# Energy assessment at water resource recovery facilities

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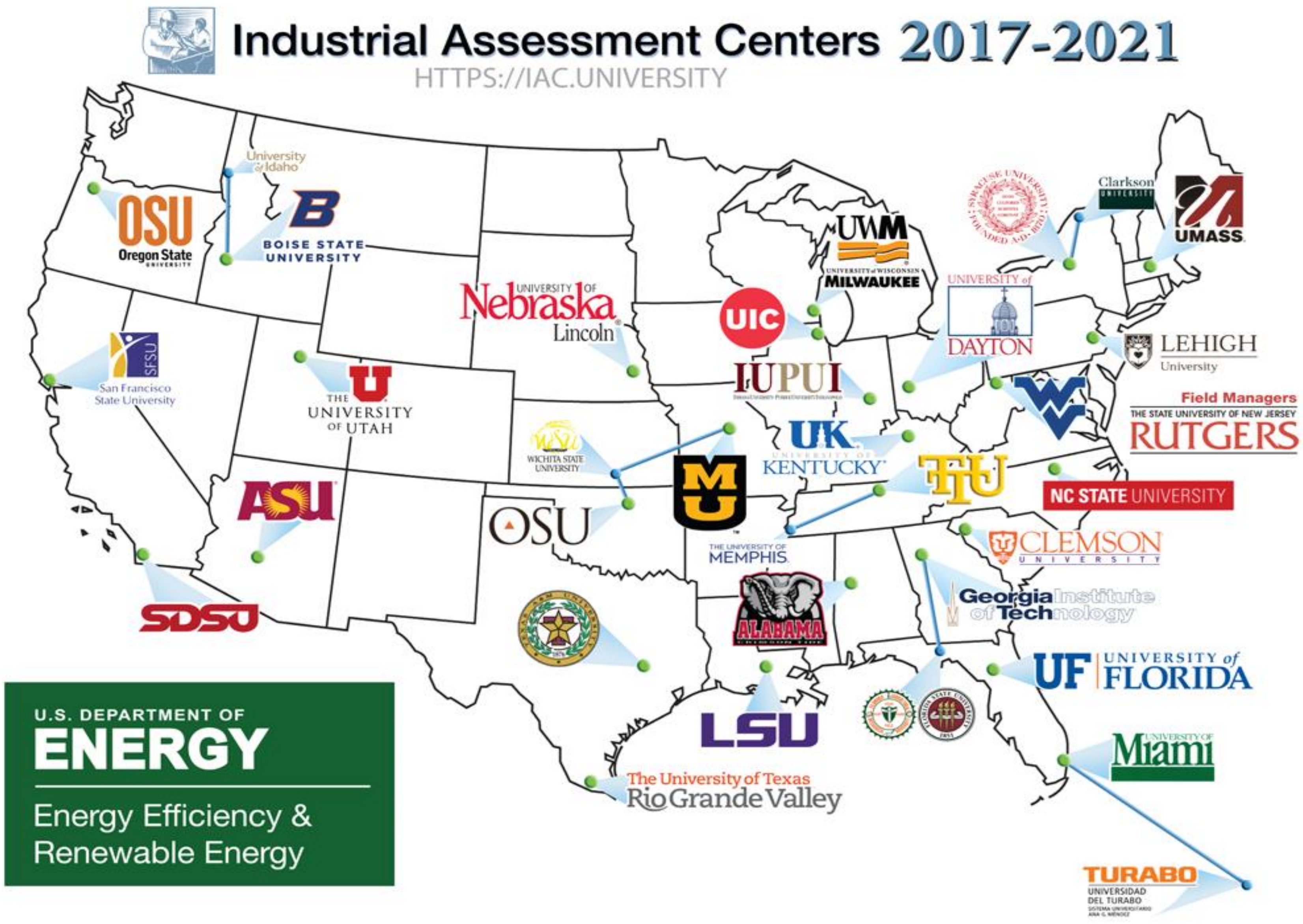
South Carolina Environmental Conference, Myrtle Beach, SC. August 9, 2021

CLEMSON
INDUSTRIAL ASSESSMENT CENTER

# Clemson's IAC is part of DOE's nationwide network.



# Clemson’s SC E3 is a sister program to the IAC.

# The programs have clear energy- and cost-saving goals.

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

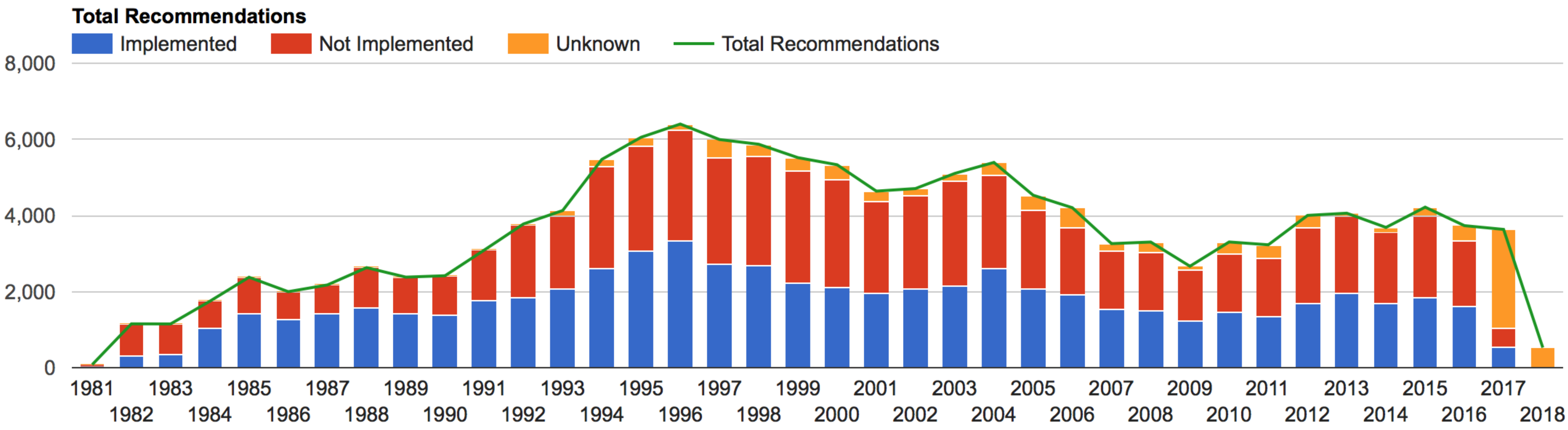
# We follow an established client-interaction process.

- Initial contact
- Pre-assessment form (1-4 weeks)
- Scheduling of site visit (1-4 weeks)
- Site visit (1 day)
- Assessment report to DOE (60 days)
- DOE review and resubmission, if needed (1-2 weeks)
- Report to client (1-2 days)
- Follow-up meeting, either phone/skype or in-person (1-2 weeks)
- Implementation survey (6 months)

# The protocol for site visits involves strong client engagement.

- Introductions and initial planning (15-30 mins)
- Site tour (1-2 hrs, depending on size of facility)
- Planning for data collection (15-30 mins)
- Initial data collection, e.g. lighting (15-30 mins)
- Break for lunch
- Data collection: boilers, chillers, compressed air, pumps, etc. (1-4 hrs)
- Re-group and initial data analysis (15-30 mins)
- Wrap-up meeting and presentation of recommendations (15-45 mins)

# The IAC database logs every assessment and recommendation.




- Database accessed at https://iac.university

# The 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:
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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.*

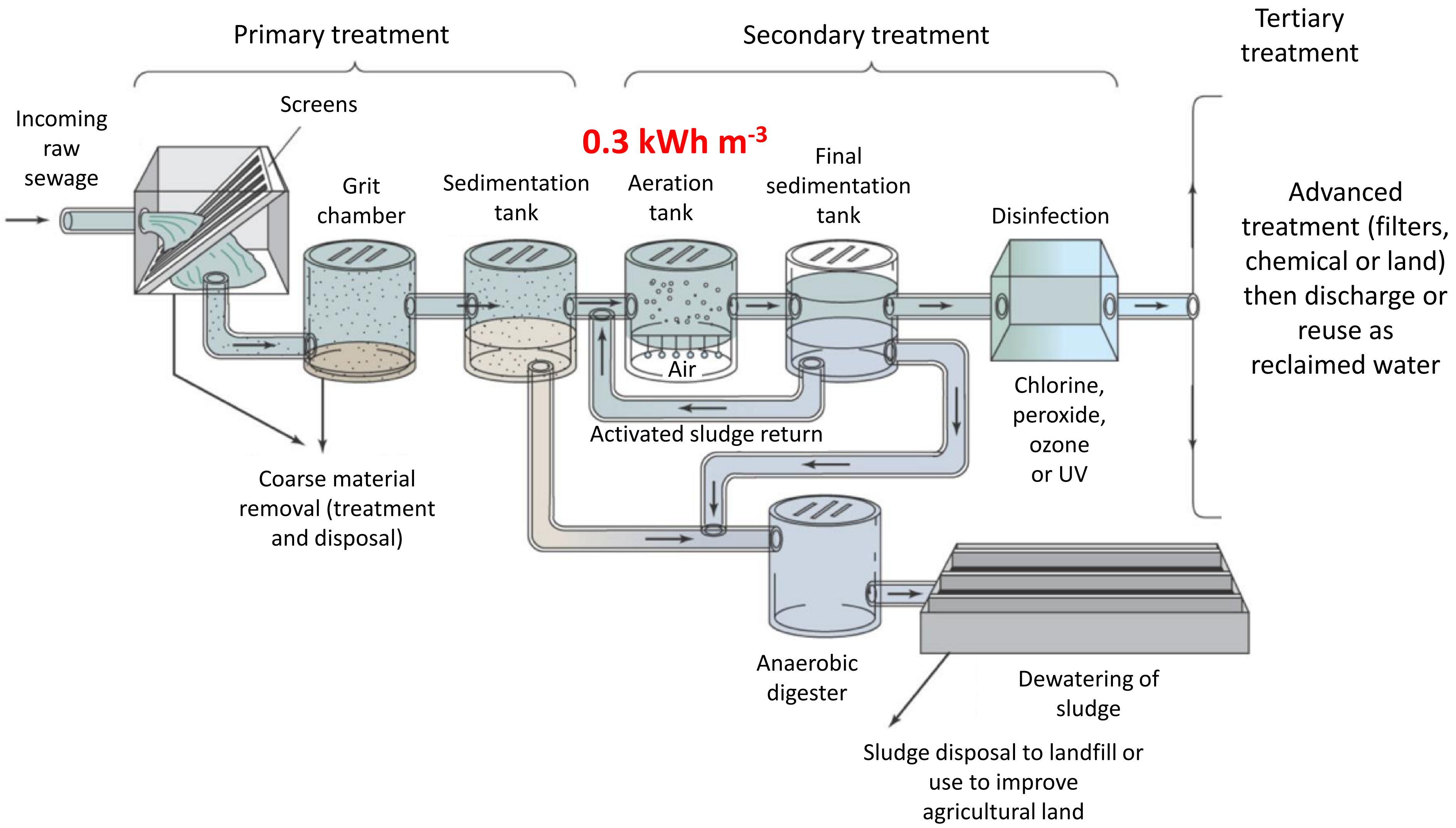
Recently DOE has emphasized wastewater treatment plants, or water resource recovery facilities (WRRFs).

# 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.

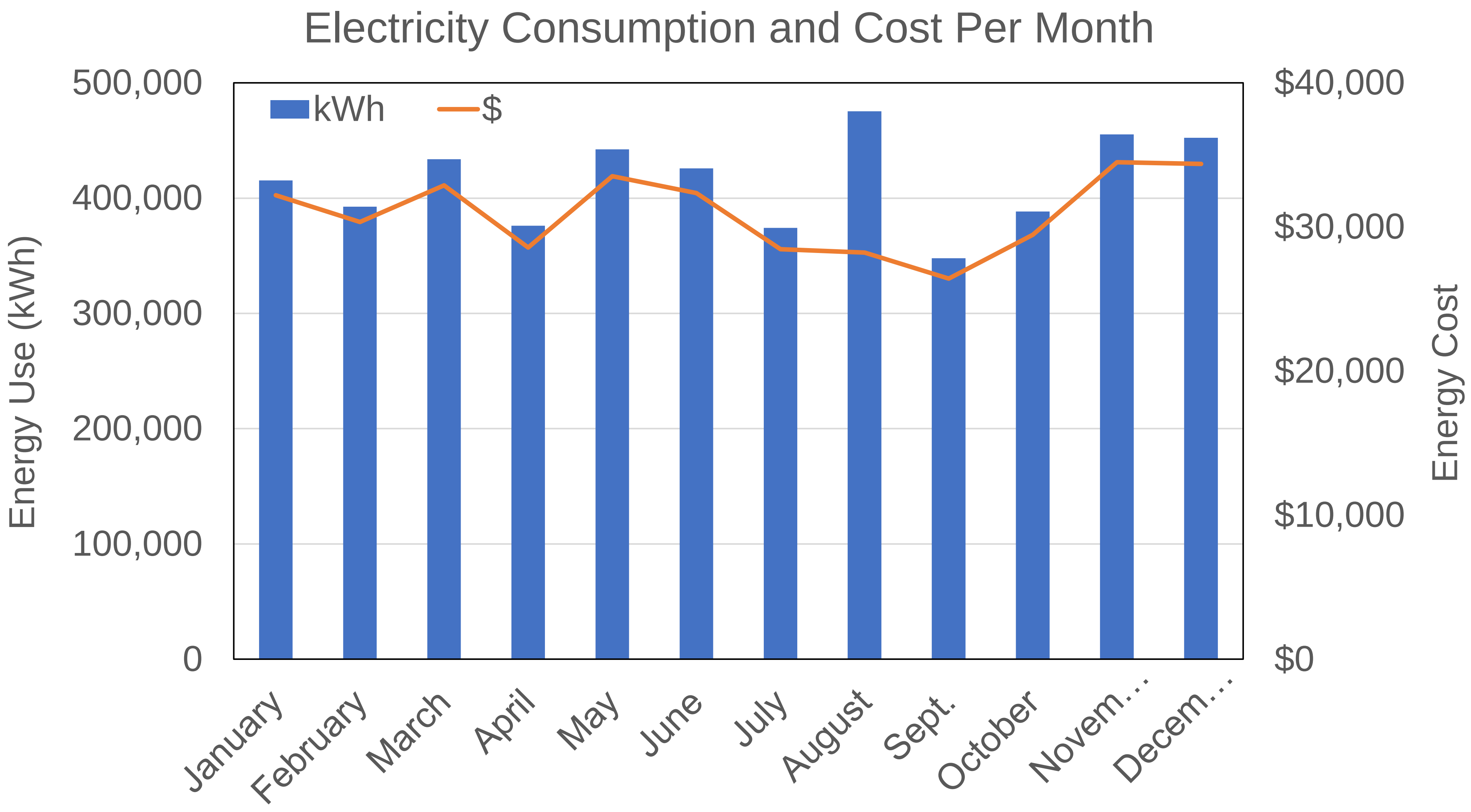
# Current domestic wastewater treatment infrastructure

**Total 0.6 kWh m$^{-3}$ used**

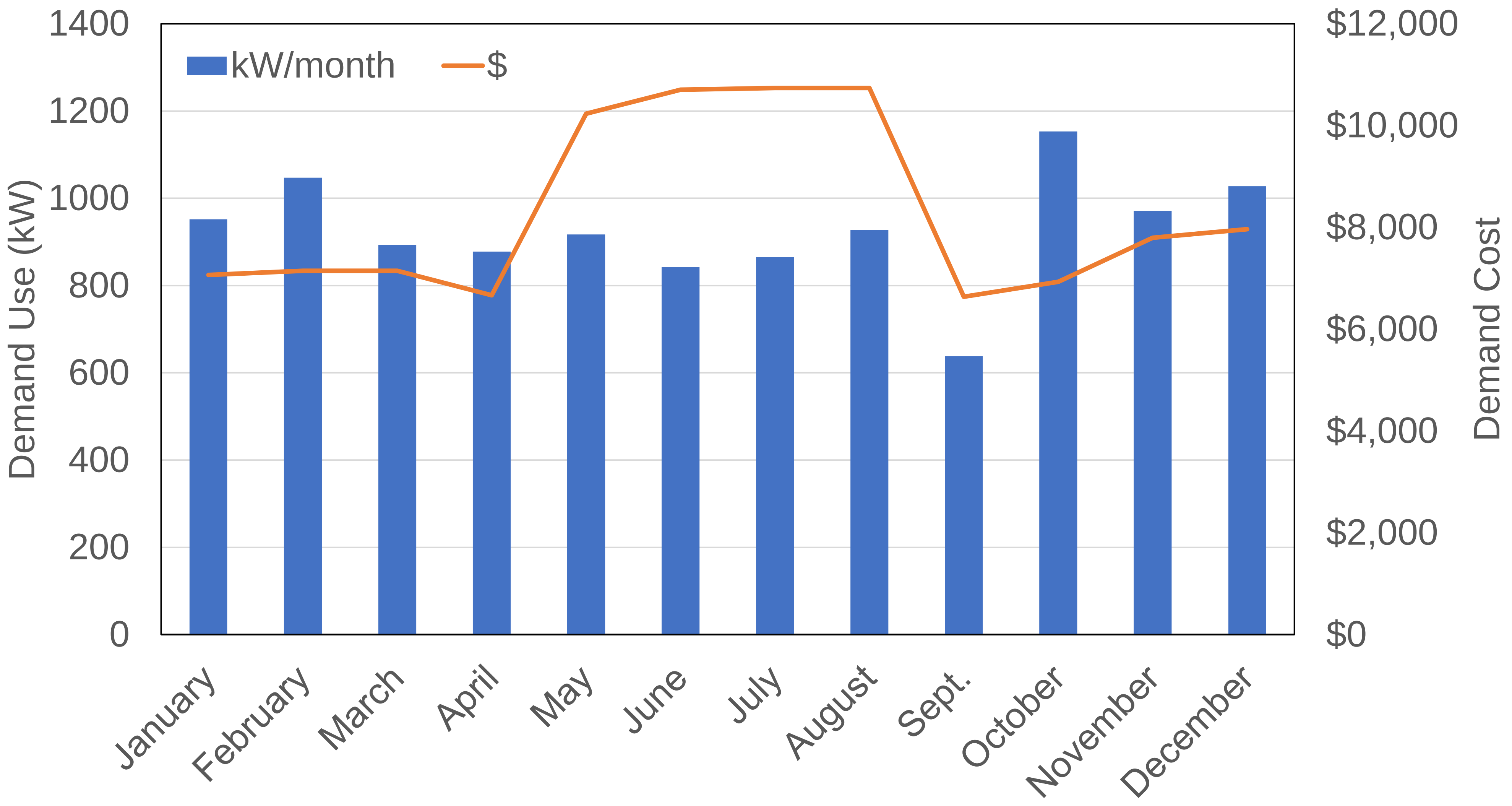



Slide from Sudeep Popat. Statistics from McCarty et al., *Environmental Science & Technology*, 2011

# Electricity consumption is the first data set evaluated.



# Electricity demand analysis is often eye opening to clients.



# 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:

$$\text{Power consumed} = 230 * 139 * 0.85 * 2$$

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

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:

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

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

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:

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

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

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

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

# 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 |

# Our current effort is to expand upon the existing ARC to create a database of wastewater-specific recommendations.

Example 1: Utilize existing tank capacity for solids storage to reduce truckload frequency.

# 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.

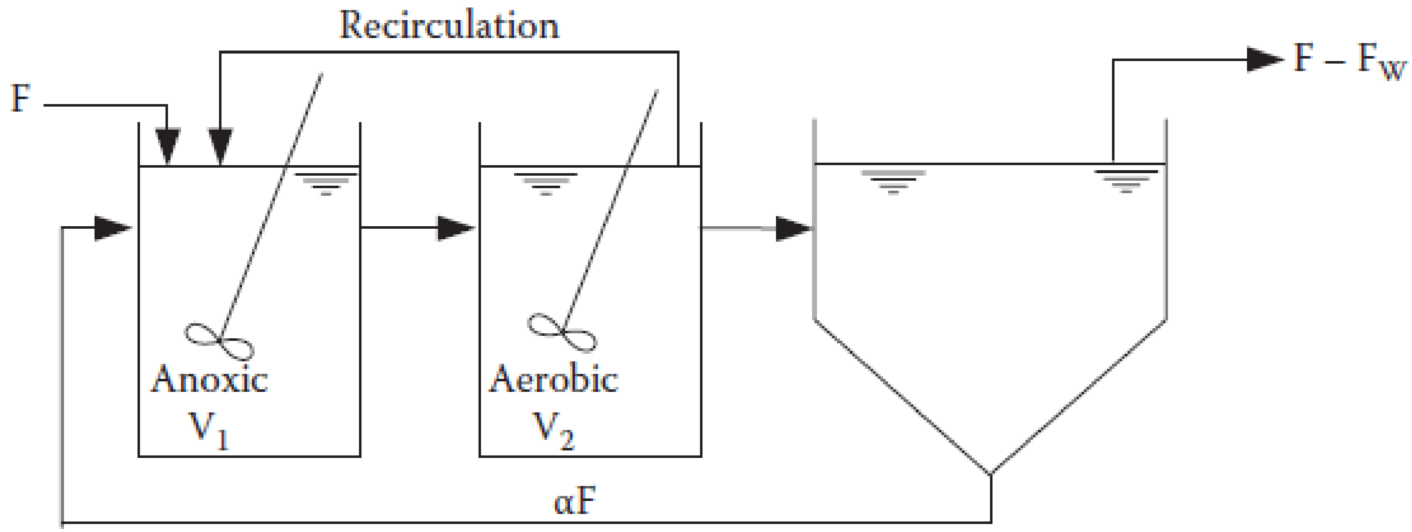
- If the DO is more than **2.0 mg/l**, the aerators should cut off or slow until it drops below 2.0 mg/l.

# Example 4: 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: $\text{organics} + NO_3^- \rightarrow CO_2 + 0.5N_2$




*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):

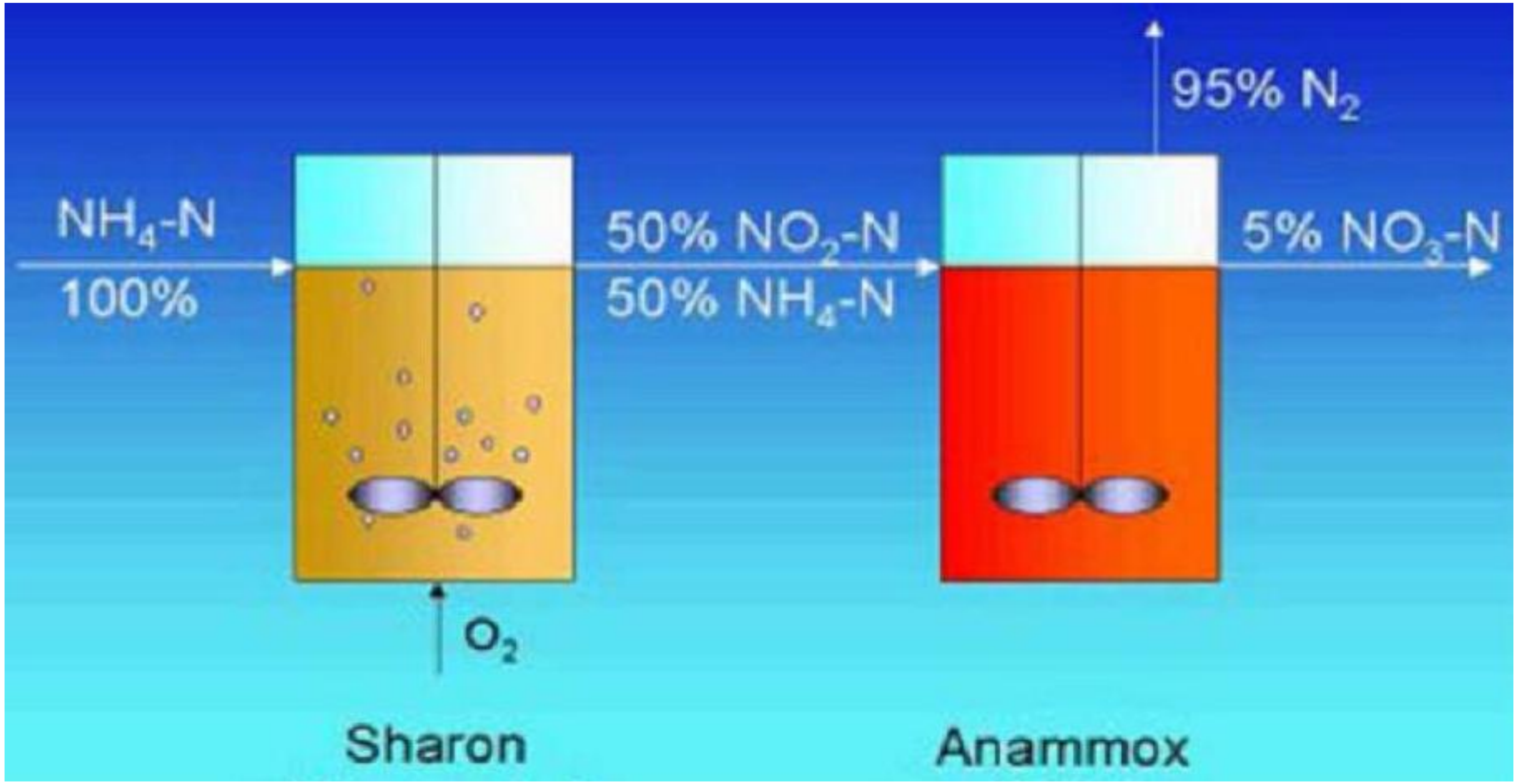
$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$

- 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

# Example 5: Install VFD 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)”

# Example 5: Install VFD 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.

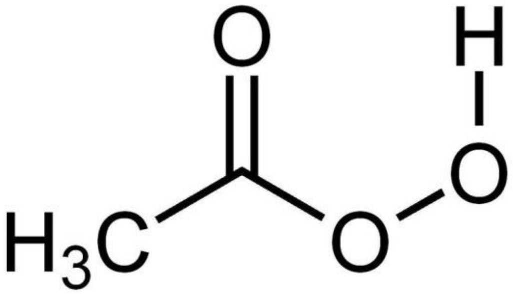
Source: “Energy Efficiency in Wastewater Treatment in North America: A Compendium of Best Practices and Case Studies of Novel Approaches” Doc by “Water Environment Research Foundation (WERF)”

# This table shows 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 6: Employ peracetic acid to decrease disinfection energy costs.

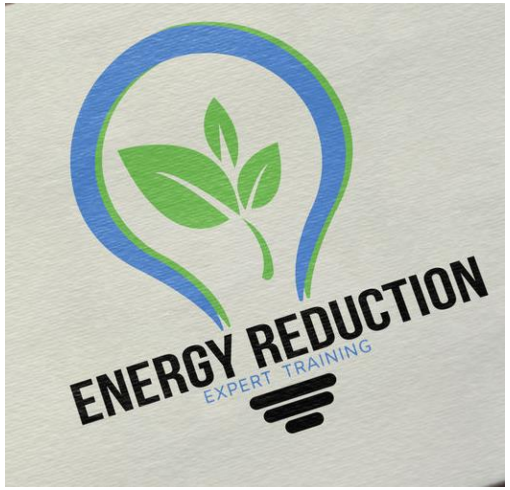


Peracetic acid

+


Ultraviolet disinfection

=




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

# 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

# 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.” –DOE IAC internal website

# The Clemson IAC Team

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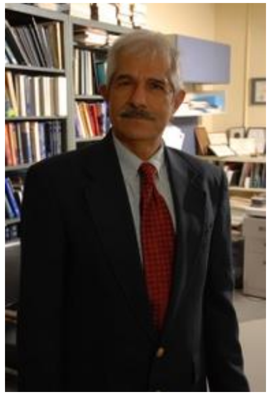

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# Special thanks to some wastewater treatment experts.

Larry Camp
ReWa

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