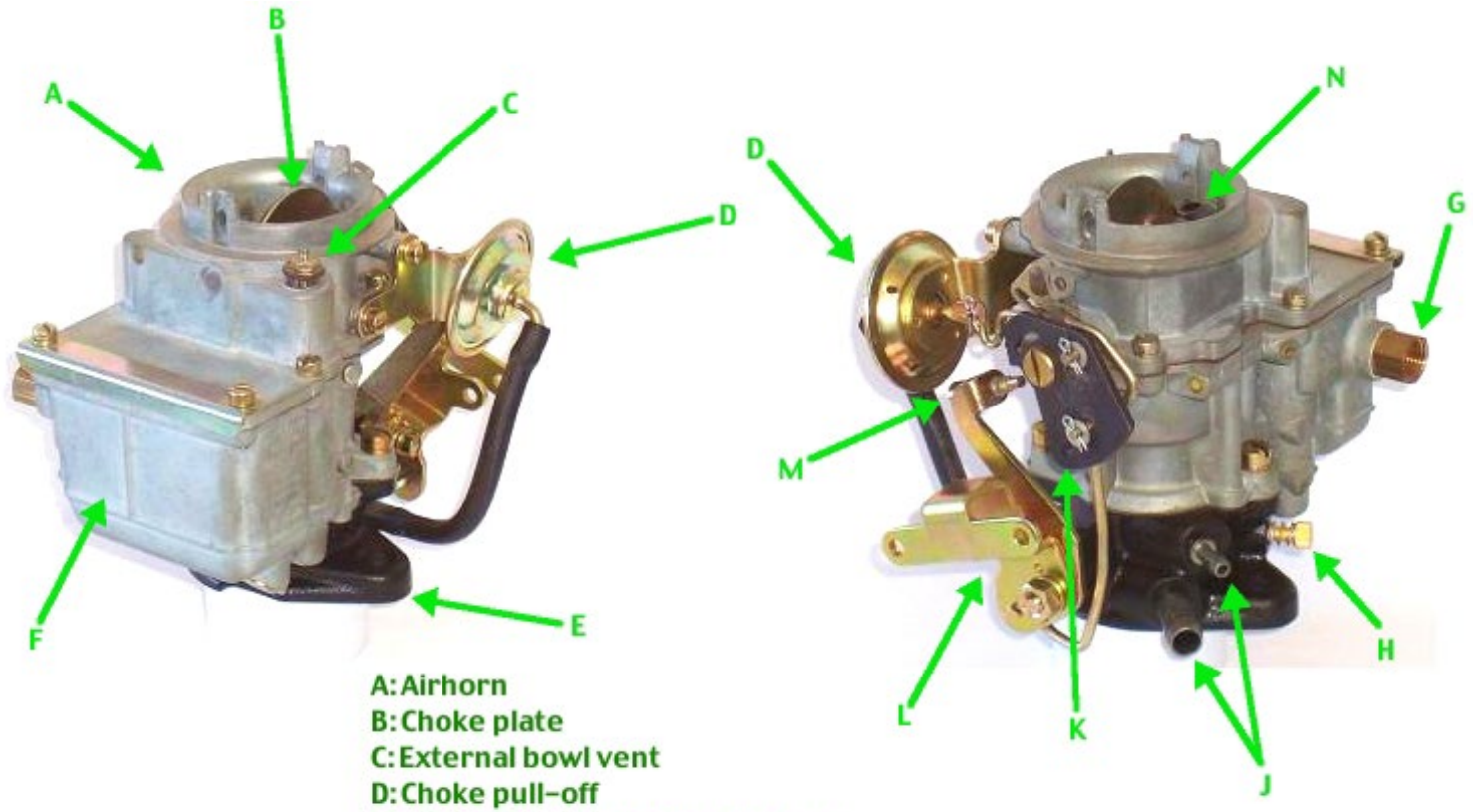
David A. Ladner, Harish Lakshmi Srinivasan, Ashley Martin, and Michael Carbajales-Dale

ECU Webinar, April 4, 2022

SC E3

CLEMSON INDUSTRIAL ASSESSMENT CENTER

Carburetor



A: Airhorn
B: Choke plate
C: External bowl vent
D: Choke pull-off
E: Throttle body & mounting base
F: Float bowl
G: Fuel inlet
H: Idle mixture adjusting screw
J: Vacuum nipples
K: Fast-idle cam
L: Throttle lever
M: Idle speed adjusting crackscrew
N: Internal bowl vent

Source: Wikipedia

Activities are part of the SC E3 program.

Search “SC E3 Clemson” to find the web site.

The SC E3 program is geared toward pollution prevention; energy reduction helps.

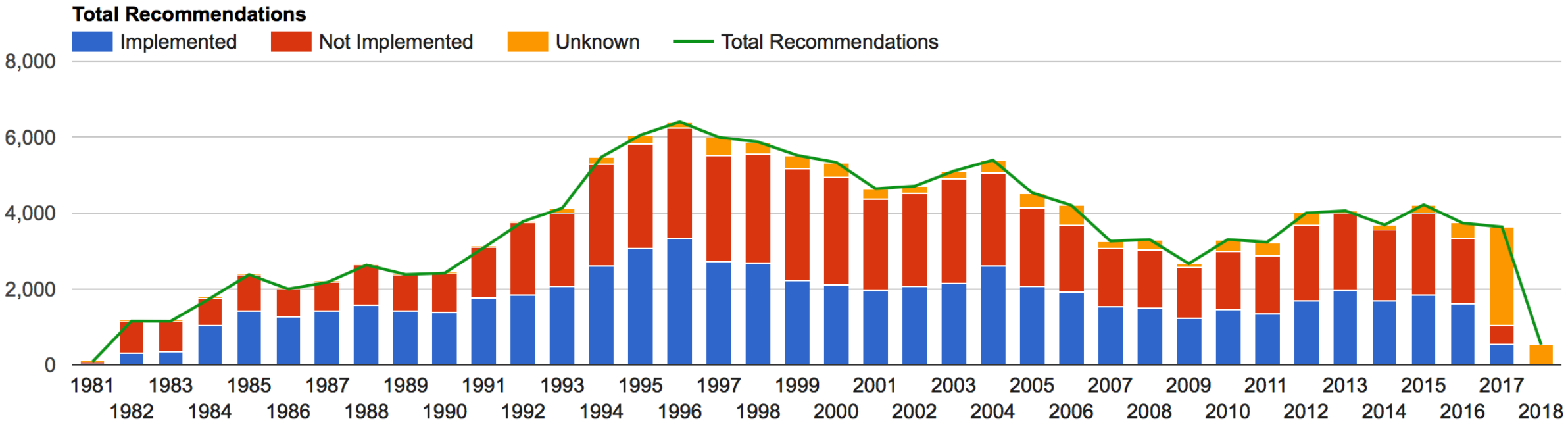
The greenest watt is the one that doesn't have to be produced

Our goal is to save the client money by reducing their energy/power bill while maintaining the same (or better!) productivity.

We do this by:

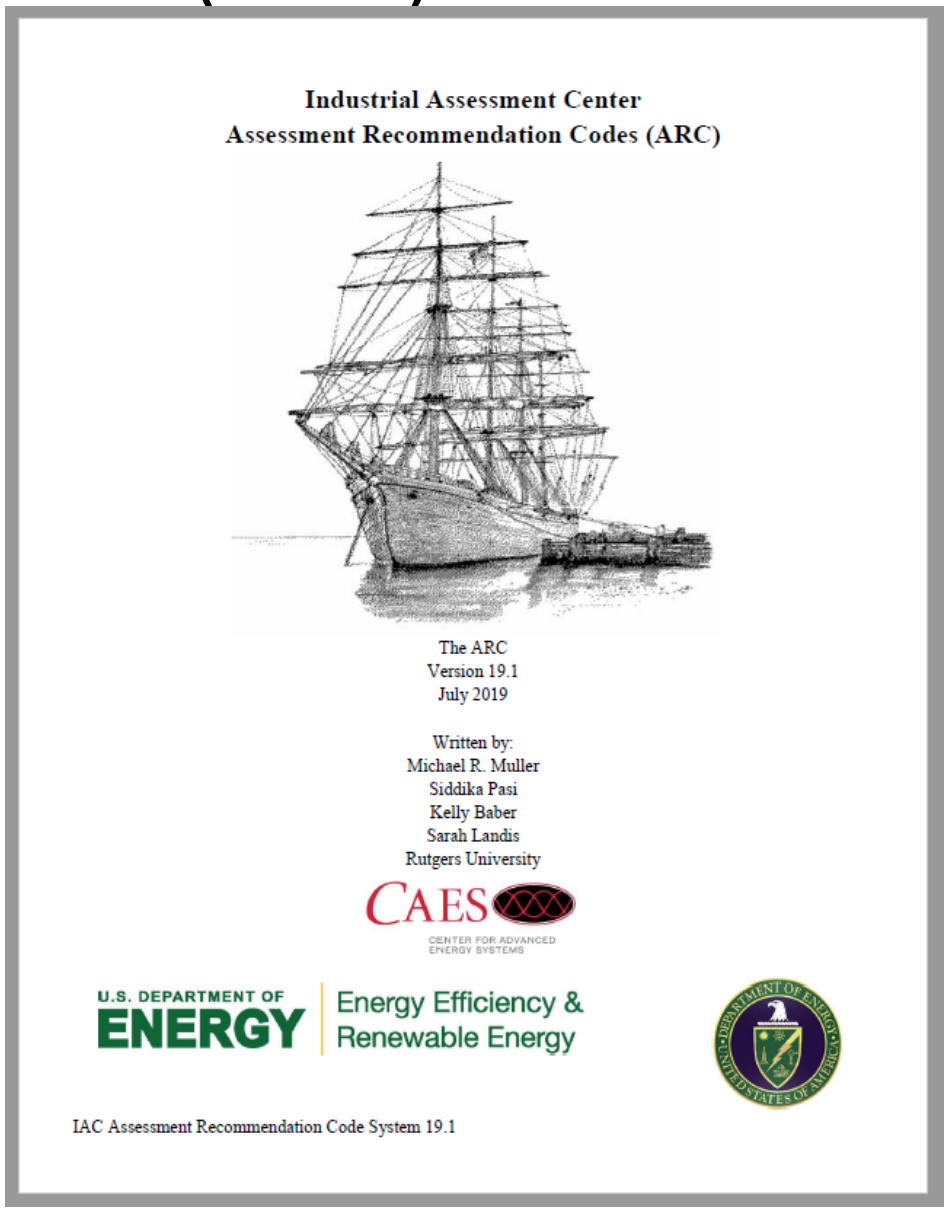
- Calculating current energy and power consumption
- Identifying potential issues
- Determining payback of potential solutions
- Presenting you with a final report of our findings

We build on knowledge from DOE's Industrial Assessment Centers (IACs).



- Database accessed at https://iac.university

The IAC database is built around the Assessment Recommendation Code (ARC).



Industrial Assessment Center
Assessment Recommendation Codes (ARC)

The ARC
Version 19.1
July 2019

Written by:
Michael R. Muller
Siddika Pasi
Kelly Baber
Sarah Landis
Rutgers University

CAES
CENTER FOR ADVANCED ENERGY SYSTEMS

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

IAC Assessment Recommendation Code System 19.1

The ARC is divided into three recommendation categories.

- 2. Energy Management
  - 2.1 Combustion Systems (furnaces, ovens, boilers, etc.)
  - 2.2 Thermal Systems (heating, cooling towers, chillers, etc.)
  - 2.6 Building and Grounds (lighting, space conditioning, etc.)
- 3. Waste Minimization / Pollution Prevention
  - 3.1 Operations (stripping, by-product use, material application, etc.)
  - 3.4 Water Use (water quality, water treatment, etc.)
  - 3.5 Recycling (liquid waste, solid waste, etc.)
- 4. Direct Productivity Enhancements
  - 4.1 Manufacturing Enhancements (bottleneck reduction, defect reduction, etc.)
  - 4.3 Inventory (just-in-time, etc.)
  - 4.6 Reduction of Downtime (maintenance, quick change, alarms, etc.)

Note: The sub-categories listed above are just a few examples. There are several dozen sub-categories.

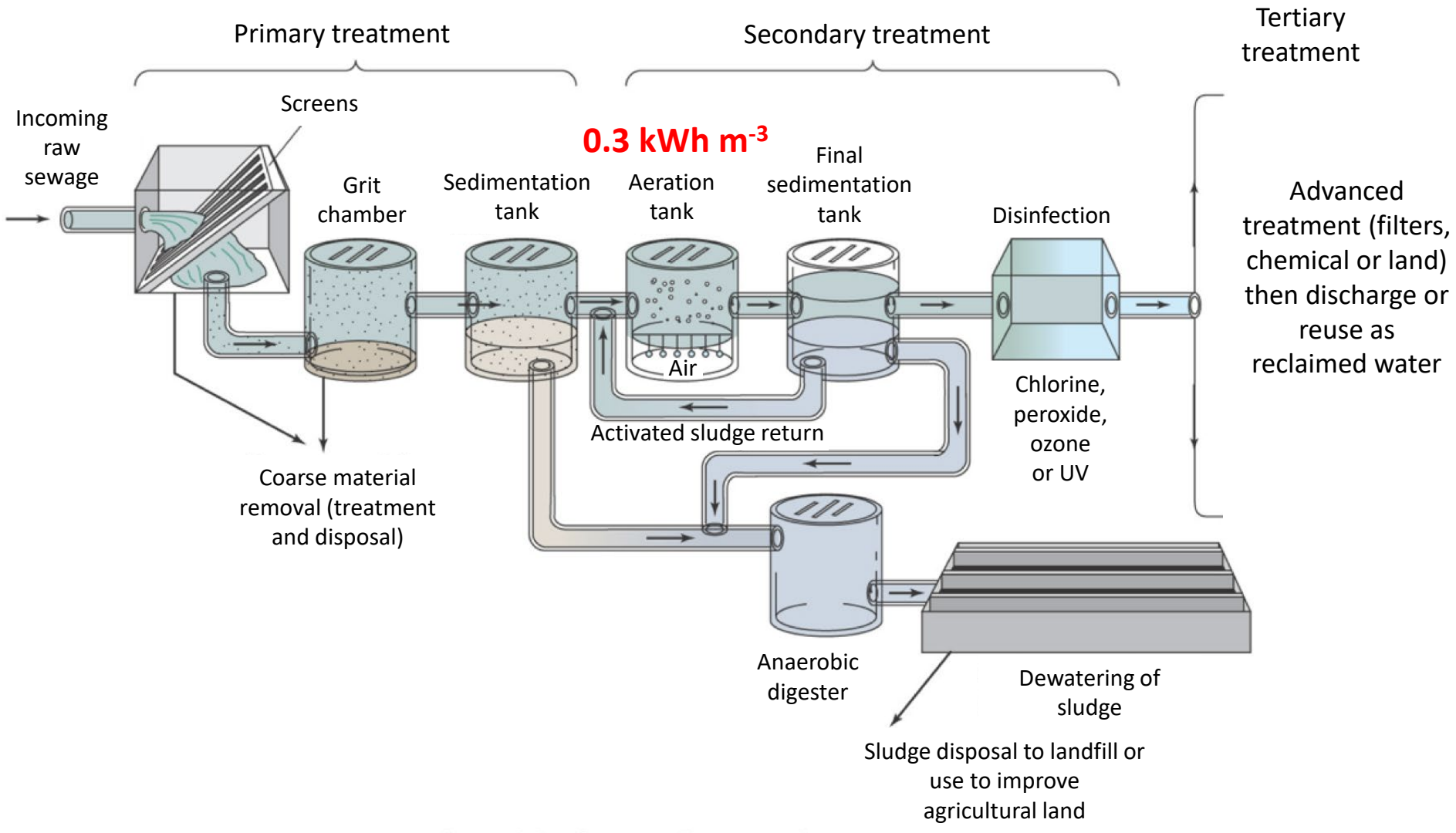
Recently DOE has emphasized wastewater treatment plants, or water resource recovery facilities (WRRFs).

Why is energy a big deal in WRRFs?

- Water and wastewater treatment accounts for about **3%** of the total U.S. energy use.
- The total annual energy use by municipal wastewater treatment systems in the U.S. is approximately **30 billion kWh**.
- Aeration alone takes approximately **60%** of the energy requirement for the wastewater treatment plant.

Current domestic wastewater treatment infrastructure

Total 0.6 kWh m^{-3} used



Slide from Sudeep Popat. Statistics from McCarty et al., *Environmental Science & Technology*, 2011

What do you think are the most common energy-saving recommendations?

What have you done at your facility to save energy?

What would you like to do?

From the IAC database some general trends are apparent.

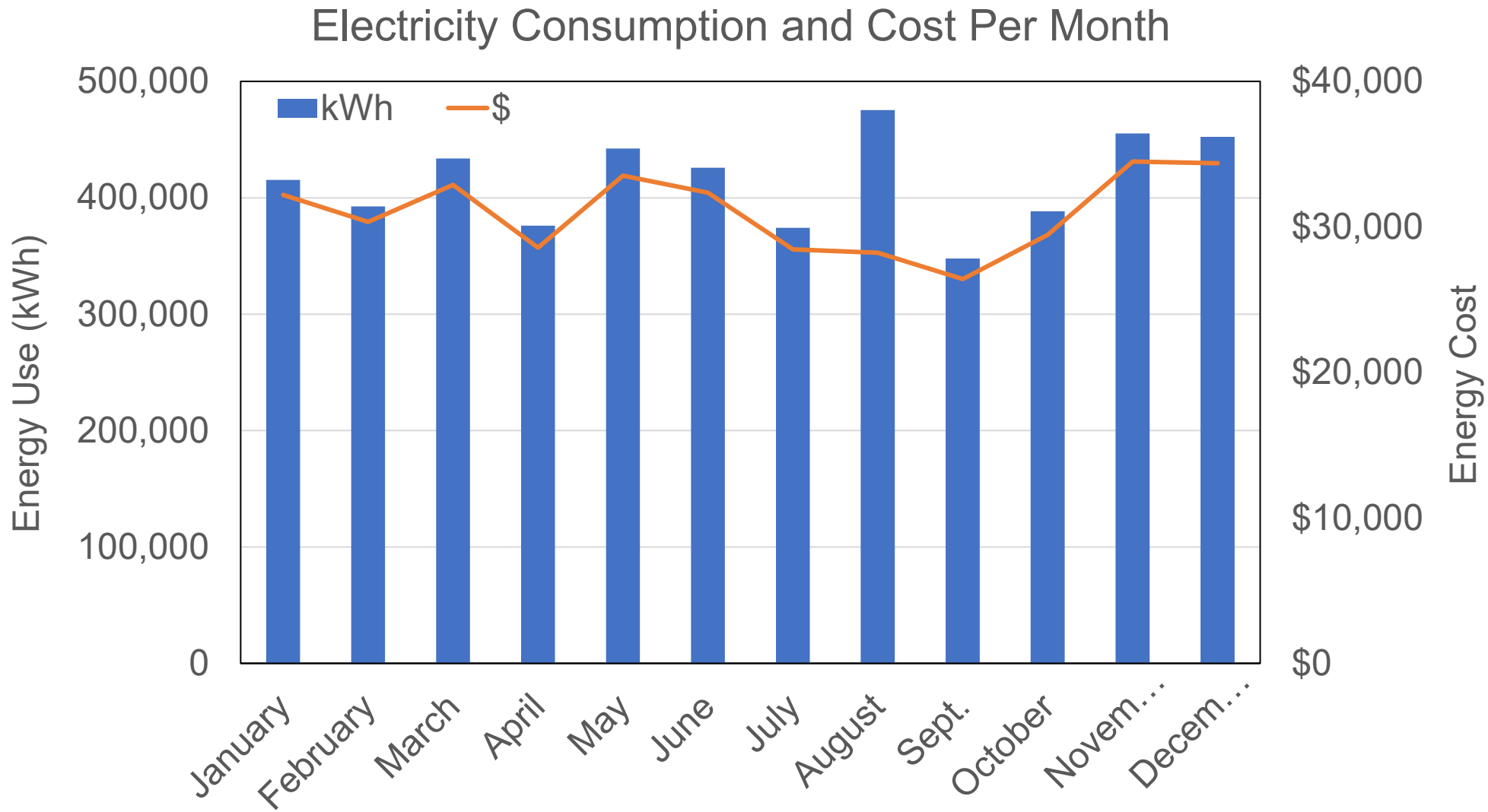
Most often-used recommendations

ARC	Description	Number of Recommendations	Percent of All Recommendations
2.7142	UTILIZE HIGHER EFFICIENCY LAMPS AND/OR BALLASTS	120	16%
2.4146	USE ADJUSTABLE FREQUENCY DRIVE OR MULTIPLE SPEED MOTORS ON EXISTING SYSTEM	107	14%
2.7135	INSTALL OCCUPANCY SENSORS	37	5%
2.4322	USE OR REPLACE WITH ENERGY EFFICIENT SUBSTITUTES	35	5%
2.4111	UTILIZE ENERGY-EFFICIENT BELTS AND OTHER IMPROVED MECHANISMS	23	3%
2.4133	USE MOST EFFICIENT TYPE OF ELECTRIC MOTORS	23	3%
2.3415	USE A FOSSIL FUEL ENGINE TO COGENERATE ELECTRICITY OR MOTIVE POWER; AND UTILIZE HEAT	18	2%

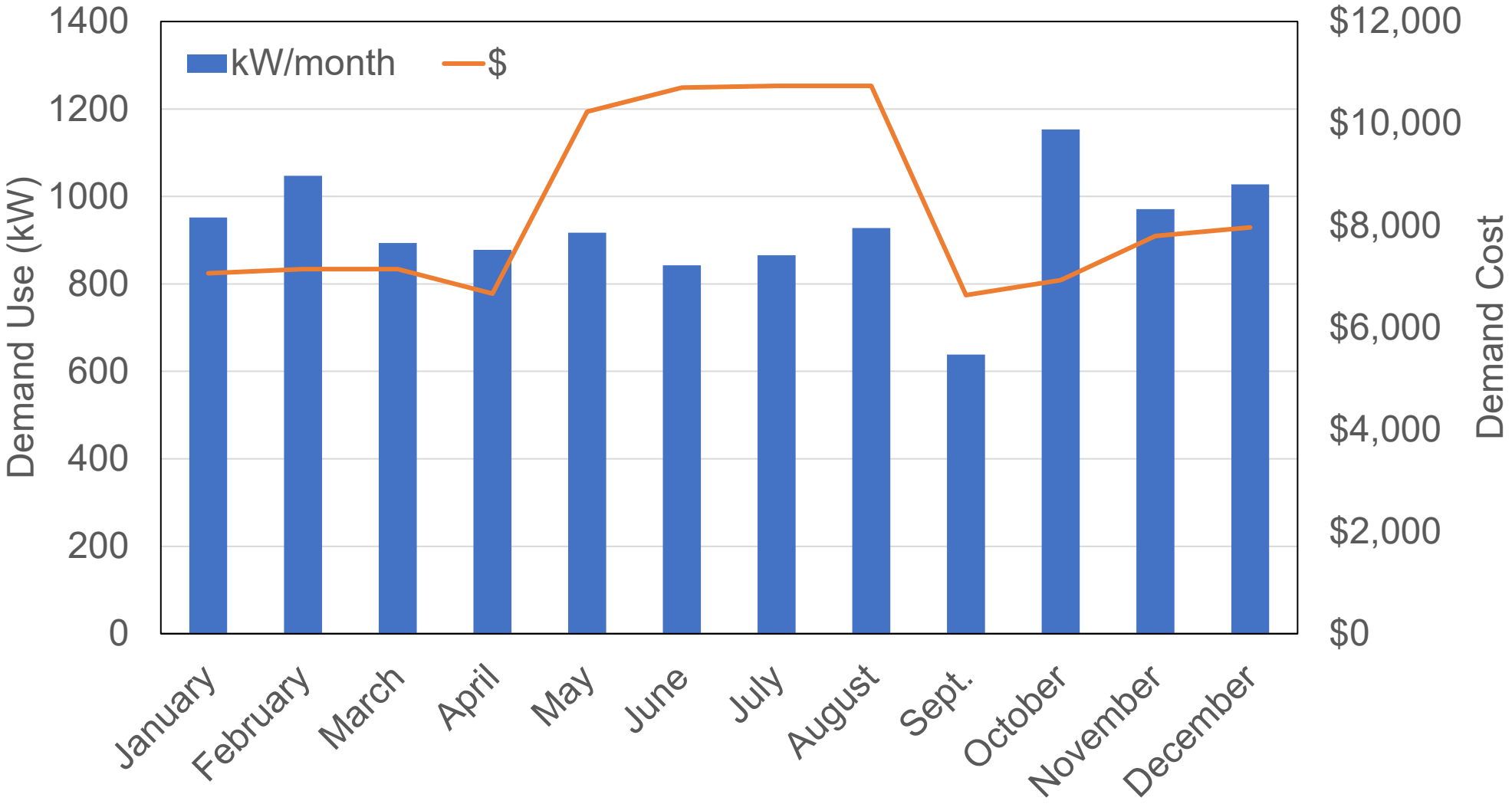
- **SIC:** 4952 - Sewerage Systems
- **NAICS**: 221320 - Sewage Treatment Facilities
- 726 Recommendations

Six Example Recommendations

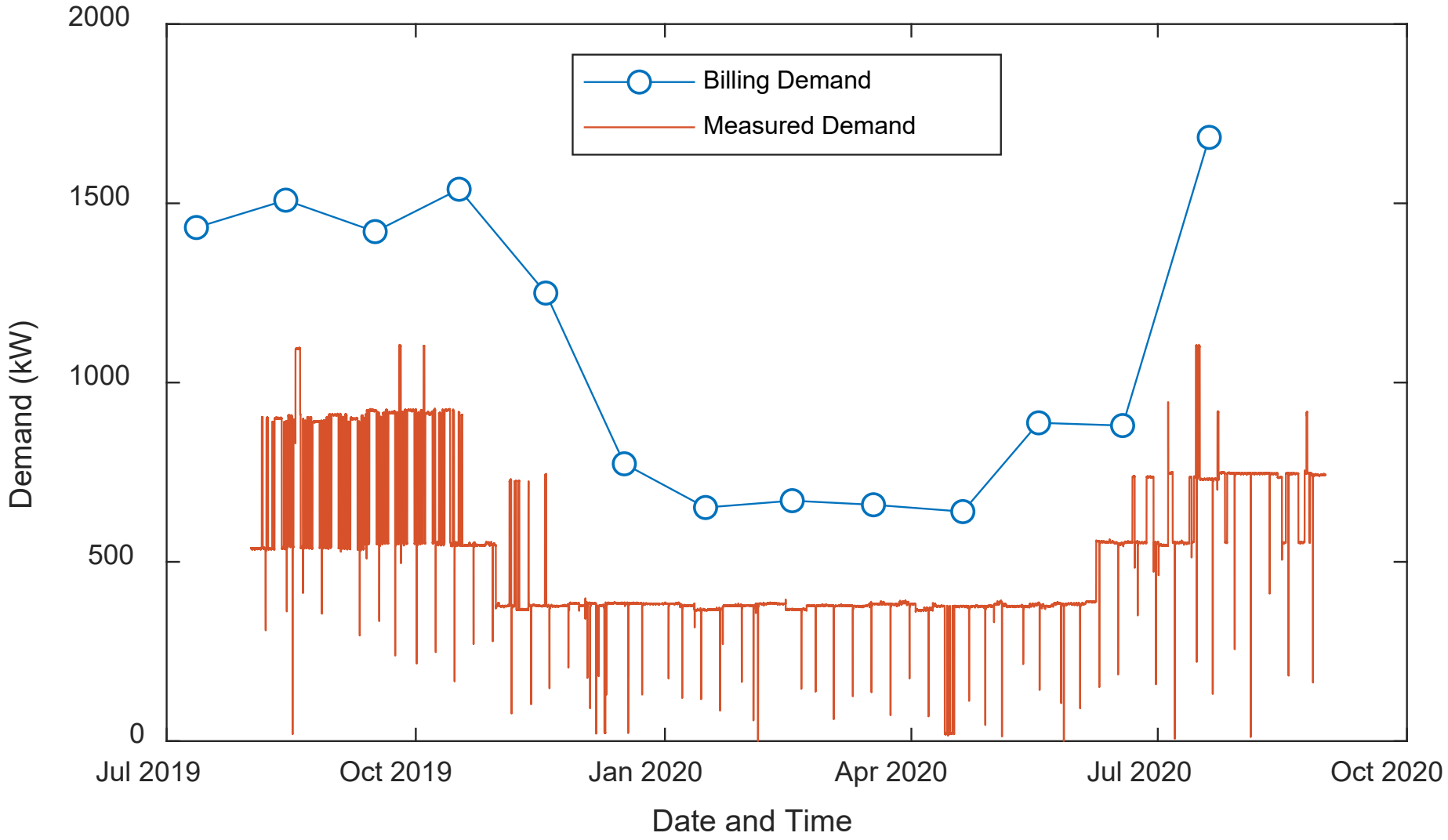
Example 1: Demand Management.



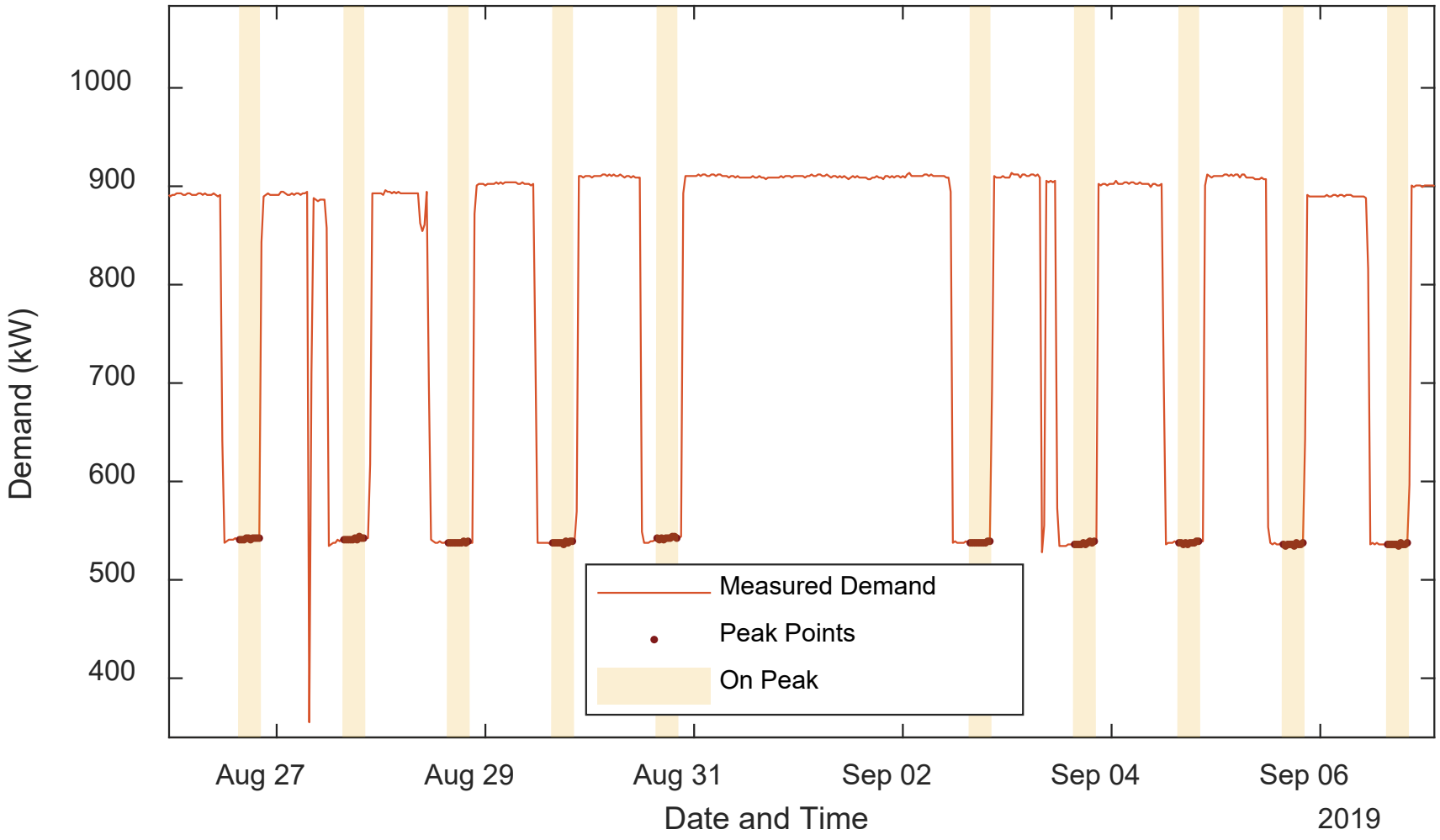
Electricity demand analysis is often eye opening to clients.



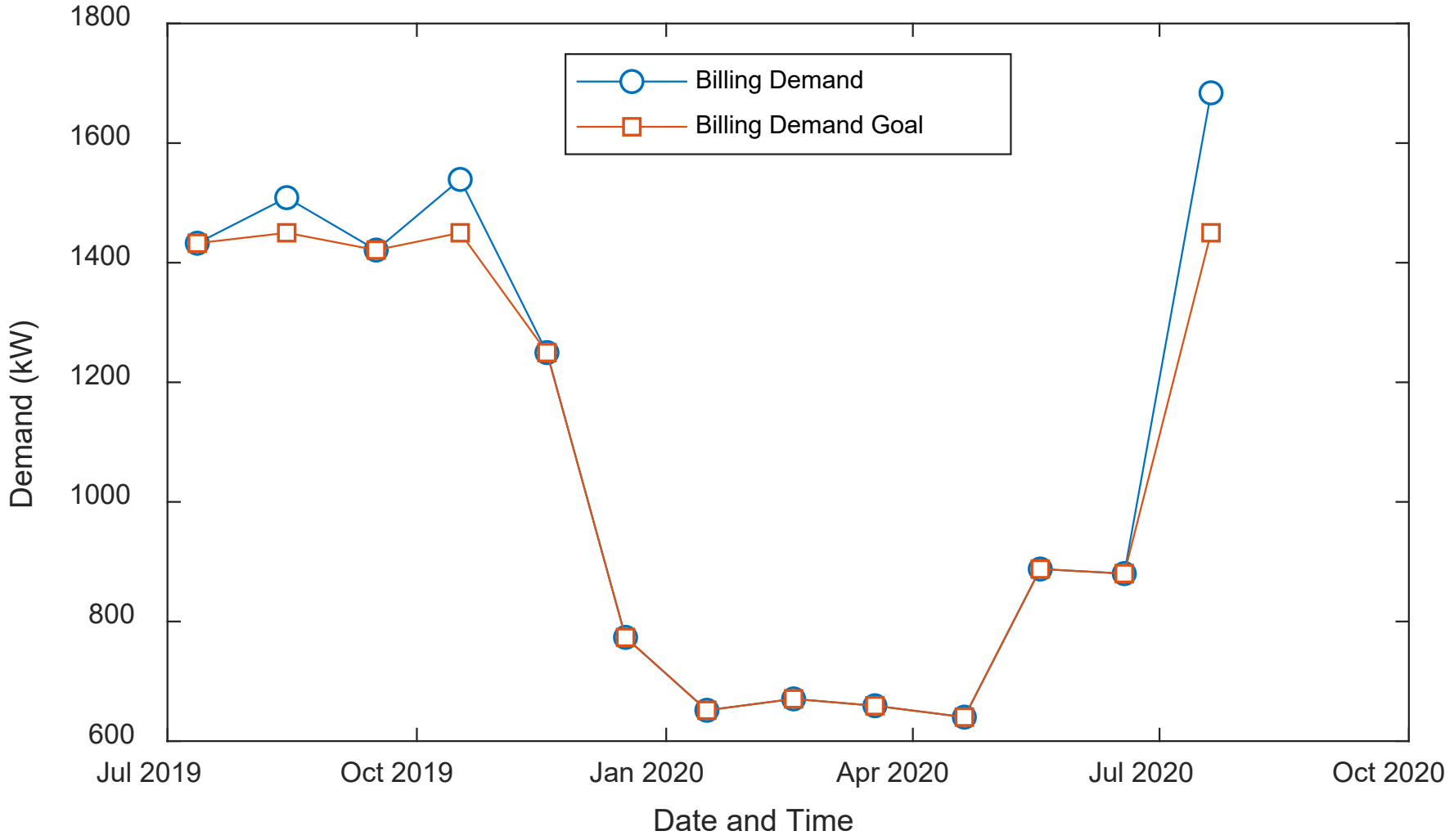
Plotting 15-minute interval data gives deeper insight.



This facility understood how to avoid peak demand charges.



Example numbers: Reducing demand by 382 kW-months at a rate of $5.18 per kW-months/yr saves $1979 per year.

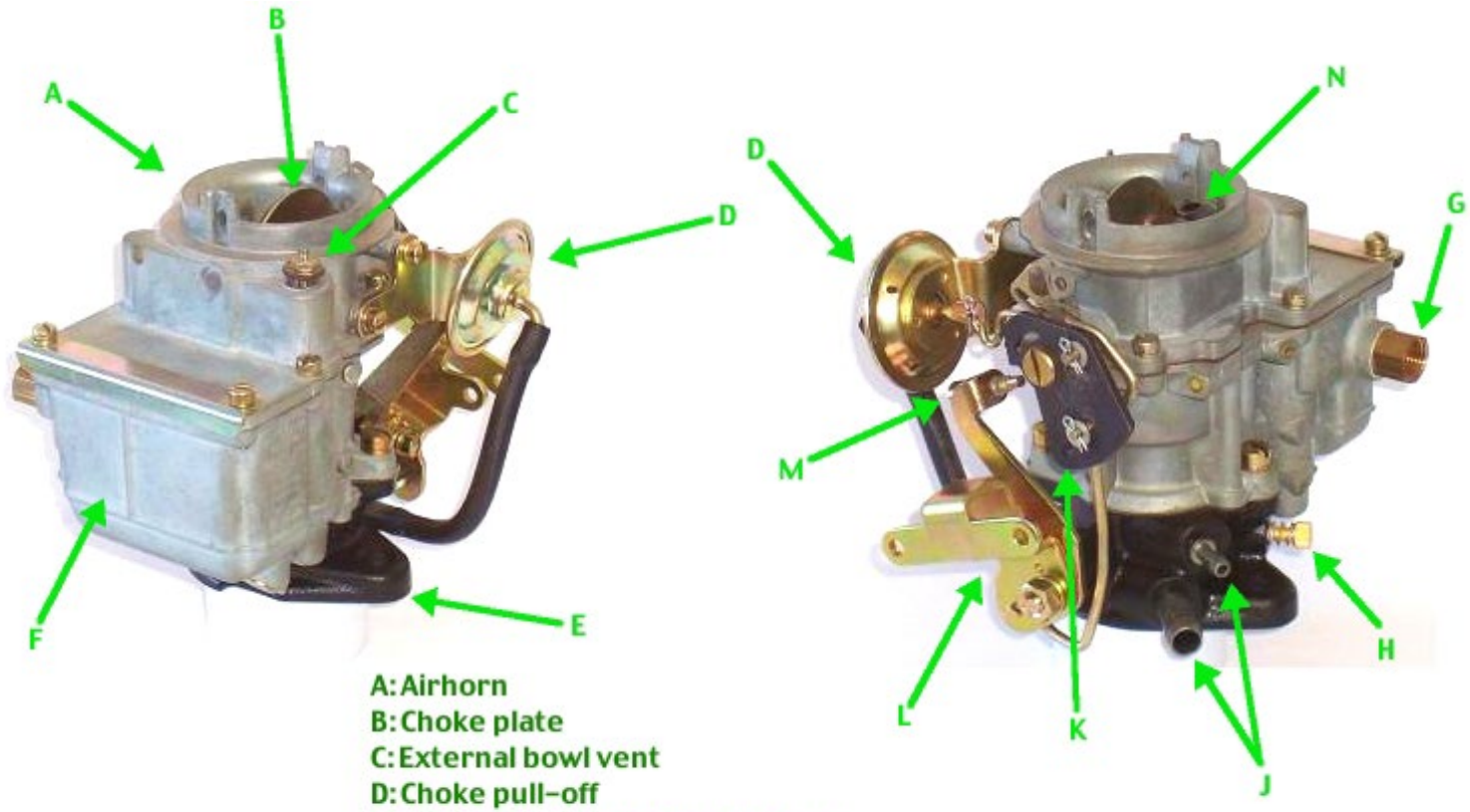


Example 2: Replace surface aerators with fine-bubble diffusers.

Average standard aeration efficiency (SAE) for mechanical mixers is 2.1 kg O_2/kWh and for fine bubble diffusers is 5.75 kg O_2/kWh.

More details at
https://cecas.clemson.edu/sce3/wastewater-treatment-energy-saving-recommendation-install-fine-bubble-aerators/
Images from environmental-expert.com *and* hydriawater.se

Carburetor



A: Airhorn
B: Choke plate
C: External bowl vent
D: Choke pull-off
E: Throttle body & mounting base
F: Float bowl
G: Fuel inlet
H: Idle mixture adjusting screw
J: Vacuum nipples
K: Fast-idle cam
L: Throttle lever
M: Idle speed adjusting crackscrew
N: Internal bowl vent

Source: Wikipedia

Fuel injectors

Benefits of Electronic Fuel Injection (EFI) technology

Cub Cadet fuel-injected engines boast serious strength. They deliver the kind of high performance you'd expect from Cub Cadet.

Easier to Start.

EFI technology provides quicker startup, making both hot and cold restarts easier.

More power with IntelliPower™.

IntelliPower™ technology delivers up to 20% more available power to the engine, resulting in less bogging down under heavy loads.*

Source: https://www.cubcadet.com/en_US/efi-engines.html

Example 2: Replace surface aerators with fine-bubble diffusers.

Average standard aeration efficiency (SAE) for mechanical mixers is 2.1 kg O_2/kWh and for fine bubble diffusers is 5.75 kg O_2/kWh.

More details at
https://cecas.clemson.edu/sce3/wastewater-treatment-energy-saving-recommendation-install-fine-bubble-aerators/
Images from environmental-expert.com *and* hydriawater.se

Example 3: Automate aeration equipment using a DO probe.

- Identify target dissolved oxygen content (example: DO = 2 mg/l subject to change according to activated sludge system design)
- If motors are running at same speed, we will provide more aeration than required.
- If the DO is more than **2.0 mg/l**, the aerators should cut off or slow until it drops below 2.0 mg/l.

Example 4: Install VFDs for motors.

- VFDs match utility energy consumption to system energy requirements.
- The maximum output speed, torque, or power performed by a driver, typically an electrical motor, frequently does not match that required by the driven equipment.
- VFDs operate by reducing the utility power frequency.

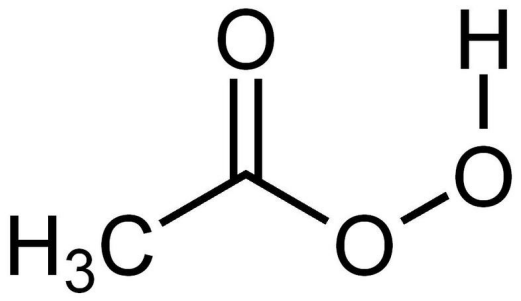
Source: “Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches” Doc by “Water Environment Research Foundation (WERF)”

This table shows an example of savings using VFDs.

Duration hrs/day	Speed	Constant Speed		VFD	
	% of full	Energy hp hrs	Cost USD$/day	Energy hp hrs	Cost USD$/day
2	100%	40	3.28	40	3.28
3	90%	60	4.92	54	4.43
5	80%	100	8.21	80	6.56
7	70%	140	11.49	98	8.04
4	60%	80	6.56	48	3.94
3	50%	60	4.92	30	2.46
24		480	39.39	350	28.72

Source: “Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches” Doc by “Water Environment Research Foundation (WERF)”

Example 5: Employ peracetic acid to decrease disinfection energy costs.



Peracetic acid

+

Ultraviolet disinfection

=

ENERGY REDUCTION
EXPERT TRAINING

Images from umn.edu, flowtechnics.com, and freelancer.pk

Example 6: Utilize existing tank capacity for solids storage to reduce truckload frequency.

A few other observations/considerations have been gathered.

- Energy-saving measures need to be balanced with treatment effectiveness considerations.
- The field would benefit from evaluating energy savings from past upgrades.
  - SCADA data are plentiful, but often under-utilized.
- We are considering inviting retired engineers and operators to volunteer their time and participate in assessments.
- Often plants need to hear the same recommendation from several sources to act on an idea.

Special thanks to some wastewater treatment experts.

Larry Camp
ReWa

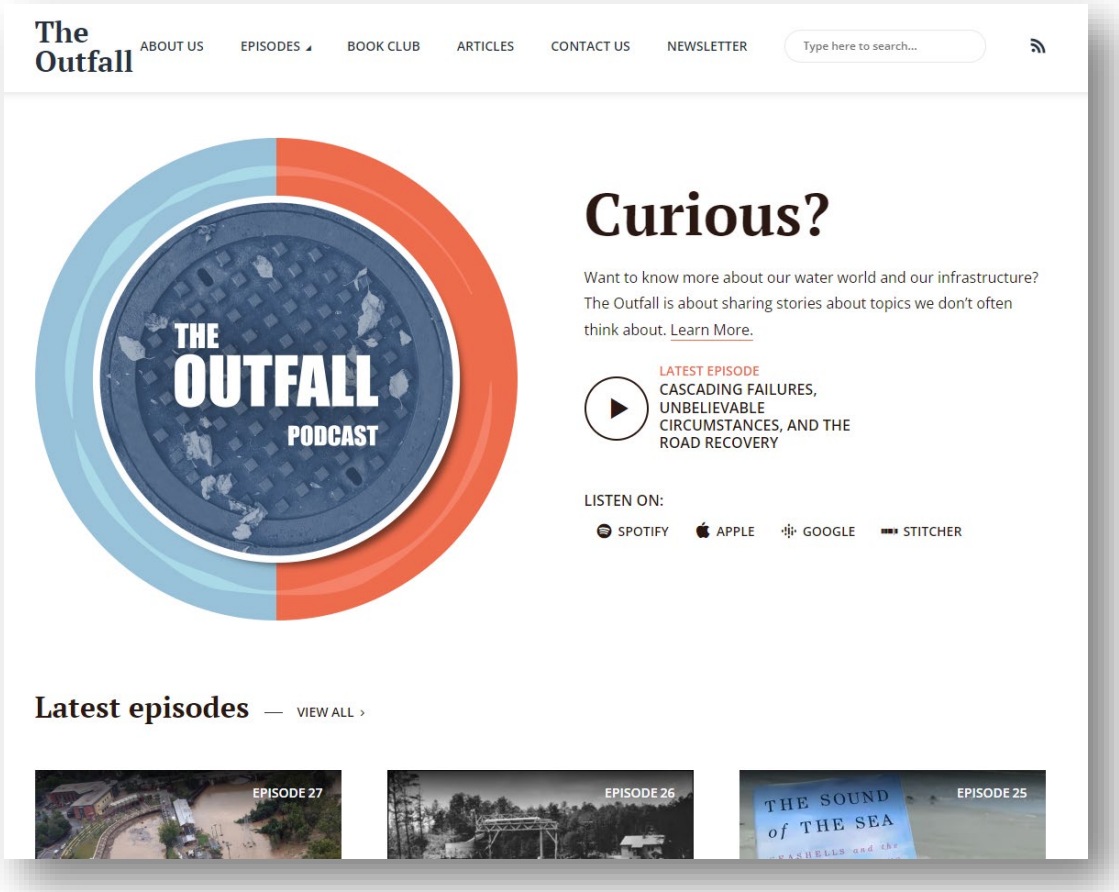
Harish Lakshmi Srinivasan
Graduate Student
Clemson EEES

Ashley Martin
Graduate Student
Clemson EEES

David Freedman
Department Chair
Clemson EEES

Other ReWa Employees/Operators:
Brice Green, Fred Nesbit, Russel Moore
Jay, David, and Josh

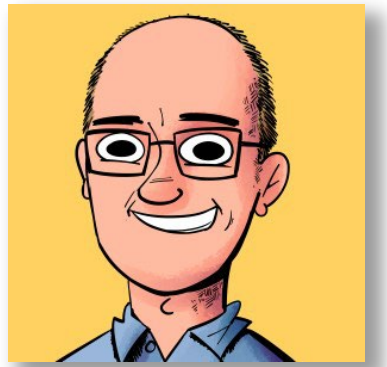
The Outfall Podcast



http://theoutfall.com/

Robert Osborne

Amy Anderson



David Ladner

Supplemental slides

Another analysis of the IAC database reveals additional line items.

Description of recommendation	Recommended	Percentage	Implemented	Percentage
UTILIZE HIGHER EFFICIENCY LAMPS AND/OR BALLASTS	137	16	93	68
USE ADJUSTABLE FREQUENCY DRIVE OR MULTIPLE SPEED MOTORS ON EXISTING SYSTEM	117	14	46	39
INSTALL OCCUPANCY SENSORS	43	5	32	74
USE OR REPLACE WITH ENERGY EFFICIENT SUBSTITUTES	37	4	12	32
UTILIZE ENERGY-EFFICIENT BELTS AND OTHER IMPROVED MECHANISMS	31	4	13	42
USE MOST EFFICIENT TYPE OF ELECTRIC MOTORS	31	4	15	48
ELIMINATE OR REDUCE COMPRESSED AIR USAGE	23	3	11	48
USE A FOSSIL FUEL ENGINE TO COGENERATE ELECTRICITY OR MOTIVE POWER; AND UTILIZE HEAT	18	2	5	28
UTILIZE CONTROLS TO OPERATE EQUIPMENT ONLY WHEN NEEDED	18	2	8	44
REPLACE OVER-SIZE MOTORS AND PUMPS WITH OPTIMUM SIZE	17	2	8	47

Example recommendations from an assessment.

Recommendation	Annual Conservation	Annual Savings	Implementation Cost	Simple Payback (months)
1. Utilize Higher Efficiency Lights (ARC 2.7142) Install occupancy sensors (ARC 2.7135)	229,221 kWh	$23,521	$20,682	10.6
2. Use multiple speed motors or AFD for variable pump, blower, and compressor loads (ARC 2.4141)	230,825 kWh	$22,987	$32,413	16.9
3. Utilize Controls to Operate Equipment only when needed (ARC 2.6231)	57,840 kWh	$4,338	$12,000	33.2
4. Use or Replace with Energy Efficient substitutes (ARC 2.4322)	1,857,000 kWh	$162,118	$350,000	25.9
5. Use waste heat with a closed-cycle gas turbine-generator set to cogenerate electricity and heat (ARC 2.3417)	1,064,795 kWh	$92,958	$400,000	51.6
TOTAL	**3,439,681 kWh**	**$305,922**	**$815,095**	**32**

Each recommendation has a breakdown of its findings.

3.2 RECOMMENDATION 2: USE MULTIPLE SPEED MOTORS OR AFD FOR VARIABLE PUMP, BLOWER, AND COMPRESSOR LOADS (ARC 2.4141)

Est. Electric Consumption Savings	*= 230,825 kWh/yr.*
Est. Electric Consumption Cost Savings	*= $17,312/yr.*
Est. Electric Demand Savings	*= 632 kW/yr.*
Est. Electric Demand Cost Savings	*= $5,675/yr.*
Est. Total Cost Savings	*= $22,987/yr.*
Est. Implementation Cost	*= $32,413*
Simple Payback Period	*= 16.9 months*

Recommended Action

It is recommended to update the existing compressors and pumps running on part load with variable frequency drives (VFD). VFDs have a lower energy requirement for the same amount of work done.

Each recommendation includes its calculation methodology.

(ii) The plant currently runs a 60 hp recirculation pump at 230V/139A/0.85 power factor. The power consumed by this compressor is given by:

$$Power\ consumed = 230 * 139 * 0.85 * 2$$

$$= \mathbf{54.35\ kW}$$

For this calculation, an estimate of 50% reduction in power consumed is used. Note that this value may be higher or lower based on many variables:

$$\text{Reduction in power consumption (50\%)}(RPC) = (½) * Power\ Consumed$$

$$= \mathbf{27.18\ kW}$$

The annual *electricity consumption saving* for the pump can be calculated as the product of kW saved and the hours of operation of the unit:

$$Electrical\ consumption\ saving\ (ECS) = RPC * Operation\ hours$$

$$= 27.18\ kW * 4380\ hour/yr.$$

$$= \mathbf{119{,}048\ kWh/yr.}$$

Other Possible Recommendations

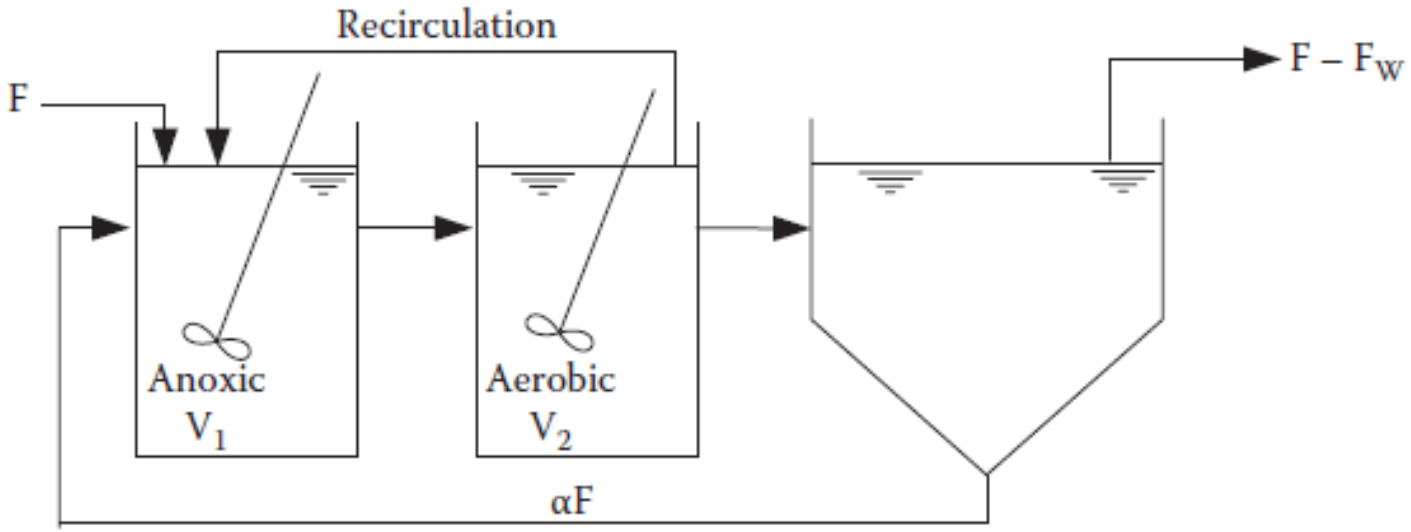
- Potential for reuse of treated water. Can be used for cooling purpose in nearby industry.
- Reduce the pressure of compressed air to minimum required
- What happens during demand hours? Manage peak demand hours using combined heat and power (CHP) to completely power the plant during peak hours.
- Sell biogas obtained from anaerobic digester to outside company, e.g. GreenGas https://greengasusa.com

Example 4: Switch to anammox to treat digester effluent.

- The conversion of ammonia to nitrate by nitrifiers requires a lot of oxygen and aeration is an energy-intensive process.

Nitrification: $NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$

Denitrification: organics + $NO_3^- \rightarrow CO_2 + 0.5N_2$



MLE SYSTEM

Example 4: Switch to anammox to treat digester effluent.

- Anammox - ANaerobic AMMonium OXidation
- ANAMMOX system: Partial nitrification (half of the ammonium to nitrite by ammonia oxidizing bacteria):

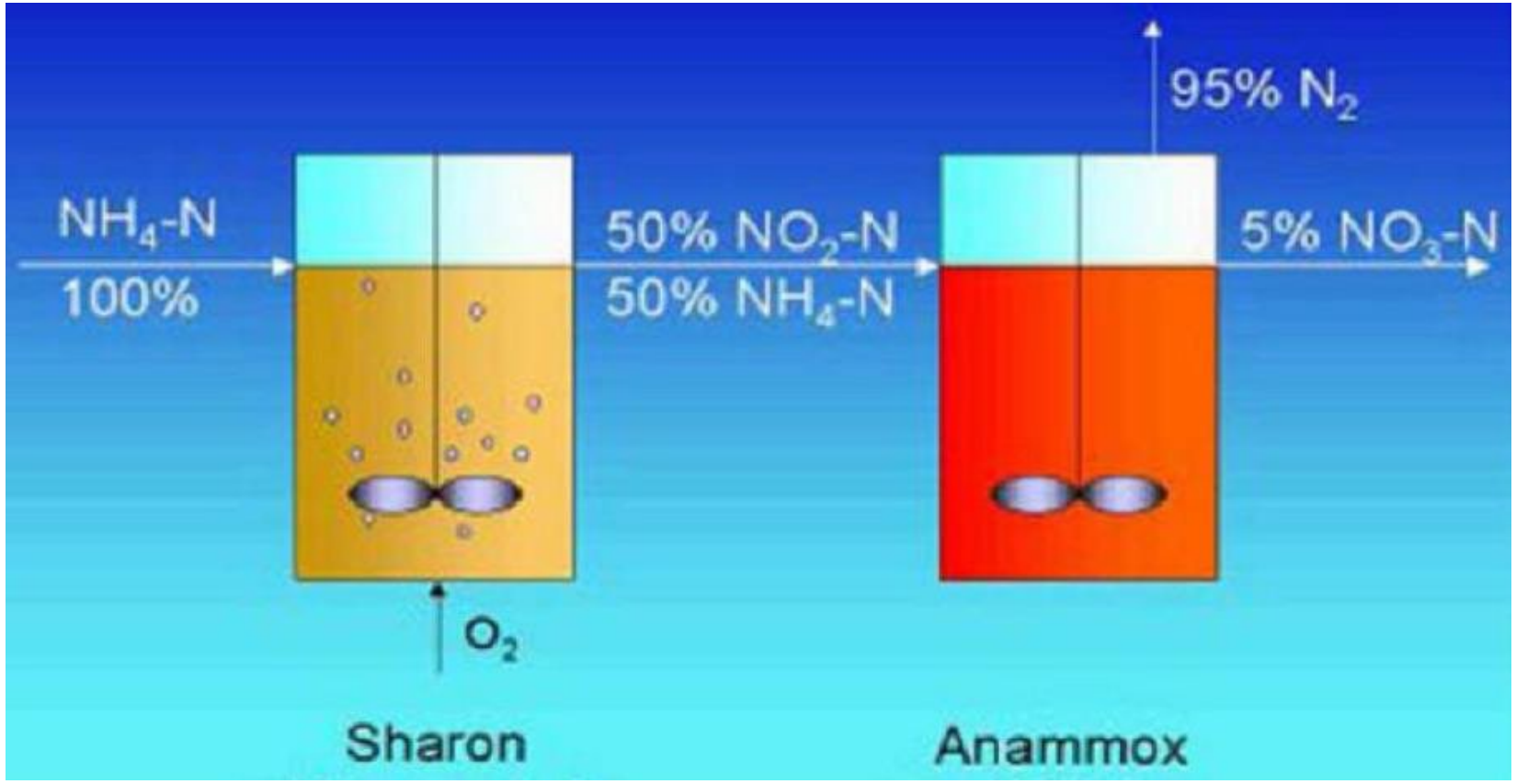
$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

- The resulting ammonium and nitrite are converted in the anammox process to nitrogen gas

$$2NH_4^+ + 2NO_2^- \rightarrow 2N_2 + 4H_2O$$

- 0.75 mol of O_2 are needed per mole of NH_3, compared to 2 mol of O_2 per mole of NH_3 for nitrification. Also, the end product is N_2 instead of NO_3^-.

Example 4: Switch to anammox to treat digester effluent.



Sharon-Anammox

Source: HUMBERT, S. (2011): Discovery of Anammox Bacteria in Terrestrial Ecosystems. (= PhD Thesis). Neuchâtel: Université de Neuchâtel