Berkeley Lab

MEMO

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To: Katy Hatcher (EPA)
From: Christie Galitsky, Bailey Green, Rich Brown
RE: Review of Existing Guidebooks for Energy Efficiency in Water and Wastewater Treatment

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As a part of the U.S. Environmental Protection Agency's ENERGY STAR® Program for the Municipal Water and Wastewater Industry, LBNL has been asked to review the existing literature on energy efficiency in these sectors to determine if an updated, comprehensive energy management guidebook is needed. To serve the goals of its program, ENERGY STAR intends to provide such a guidebook for facility operators and managers across the U.S. The aim is to provide a comprehensive guide to energy efficiency measures with enough data on energy savings, costs and monetary savings and/or payback periods to enable a facility operator to be able to make the case for implementing an energy efficiency measure. It will include data from case studies, where possible, in order to inform the plant manager of actual cases where the measure has already been implemented and provide enough information to make a wise investment decision. Where possible, the energy guidebook will address both conventional and advanced technologies, as well as existing and new plants.

In our literature search we have found thirteen similar guidebooks; however, we believe none of them fully capture the goals described above in a single, complete document targeted at the right audience, i.e., water and wastewater plant managers and operators. Below we identify each guidebook, list the topics covered by the guidebook, and summarize the types of information they provide or lack. We believe that the EPRI guides and the Alliance to Save Energy's Watergy report (references 2-4 below) are most similar to the type of guides that ENERGY STAR intends to publish, but lack information in important areas or include extraneous information. Therefore we believe that an effort is warranted to compile a new guidebook, drawing on the existing literature where possible.

1. **Burton, Franklin L. 1996. *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. Burton Environmental Engineering, Los Altos, CA. Prepared for the Electric Power Research Institute. Palo Alto, California. Report CR-106941. September.**
    - Widely-cited report covers municipal water and wastewater
    - Two target audiences--electrical utilities and water/wastewater utilities
    - Describes treatment technologies and processes; provides schematics and generic energy use characteristics for several of the most commonly used water and wastewater treatment technologies
    - Provides examples of energy management opportunities drawn from water and wastewater treatment facility case studies (13) and energy audits (18) with energy management recommendations from mid 1980s to mid 1990s

- Provides guidance for developing and evaluating energy management programs and systems
- Estimates national energy use in municipal water and wastewater industries based upon the 1988 EPA Needs Assessment and publications from 1980s and early 1990s;
- Burton estimates total electrical energy demand within the municipal water and wastewater industries to be around 41 billion kWh/yr (in 1988) and, when 1988-identified "needs are met," around 51 billion kWh/yr. Burton also projects an increase in electricity use of around 33% "over the next 20 to 30 years." His estimate for 1996 consumption is 75 billion kWh/yr, "about 3% of annual U.S. electricity use" (executive summary). These energy consumption estimates are one of the only national estimates for this sector, and have been extrapolated by others including CEC and CEE using subsequent (post-1996) growth in electrical energy demand for scaling

Summary: This guidebook summarizes energy management opportunities in the municipal water and wastewater industries and is national in scope. It presents information from the engineering literature and a limited number of case studies and energy audits in order to summarize the energy characteristics of the municipal water and wastewater treatment industries, to estimate national electrical energy consumption within the sector and to identify energy management opportunities. This energy management information does not contain the detailed savings and cost data that plant managers need to justify investing in upgrades.

2. **EPRI. 1997. *Quality Energy Efficiency Retrofits for Water Systems*. Palo Alto, California: EPRI.**
   - Retrofit "roadmap" (for customers) – like an energy management plan (pg 1-2)
   - Chapter 2, energy management process ("retrofit process"): identifying projects, funding them, understanding billing, understanding systems, energy audits, predesign and design, selecting contractors/vendors, installation, start-up, follow-up and maintenance, and documenting energy and cost savings
   - Chapter 3, VSDs: benefits, how they work/what types exist, advantages/disadvantages, equipment selection, impacts, implementation, (i.e., most of the steps above) and a checklist for each step of energy management
   - Chapter 4, energy efficient motors: same as above (SAA)
   - Chapter 5, SCADA: SAA
   - Chapter 6, Lighting retrofits: SAA for many measures
   - Chapter 7, O & M: SAA on pumps and motors
   - Chapter 8, no-cost/low-cost *process* changes: these include demand reduction or load shifting, flocculation energy optimization, impeller changes, and water conservation.
   - The report does not contain specific case study data on costs and paybacks, but rather serves as a guideline for energy managers to help them screen and implement projects.

Summary: This guidebook provides an extensive list of energy efficiency measures in the categories it addresses, namely variable speed drives, energy efficient motors, SCADA, lighting, O&M and a few process changes, with good information on what it takes to install the measures. However, it does not contain cost, savings or payback period data for any of these measures. It also does not address all measures we believe should be included in an Energy Star guidebook, and therefore we consider it incomplete.

3. **EPRI. 1998. *Quality Energy Efficiency Retrofits for Wastewater Systems*. CR-109081, P400-98-013. Palo Alto, California: EPRI. (prepared for the EPRI Water and Wastewater Program by HDR Engineering, Inc., ENTEG, Inc. and Black & Veatch, LLP with support from EPRI and the California Energy Commission)**
    - Companion guidebook to document 3 above; covers municipal wastewater treatment systems only
    - Targeted to the operations and engineering staffs of wastewater treatment facilities; scope is limited to project implementation issues (1-1)
    - Chapters 2-11 each include a section on project implementation, additional references and a retrofit checklist
    - Chapter 2, energy management process: energy assessment or audit; methods of reducing energy use and costs are grouped in the following three categories—shifting electrical loads to reduce peak demand, process changes, and improving equipment efficiency; retrofit financing options and steps to a successful retrofit
    - Chapter 3, VSDs: advantages and disadvantages of three types of VSDs, distinguished by their inverters—Pulse Width Modulated (PWM) inverters, Voltage-Source Inverters (VSI) and Current-Source Inverters (CSI)
    - Chapter 4, energy efficient motors: SAA, and advantages and disadvantages of open and closed motors and their minimum full-load nominal efficiency levels under the Energy Policy Act (EPACT) of 1992
    - Chapter 5, SCADA: includes a SCADA retrofit project success story about the Upper Gwynedd Towamencin Municipal Authority's 4.5 MGD WWTP in eastern Pennsylvania that lower their average monthly demand by 23% and reduced energy costs annually by $59,580
    - Chapter 6, pumping stations: testing and modifications such as impeller replacement, pump replacement and pumping system optimization
    - Chapter 7, cogeneration: cogeneration optimization, types of electric generators, types of prime movers, system sizing, fuels, gas storage, gas quality and heat recovery
    - Chapter 8, aeration systems: retrofit technologies including fine-bubble diffusers, fine bubble ceramic disc diffusers, membrane tube diffuser, panel diffusers, automated dissolved oxygen control
    - Chapter 9, ultraviolet disinfection: benefits and average energy intensities for low-pressure and medium-pressure UV systems with a retrofit success story from Elsinore Valley (CA) Municipal Water District's 4 MGD Wastewater Reclamation Facility but without energy and cost savings data
    - Chapter 10, load management: alternatives for managing plant loading, advanced primary treatment (APT) and flow equalization to trim the peak off the typical diurnal flow pattern by use of storage basins; includes an APT success story from the Sanitation Districts of Orange County (CA) and a flow equalization success story from Irvine Ranch Water District (CA)
    - Chapter 11, lighting retrofits:

    Summary: This energy efficiency retrofit guidebook for wastewater treatment systems provides the most detailed list of energy efficient retrofits to date, covering variable frequency drives, energy efficient motors, SCADA, pumping station modifications, cogeneration optimization, aeration systems, ultraviolet disinfection, alternatives for

managing plant loading and lighting retrofits. It contains lots of helpful information about how to implement specific retrofits and measure the energy use and cost savings. However, it provides little actual data on energy and cost savings from retrofits; nor does it address all of the energy conservation measures for WWTFs that we would include in a WW guidebook. Therefore, we consider it to be incomplete.

4. **James, Kevin, Stephanie Campbell and Christopher Godlove. 2002. *Watergy: Taking Advantage of Untapped Energy and Water Efficiency Opportunities in Municipal Water Systems*. Washington D.C.: Alliance to Save Energy.**
http://www.eere.energy.gov/femp/information/download_watergy.cfm
    - Describes watergy (energy and water) efficiency management structures, much like described in other ENERGY STAR guides (management is differentiated by "level" – 1 ad hoc, 2 single manager, 3 team). A case study is provided for Columbus, GA. This section is VERY detailed
    - Monitoring systems. Same as above – very detailed, provides case studies for Bunbury and Sydney, Australia, which include costs and savings
    - Case studies also on system improvements – pump system improvements
    - Supply side improvements – everything from leaks to efficient motors and pumps to ASDs to pump impeller reductions to water reclamation to maintenance. Lots of data, some case studies from around the world.
    - Also data for wastewater processes efficiency
    - Water reclamation (pg 50) with case study
    - Also covers demand side water-efficiency improvements (e.g., residential – toilets, showers, clothes washers; commerical, industrial – recycling process water, cooling tower measures, etc.)
    - Several more very detailed case studies with data are provided in the "case study compendium" in the back of the report
    - Appendices provide other reports and references, tools, associations, with information on energy/water efficiency
    - Tip sheets are also provided in the appendices

Summary: Watergy provides excellent information on energy management, simliar to the ENERGY STAR guidelines adopted for the industrial sector (see e.g., Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry. A Guide for Energy and Plant Managers). Watergy also provides information and case study data, like the kind we would provide, on several areas, such as monitoring systems, leaks, pumping, motors, valves, capacitors, pipes as well as demand side improvements. While usually thought of as a policy document, this may be the most comparable guidebook in that it provides costs and savings data for many measures. However, we do not consider this guidebook to be comprehensive in its analysis of energy efficiency measures; it does not include all available case study data for all measures. In addition, structurally, this reference may not best serve the plant manager audience because it includes additional policy information that is not relevant to that audience.

5. **Elliott, Todd, Benjamin Zeier, Irene Xagoraraki and Gregory Harrington. 2002. *Use at Wisconsin's Drinking Water Utilities.* Madison, Wisconsin: University of Wisconsin, Madison.** (Available through Energy Center of Wisconsin and Wisconsin Focus on Energy)
    - Energy use summary at water treatment plants (only drinking water)
    - List of efficiency opportunties (e.g., premium motors, controls, etc)
    - Summary table of electricity requirements for different sized plants (pg 4)
    - Energy surveys (109) and energy audits were conducted on water treatment facilities
    - List of most cost effective options and less cost effective options, but no data are provided
    - List of efficiency options by equipment type. (e.g., replacing oversized motors by correctly sized high efficiency motors). Some data supplied but not for most measures. Lists include measures for the following sections: motors, pumps, drives, valves, blowers and compressors, lighting, hvac, and *processes*- ozone disinfection, uv disinfection, membrane filteration.
    - Case studies are provided for some of the measures above, including ozone disinfection, and some data are provided for the process measures
    - Case studies are provided for plants – e.g., Ann Arbor, MI and Bexas Met District, TX. Both provide data on savings and costs.
    - Lastly, a checklist is provided.

    Summary: This guidebook provides recommendations for some energy efficiency measures categorized as "most cost effective" and "less cost effective", via a survey for 109 water treatment systems. It is not a comprehensive list of energy efficiency measures and does not provide the data that operators would need about costs, savings and payback periods. In addition, this guidebook was prepared for Wisconsin facilities and lacks national scope, potentially omitting some applicable U.S. measures. It only covers the drinking water sector.

6. **Jacobs, John, Thomas A. Kerestes and W.F. Riddle. 2003. *Best Practices for Energy Management.* St. Paul, Minnesota: AWWA Research Foundation.**
    - Survey of 24 water and/or wastewater facilities (15 are combined water and wastewater facilities).
    - Data for energy use as % operating costs, energy cost per volume delivered, energy per volume delivered, average electric cost/kWh, volume delivered per electric use,
    - Survey results show the possible reduction in energy use or costs due to (% savings in parentheses):
        - strategic energy planning (60%)
        - implementing energy management (50%)
        - procurement strategies (35%)
        - negotiating with energy providers (30%)
        - tracking energy use and load shifting (30%)
        - process optimization (35% from supply; 20% from treatment; 45% from distribution)
        - equipment maintenance (50%)
        - repair/replace decisions for motors (30%)
        - knowledge of on-line and historical energy usage (30%)

- Case studies of 3 facilities (one was oil refinery, one was water/wastewater utility and the last a water utility). Each resulted in a list of "findings" (i.e., energy efficiency measures). Some data is given in appendices for each "finding"
- Best Management Practices (BMPs) are given for several areas – descriptions only.

Summary: This guidebook, in the form of a series of surveys, provides a list of energy efficiency measures related to energy management and how often they were adopted, but lacks more quantitative costs and savings data. Only 3 case studies were given, derived from survey results. This guidebook focuses exclusively on energy management (not efficiency technologies), and in that way is not complete. It will be useful in determining baseline or average uses of some energy efficiency measures (on energy management), but we do not consider this a comprehensive guidebook for plant managers.

7. **Landon, Dave, Kirstie Hearn, Jeremy Dudley, Tony Dee, Dave Shepherd, Tom Hall, Ed Glennie, Don Voigt, Chad Olsen, and Jared Feider. 2003. *Report On The Development Of Energy Consumption Guidelines For Water/ Wastewater*. Madison, WI: Wisconsin Focus on Energy. May.**
http://www.focusonenergy.com/data/common/pageBuilderFiles/WFOEb.pdf
    - Evaluates BMPs
    - Evaluates 10 facilities in detail (energy use; savings opportunities), with case studies for 10 facilities – only 2 are water, rest are wastewater (3.3 MGD EAU and 3.6 Kenosha)
    - Extensive discussion of benchmarking, particularly model-based benchmarking.
    - Guidelines for motors (replacement, manipulating power factors), pumps (scheduling, sizing), aeration (wastewater only), and *processes* (mostly wastewater, biogas use)
    - General recommendations for WI facilities. General – just descriptive, no data.
    - Specific recommendations for audited facilities - detailed data on energy use at the two facilities; case study data reported for specific measures (e.g. motor replacement)
    - Very good information on motors.
    - Might be better for wastewater section (esp. aeration).

Summary: This guidebook provides general recommendations for water and wastewater facilities, with case study data from 10 audited facilities (two water and eight wastewater facilities). The provided data on measures are not complete, i.e., data are only provided for measures that apply to the audited facilities. In addition, this guidebook was prepared for Wisconsin facilities and lacks national scope, potentially omitting some applicable U.S. measures.

8. **Pakenas, Lawrence J. 1995. *Energy Efficiency in Municipal Wastewater Treatment Plants*. New York: NYSERDA.**
    - Wastewater only; NY State specific
    - Brief overview of NY State municipal wastewater sector, number of plants, range of capacities
    - DSM opportunities in effluent hydropower, aeration retrofits, improved aeration controls and on-site cogeneration

- Estimated costs by capacity for retrofits and expected energy savings for fine pore aeration and controls
- DSM barriers discussed briefly
- Cost data for biosolids (sludge) drying, hauling and disposal

Summary: This brief technology assessment (17-pages including references) is specific to New York State. Demand side management for municipal wastewater treatment facilities is defined as "any opportunity to reduce total energy cost and, in many instances, energy use by generating electricity on-site; reducing the amount of electricity purchased from the utility; shifting electricity use to off-peak hours; and, using alternative fuels and treatment technologies." DSM examples focus on improved aeration (e.g. coarse air to fine pore retrofits), improved aeration controls, and on-site cogeneration. There is little attention to wastewater treatment technologies other than activated sludge and trickling filters. Sludge drying, hauling and disposal costs are given from an earlier 1992 NYSERDA report. All references are from 1982 to 1993. We do not consider this a comprehensive guidebook for plant managers.

9. **Reardon, David. 1994. *Energy Audit Manual for Water / Wastewater Facilities: A Guide for Electric Utilities to Understanding Specific Unit Processes and their Energy/Demand Relationship at Water and Wastewater Plants*. CEC Report CR-104300, St. Louis, Missouri, EPRI Community Environmental Center, July.**
    - Brief energy audit handbook prepared to introduce the fundamentals of water and wastewater systems to marketers and field personnel of electric utilities
    - Describes how to conduct walk-through and detailed process energy audits for water and wastewater treatment plants
    - Provides some typical ranges of energy intensity (kWh/MG treated) for lagoons, trickling filters, activated sludge and oxidation ditch/extended aeration type wastewater treatment facilities (Figure 3-1), and surface water treatment plants (Figure 3-2)
    - Provides relative distribution of energy use by process at a 10-MGD surface water treatment plant (Figure 3-3) and a 7.5-MGD secondary wastewater treatment plant (Figure 3-4)
    - Chapter 4 summarizes in a paragraph or two some of the potential energy conservation measures (ECMs) for:
    - conventional processes at wastewater treatment facilities (including pumps, aerated grit chambers, primary clarifiers and biosolids pumping, trickling filters, rotating biological contactors (RBCs), activated sludge aeration devices, secondary clarifiers, utility water systems, anaerobic digestion, biosolids thickening and dewatering, load shifting, energy efficient motors, cogeneration with estimates of simple payback periods at different electricity prices, and space heating)
    - water treatment plants (including raw and finished water pumping, rapid mixing of coagulant chemicals, backwashing, ozonation, load shifting, well systems, water distribution systems, SCADA and energy efficient motors
    - Chapter 5 provides tips to develop a successful energy conservation program

- Chapter 6 describes monitoring and follow-up activities after the energy audit is completed
- References (9) are from 1974 through 1988
- Seven sample ECMs are given for a 10-MGD Wastewater Treatment Plant and four sample ECMs for a 10-MGD Water Treatment Plant with estimated capital costs, yearly savings and simple payback period for each sample ECM

Summary: This energy audit guide is both limited and out dated. It focuses on a few generic conventional water and wastewater processes. It does provide helpful information about how to conduct an energy audit and the importance of post-audit energy use monitoring and evaluation. It provides a limited number of examples of ECMs with estimated costs, annual savings and simple payback periods, but these estimates are not based on primary case studies or actual plant data, rather the secondary literature. This brief energy audit guide is more than ten years old; its references are primarily form the 1970s and 1980s; and, its intended audience is the field personnel and marketing personnel of electric utilities.

10. **State of Wisconsin. 2002. *Roadmap for the Wisconsin Municipal Water and Wastewater Industry*. Madison, WI: State of Wisconsin.**
    - Energy Efficiency opportunities: motors, pumps, systems, scheduling, etc. Descriptions only. (water and wastewater).
    - Opportunities to produce energy (self-generation) – wastewater only
    - Future energy efficiency opportunities (microfiltration, ozonation, ultrafiltration)
    - Design checklists for new water/wastewater treatment facilities (e.g., specify high efficiency pumps and motors, DSM, reuse, control system, etc) – checklists only
    - Several sections not applicable to the ENERGY STAR Focus (water/utility roadmap)
    - Pg 29 lists compliance requirements and technology options. Might be useful in writing the regulations section (included in energy management perhaps)
    - Includes list of new technologies and decision variables, but does not provide detail

    Summary: Several lists of energy efficiency opportunities are given, but the report lacks the data that we believe are needed on costs, savings and payback periods. In addition, this guidebook was prepared for Wisconsin facilities and lacks national scope, potentially omitting some applicable U.S. measures.

11. **US EPA. 2004. *Achieving Environmental Excellence: An Environmental Management Systems Handbook for Wastewater Utilities*. Washington, DC: U.S. Environmental Protection Agency, Office of Wastewater Management. August.**
    http://www.epa.gov/ems/assist/guide/emswastewaterhandbook.pdf
    - Wastewater only
    - Intended for facility operators implementing the ISO 14001 Environmental Management System
    - Focused on the EMS planning process and the information that should be in an EMS plan
    - Advocates an iterative or ongoing process for environmental management, similar to the ENERGY STAR energy management process

- Broad coverage of all environmental impacts from wastewater treatment (e.g., nutrients, solid waste disposal, land use, etc.). Mentions energy use as one of the environmental impacts to be managed.

Summary: This handbook is a good reference to cite for information about the process of energy management and how energy can be viewed in the larger context of a plant's environmental impacts. It does not provide any technical details—such as about how energy is used or energy efficiency technologies—that a plant manager would need to identify energy efficiency upgrades and make the case for investing in these upgrades.

12. Water Environment Federation (WEF)'s Energy Conservation Task Force. 1997. *Energy Conservation in Wastewater Treatment Facilities*. Alexandria, VA: Water Environment Federation.

- Wastewater only
- Generic "electricity requirements" disaggregated by sub process for 1, 5, 10, 20, 50 and 100 MGD capacity WWTF using (1) Activated Sludge, (2) Trickling Filter, (3) Advanced Wastewater Treatment w/o nitrification and (4) Advanced Wastewater Treatment w/ nitrification are taken from Burton (1996)
- More detailed information than in Burton (1996) on energy use of wastewater treatment processes and sub-processes
- Contains chapters on electric motors (Ch. 4), pumps (Ch. 5), variable controls (Ch. 6), aeration (Ch. 8) with 13 case studies, and solids processing (Ch. 9) with a breakdown of energy use during anaerobic digestion and post-digestion solids handling
- Provides detailed technical descriptions of WW treatment processes and energy efficiency technologies, but only provides case studies with cost and energy savings data for aeration technologies.
- Chapter 3 summarizes electrical utility billing procedures and energy saving incentives
- Chapter 10 summarizes energy management planning and provides examples of energy conservation measures and cogeneration opportunities

Summary: This guidebook provides a detailed treatment of disaggregated wastewater treatment facility electrical energy use, although it relies in its introduction on estimates taken from Burton (1996). It does not provide comprehensive case study data on costs and payback for a comprehensive set of energy efficiency technologies. It does discuss the energy conservation implications embedded within various electrical utility billing procedures. Chapter 10 on Energy Management follows a step-wise method for energy management planning and the development of conservation opportunities and strategies. This 1997 guidebook is dated. For example, advanced treatment technologies for tertiary treatment today must include nitrification and denitrification. Biological Nutrient Removal is discussed briefly (pp. 96-97), but denitrification energy is omitted from the "electricity requirements" tables in Chapter 1, again because it is based on pre-1996 data. The guide does not address the increase in electricity use due to advanced wastewater treatment with nitrification and denitrification.

13. **Williams, Robert B., and Gordon L. Culp, ed. 2001. *Handbook of Public Water Systems, 2nd edition*. New York: John Wiley and Sons.** (Chapter 29: Energy Conservation for Water Treatment Facilities)
    - Discussion of electricity, energy costs, energy uses in water/wastewater facilities, some data on facilities (prices, etc).
    - Efficiency measures addressed include: efficient motors, motor sizing, submersible pumps and motors, optimum conveyance systems, pump selection, pump testing and maintenance, variable frequency, SCR dc, load commutated inverter with synchronous ac motor, power factor/time of use/demand, distribution system, energy management, various lighting measures, hvac, metering, waste heat recovery, central heating and cooling systems, synthetic lubricants. For each there is an explanation but no data (on savings, costs, payback periods).

    Summary: This updated guidebook (first published 1986) provides a list and description of many energy efficiency measures but lacks data that plant managers need on costs, savings and payback periods. In addition, the list of measures is not complete.