Carbon Diversion and its Role in Energy Efficiency

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Over the years, the wastewater industry has developed treatment technologies that are effective at removing pollutants and nutrients, even as effluent standards have become more and more stringent. There are, however, still obstacles to overcome. The cost of treating wastewater is always increasing, and the regulations are always creating lower effluent limits. This is a battle many municipalities are continually faced with. The real improvement now and moving forward is the goal of building and maintaining energy-efficient water resource recovery facilities (WRRFs).

During the last decade, the wastewater treatment industry has rapidly advanced in the development of technologies to enable its facilities to be more energy efficient. One way to do this is to divert or redirect the carbon in raw wastewater. These carbon diversion technologies can capture more organics from the influent wastewater stream, resulting in a greater amount of the biochemical oxygen demand (BOD) load diverted to the biosolids line in lieu of aeration tanks. As a result, carbon diversion shifts the typical energy balance in a WRRF by diverting carbon-rich biosolids to the anaerobic digestion facilities, thereby increasing biogas production, while simultaneously reducing the amount of carbon oxidized in the mainstream activated sludge process.

Background

Wastewater treatment in the United States has evolved greatly since the 1800s when sewers were installed to replace pit privies and open ditches (with the primary purpose of disease prevention), and the treatment was mostly dilution into receiving waters.

During the first half of the 1900s, the primary focus was on water quality. The earliest treatment plants that were constructed included the first tricking filter facility in Madison, Wis., and the first activated sludge facility in San Marcos, Texas, in 1916. During this period, wastewater treatment was linked with the importance of dissolved oxygen (DO) to aquatic life, aesthetic properties of surface waters (i.e., odor, color, and solids), and measurement of organic matter in sewage as BOD. In 1948, the Federal Water Pollution Control Act was passed, which primarily provided federal funds for water quality surveys and construction of wastewater collection and treatment facilities.

The last 40 years of the 20th century brought dramatic changes to the way that wastewater was collected and treated, which has set the standards for treatment moving forward. An important milestone was the implementation of the 1972 Federal Water Pollution Control Act Amendments (PL 92-500) that were signed into law by President Richard M. Nixon and amended in 1977 (Clean Water Act) and 2002.

The law provided for:

- Water quality standards for receiving waters based on designated uses and related human health and aquatic life criteria.
- Antidegradation policy with ambient monitoring.
- Strategies and controls that would be put in place to improve impaired waters using a total maximum daily load (TMDL) approach.

During this same period, there have been treatment process advances to improve receiving water quality, nutrients (nitrogen and phosphorus) removal, improved biosolids management to improve the finished quality of the biosolids, incorporation of advanced technologies (membranes ultraviolet disinfection, etc.), and resource recovery (water reclamation, biosolids reuse, etc.). During this period, the analytical methods used to analyze pollutants in the wastewater improved, with the ability to analyze water quality parameters to lower levels of detection.

Now the paradigm of wastewater treatment has changed, and many utilities have added to the goal of meeting permit limits a target goal of resource recovery. Water reclamation has become the norm at many utilities; in fact, Florida leads the U.S. in this form of resource recovery, reusing nearly 800 mil gal per day (mgd) of the wastewater treated. Many utilities are turning toward both energy and/or nutrient recovery as an added target goal to further optimize their facility's operational costs.

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Carbon Diversion

The treatment of wastewater has always been a large burden on taxpayers. Typically, in most communities throughout the U.S., their WRRFs are the largest energy consumer. The goal now is to find a way to get these facilities to be less of a financial burden, and in some cases, act as an energy producer. The industry has a solid understanding of bacteria in the treatment process and has improved aeration processes to optimize the air provided to the bacteria so as not to waste one of the largest energy requirements at these facilities. The task now is figuring out how to apply these microbial populations in the most energy-efficient manner possible.

Different studies have focused on solutions to increase the energy efficiency of WRRFs. The goal of having WRRFs as net energy producers is an ambitious—yet feasible—one (McCarty et al., 2011; Hao et al., 2015). The self-sufficiency target is deemed achievable since wastewater already contains two to four times the amount of energy required for the wastewater treatment process (Tchobanoglous et al., 2009; Water Environment and Research Foundation [WERF], 2016). Additionally, several other WERF reports state that raw wastewater contains nearly five to ten times the amount of energy needed for the wastewater treatment process. The energy content from wastewater with a chemical oxygen demand (COD) of 500 mg/L is 1.93 kilowatt hours per cu meter (kWh/m^3), while typical energy consumptions ranges from 0.3 to 0.8 kWh/m^3 (WERF, 2016; Hao et al., 2015).

The industry has understood carbon diversion for a long time, but the goals for wastewater management have primarily focused on effluent criteria, rather than energy management. Historically, engineers and utilities have relied on conventional primary clarification or chemically enhanced primary clarification (CEPT), with the goal of reducing the organic and/or solid load(s) on the downstream processes. In the latter half of the last century, high-rate clarification that combines the techniques of chemically enhanced settling with lamella plates or tube settlers entered the marketplace; however, this technology was mainly used for wet weather treatment.

Figure 1 depicts where carbon diversion technologies are typically installed within a treatment process flow scheme.

Emerging Technologies

The term carbon diversion (or redirection) has been adopted by the industry, and this technology can capture more organics from the influent wastewater stream, resulting in a greater amount of the BOD load being diverted to the biosolids line, in lieu of aeration tanks. Diverting more organics to anaerobic digestion enables utilities to capitalize on renewable energy opportunities by generating more biogas.

Several technologies have recently emerged to provide a higher degree of primary treatment, reduced footprint, and decreased operational and maintenance requirements when compared to conventional primary clarification (WEF, 2018). These emerging technologies can be grouped into two general categories:

- Mechanical
  - Primary effluent filtration using disk filters.
  - Screened raw wastewater filtration using disk filters, rotating screens, or rotating belt filters.
- Biological
  - Biosorption and bioflocculation incorporating gravity clarification or dissolved air flotation.

Depending upon the goal of the utility, these technologies can either work in concert with the existing primary clarifiers or replace primary clarification all together. These technologies are designed to capture the wastewater solids and organics (achieving increased BOD and total suspended solids [TSS] removal) before discharging to the secondary treatment processes, thereby directing the BOD and TSS to a WRRF's sludge stabilization facilities for further processing and conversion to energy.

The overall performance of these technologies is site-specific and dependent upon the characteristics of the wastewater being treated: raw or primary effluent, design (hydraulic, solids loading rates, etc.), or operational conditions. Compared to conventional primary clarification, BOD and TSS removal can be increased by 30 to 50 percent using an advanced primary treatment technology. Although not a requirement, coagulants and/or polymers can be used to increase the removal efficiencies of each of these technologies.

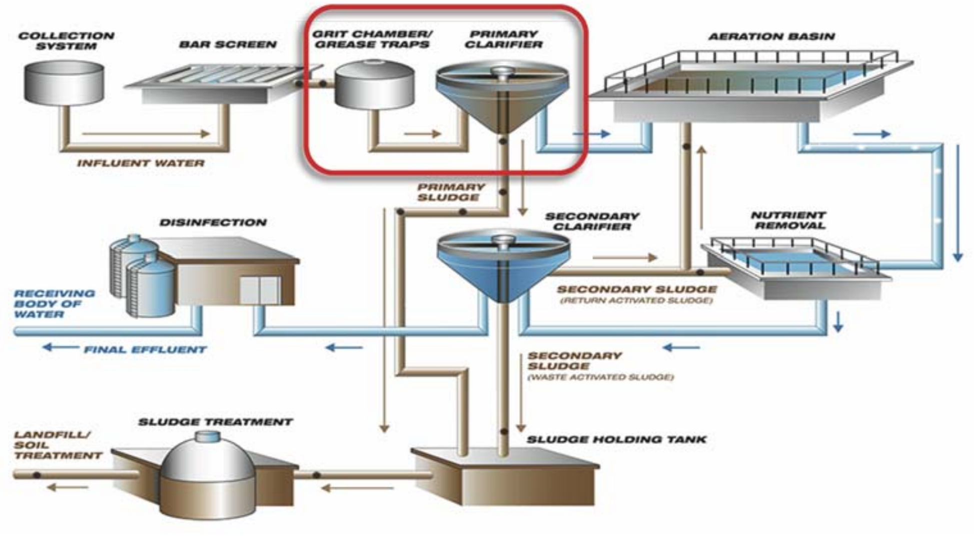

Figure 1. Locations within a water resource recovery facility where carbon diversion can be applied.

Table 1. Categories of Primary Treatment Options

Primary Treatment	Can Remove	Removal Mechanism	Treatment Efficiency[1]
Conventional	Particulate/settleable material	Sedimentation	TSS: 30 – 50% BOD: 25 – 30%
Chemically enhanced	Particulate/settleable material	Sedimentation with chemicals	TSS: 60 – 90% BOD: 40 – 70%
Mechanical (screens and filters)	Particulate larger than filter/screen size clear space openings	Physical barrier, mechanical separation	TSS: 40 – 50%[2] TSS: 50 – 90%[3] BOD: 20 – 30%[2] BOD: 10 – 55%[3]
Biologically enhanced	Particulate, colloidal, and soluble material	Biosorption and bioflocculation followed by sedimentation	TSS: 60 – 70% BOD: 50 – 60%

Notes:
1 Dependent upon design and operation conditions
2 Primary effluent filtration
3 Screened raw wastewater filtration

The mechanical technologies require effective screening (<0.25 in.) and grit removal. While the biological technology can operate with only screening, it's still recommended that an effective grit removal process prior to the biologically enhanced primary treatment (BEPT) process be provided. Regarding the hydraulic throughput of these technologies, the biological technology system can be designed for a wider range of flowrates, though a single mechanical system is limited to flow ranges of 0.1 to 15 mgd, depending upon the technology used.

Different advanced primary treatment technologies offer different advantages, each with unique design and operational features, as well as treatment performances. For example, if removal is achieved by filtration media with relatively small pore size, particle size characteristics of the wastewater will be altered to enhance the effectiveness of the secondary treatment process (Callskaner, 2018). If the advanced primary treatment process has an integrated biological treatment process component, soluble and particulate BOD will be removed. Regardless of the carbon diversion method chosen, the technology that's used must be based on the downstream treatment processes: liquid and solids.

The advantages of these advanced primary treatment technologies include:

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- Decreased electrical energy required for aeration in secondary treatment processes because of reduced organic loading.
- Increased gas energy production in the anaerobic digestion process resulting from the high organic energy content of the removed volatile suspended solids.
- Expanded facility capacity by reducing the organic loading upstream of the secondary process.

Table 1 presents the advanced primary treatment options, in comparison to the conventional and CEPT processes.

While the principle advantage of the advanced primary treatment technologies is the additional biogas that can be produced in the anaerobic digestion process, these technologies can also be installed at facilities that do not incorporate anaerobic digestion. For example, smaller facilities that incorporate aerobic digestion can benefit from this technology, primarily due to the lower organic load entering the downstream activated sludge process. Odors, however, could be a concern since additional primary solids will be entering the stabilization process, and aeration requirements to mix and oxidize these solids may increase due to the increased demand and thicker solids from the dissolved air flotation (DAF) unit.

Biologically Enhanced Primary Treatment

While each of these technologies has been piloted extensively and can provide utilities with opportunities to further move their WRRFs to being "net zero" energy facilities, the focus here is on the BEPT technology that has been developed by Evoqua Water Technologies, known as the Captivator®. This is a unique carbon diversion technology that uses biosorption to achieve high levels of BOD and TSS removal, as well as sludge thickening prior to anaerobic digestion.

This process blends waste activated sludge (WAS) from the biological treatment process with raw wastewater in a contact tank that is mildly aerated to promote rapid biosorption of soluble organics. Within the contact tank, colloidal BOD is adsorbed onto larger flocs. The hydraulic design detention time of the contact tank ranges between 20 and 40 minutes and operates somewhat like the contact stabilization activated sludge process. The typical solids concentration of the blended wastewater/WAS stream is between 400 and 600 mg/L (WEF, 2018).

The organic-rich WAS and raw wastewater particulate (organic and inert) suspended solids flow to a high-rate unit (DAF), where they are then separated (Ding et. al., 2015). The DAF functions as a highly efficient solid-liquid separator that operates at a high surface overflow rate (SOR), using about one-fifth the area of a typical primary clarifier, and cothickens the combined wastewater organics and WAS prior to anaerobic digestion. This thickening, which produces a float that is at least 3 to 4 percent solids, to as much as 6 percent solids, can eliminate the need for a separate thickening step (Doyle et al., 2018).

Floated solids from the DAF unit are rich in organic material and can be sent to digestion, often without the need for intermediate thickeners. The subnatant from the DAF unit flows to the activated sludge process that now operates with a lower organic load, resulting in less aeration energy demand and potentially smaller treatment volumes. The design hydraulic overflow rate of the DAF unit for this process ranges between 5,000 and 10,000 gal per day per sq ft (gpd/sf^2) and the recommended solids loading rate ranges from 15 to 30 pounds per day per sq ft (lbs/day/sf^2) (WEF, 2018).

A simplified process flow diagram of the Captivator system is illustrated in Figure 2.

This technology has undergone a rapid progression over the past two decades, with the first full-scale installation in January 2014 at the 32-mgd Agua Nueva Water Reclamation Facility (WRF) in Pima County, Ariz. This facility was a greenfield plant and replaced the Roger Road Wastewater Treatment Facility (WWTF). An aerial of the Agua Nueva WRF is shown in Figure 3. An evaluation of conventional primary clarification, CEPT, microscreening, and BEPT was performed by the design engineers, and it was determined that the BEPT process was the best option for Pima County.

This facility incorporates six contact tanks and DAF units that are each 60 ft by 20 ft, with a design overflow rate of 4,444 gpd/sf^2(Doyle et al., 2018). More importantly, the footprint of this BEPT process was approximately 65 percent less when compared to conventional primary clarification. In terms of performance at the Agua Nueva WRF, the BEPT process has typically achieved 65 percent TSS removal and 25 to 30 percent soluble BOD removal (Doyle et al., 2018). Additional information on the design and operation of the Agua Nueva WRF is provided in Johnson et al., 2014.

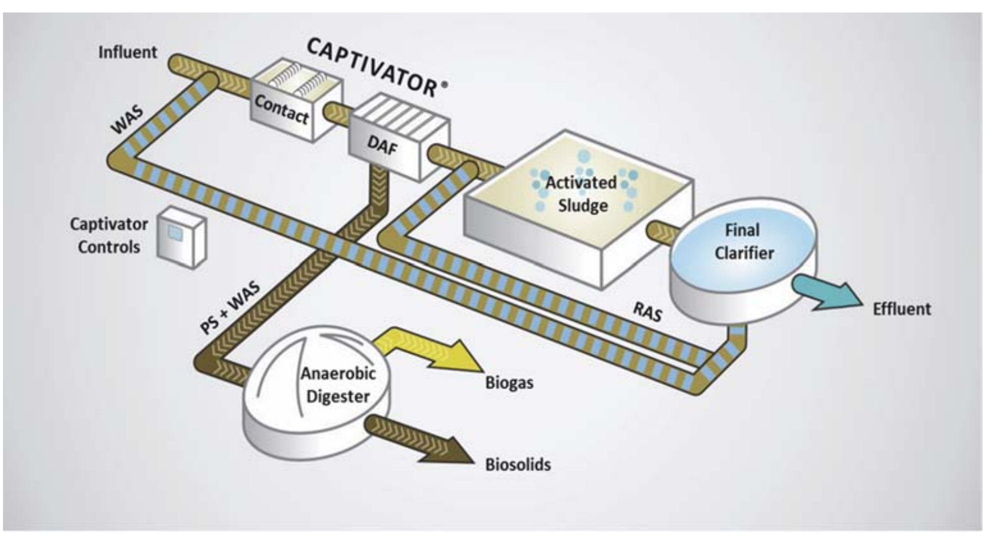

Figure 2. Biologically enhanced primary treatment process flow diagram. *(graphic: Evoqua Technologies Inc.)*

Design Example

A better understanding of the actual benefits possible with the BEPT carbon diversion technology can be provided by looking at the comparison of biogas production and aeration tank BOD reduction in a full-scale design example. In this example, the facility has a two-stage activated sludge process: high-purity oxygen (HPO), followed by conventional activated sludge for nitrification. Conventional denitrification filters using methanol as a carbon source to promote denitrification are used, and screening and grit removal precede the HPO basins.

Sludge from the primary and secondary treatment processes is thickened and then pumped to the seven mesophilic anaerobic digesters for stabilization. For this example, an annual average daily flow (AADF) of 65 mgd, with influent BOD and TSS concentrations of 180 mg/L and 161 mg/L, respectively, was used. The BOD concentration was broken down into particulate, colloidal, and truly soluble fractions using values accepted in BioWin™ and GPS-X process modeling software.

Based on values from historic testing data, the BEPT performance had a 70 percent TSS removal rate in the DAF and a 35 percent soluble BOD (sBOD) that was bio-adsorbed in the aerated contact tank. The anaerobic digestion performance was based upon a steady-state model, which results in biodegradable volatile solids (VS) destruction and gas production based upon equal mesophilic digestion hydraulic retention time (HRT) for both systems. Table 2 compares the calculated performance of a conventional primary clarification system and a BEPT at this facility.

As noted, by implementing a BEPT process there is a positive benefit to both the liquid and solids handling processes. In comparison to the conventional primary clarifiers, the increase in BOD removal nearly doubled (28 to 52 percent) when the BEPT process was

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Figure 3. Aerial view of the biologically enhanced primary treatment process at the Agua Nueva Water Reclamation Facility. *(photo: Pima County)*

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implemented. The solids sent to the anaerobic digesters will increase by approximately 15 percent, from 92,000 to 106,000 lbs/day. More importantly, since the makeup of these solids is predominately primary solids with less WAS, this mixture will be easier to digest and the biogas produced could increase by nearly an additional 41 percent, from 525,000 cu ft per day (cf^3/day) to 780,000 cf^3/day.

Summary and Conclusions

Over the past decade several technologies have emerged to provide a higher degree of primary treatment, while providing a reduced footprint when compared to technologies currently practiced (i.e., conventional and chemically enhanced primary clarification), with lower operational and maintenance requirements. These technologies offer a utility the ability to divert more carbon to anaerobic digestion, rather than treating this organic load within the activated sludge process.

These advanced technologies include:

- Filtration of the primary effluent using disk or compressed media filters.
- Filtration of the raw wastewater using disk filters, rotating belt filters, or microscreens.
- The BEPT incorporating a mildly aerated contact tank and high-rate DAF unit.

Regardless of the advanced primary treatment system implemented, they each can offer:

- Decreased electrical energy required for aeration in secondary treatment processes because of reduced organic loading.
- Increased gas energy production in the anaerobic digestion process resulting from the high organic energy content of the removed volatile suspended solids.
- Expanded facility capacity by reducing the organic loading upstream of the secondary process.
- A smaller footprint when compared to conventional primary treatment and/or CEPT systems.

A BEPT process, however, is more adaptable to all flow ranges, whereas the mechanical processes (filtration or screening) require more units due to their equipment sizes and configurations.

Other benefits of a BEPT process include:

- Typical removal efficiencies:
  - TSS: 60 to 65 percent or more
  - sBOD: 20 to 30 percent
  - Total BOD: 50 percent or more
- Thickening not required prior to anerobic digestion since float from the DAF ranges from 4 to 6 percent solids with no chemical addition.
- Equipment can often be retrofitted into existing primary clarifiers if the configuration of the clarifiers matches the needs for the contact tank and DAF units.

Since each of these differ, their performance is site-specific and the engineer involved needs to consider specific design criteria when integrating an advanced primary treatment process into a new or existing WRRF. Effective screening (<0.25-in. openings) and grit removal are required prior to any advanced primary treatment technology, regardless of the process used. It should be noted that the BEPT process is more tolerant of poor grit removal, due to the ability of the DAF to capture biological solids as float, while grit and heavy solids are deposited in the bottom and removed. Also, care must be taken to ensure that the downstream performance of the biological nutrient removal processes is not negatively impacted by the organic load that is removed, and permit conditions are not exceeded. Therefore, regardless of the technology under consideration, pilot studies are recommended before the design of full-scale facilities.

Table 2. Calculated Performance Between Conventional Primary Clarifiers and Biologically Enhanced Primary Treatment *(Evoqua, 2018)*

Description	Conventional Primary Clarification	BEPT
BOD to aeration (lbs/day)	71.000	48,000
BOD removal (%)	28	52
Solids to anaerobic digestion (lbs/day)	92,000	106,000
Solids destroyed (lbs/day)	35,000	52,000
Biogas generated at 15 cf^3/lbs (cf^3/day)	525,000	780,000
Solids to dewatering (lbs/day)	58,000	54,000
Biogas energy at 38% efficiency (kWh)	1,390	2,060

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References

- Callskaner, Onder (2018). "Carbon Diversion Decisions, Evaluating Advanced Primary Treatment Options Side by Side." Water Environment Technology, August 2018.
- Ding H.-B.; Doyle M.; Erdogan A.; Wikramanayake R.; Gallagher P. (2015). "Innovative Use of Dissolved Air Flotation with Biosorption as Primary Treatment to Approach Energy Neutrality in Wastewater Treatment Plants." Water Practice and Technology, Vol 10 (1).
- Doyle, M.; Erdogan, A.; Antonneau, N.; Johnson, B.; Babcock, R.; Tiow Ping Wong, T.; Bakri Eljerdi, H. (2018). "Biologically Enhanced Primary Treatment: A Summary of Experience from Pilot, Demonstration, and Full-Scale Systems." Proceedings of the Water Environment Federation Residuals and Biosolids Conference, Phoenix, Ariz.
- Hao, X.; Liu, R.; and Huang, X. (2015). "Evaluation of the Potential for Operating Carbon Neutral Wastewater Treatment Plants in China." Water Resources 87, 424 - 431., doi: 10 - 1016 j.watres. 2015.05.050.
- Johnson B.; Phillips J.; Bauer T.; Smith Gr.; Smith Geo.; Sherlock J. (2014). "Start-up and Performance of the World's First Large-Scale Primary Dissolved Air Floatation Clarifier." Proceedings of the Water Environment Federation WEFTEC 2014, (10) 712-721.
- Tchobanoglous, G.; Leverenz, H.; and Gikas, P. (2009). "Impacts of New Concepts and Technology on the Energy Sustainability of Wastewater Management in Climate Change, Sustainable Development, and Renewable Energy Sources." (Thessaloniki: Environmental Council of the Aristotle University of Thessaloniki).
- Water Environment Federation (2018). "Design of Water Resource Recovery Facilities – Manual of Practice No. 8." Water Environment Federation and the American Society of Civil Engineers/Environmental and Water Resources Institute, Sixth Edition, 2018.
- Water Environment Research Foundation (WERF) Energy Factsheet (2016). Water Environment & Reuse Foundation, Alexandria, Va.