The Carbon Footprint of Wastewater Treatment

When the Water Pollution Control Act Amendments (PL92-500) of 1972 were enacted by Congress, the world's population was less than 4 billion, a barrel of oil was less than $5, and the average cost of electricity in the United States was less than $0.02 kWh. Thirty-four years later the earth's population is greater than 6 billion, crude oil cost more than $100 a barrel, and the cost of electricity in the US Virgin Islands is $0.34 kWh. Each year in the United States the treatment of wastewater consumes millions of megawatts of electricity and releases millions of tons of CO_2 into the atmosphere.

The CO_2 released by a modern wastewater treatment plant originates from two sources, the microbial breakdown of the organics in human waste and the burning of fossil fuels to generate the electricity needed to operate the treatment plant itself.

Reducing CO_2 and carbon emissions has now become a global imperative as the long-term negative impacts of Global Warming are becoming increasingly evident.

> Definition: a Natural Wastewater Treatment System is a technology that uses plants and bacteria to remove pollution instead of machines.

<u>The adoption of natural wastewater treatment technologies can reduce CO_2 emissions to near zero and at the same time contribute significant quantities of oxygen to the atmosphere.</u> To understand how this happens let's do a little Biology 101 review.

Everything that humans eat originates from plants (including meat). Plants remove CO_2 form the atmosphere and use the sun's energy to combine it with water to create sugars from which they build their bodies. The formula for this process is shown below. It is commonly known as photosysthesis.

$$6CO_2 + 6H_2O \leftrightarrow C_6 H_{12} O_6 + 60_2 \qquad \text{(Eq. 1)}$$

What this formula says is that six units of carbon dioxide will combine with six units of water to form one unit of sugar (glucose) and six units of oxygen, of course it takes chlorophyll and sunlight to drive the reaction. The units can be expressed in any measure you choose (pounds, tons, kilograms, etc.) as long as the formula's ratios are maintained. The equation moves to the right when plants are growing and building biomass (CO_2 is removed from the atmosphere) and moves to the left when plants die or are eaten. They are then broken down to CO_2, H_2O and living energy.

Using the molecular weights of the different atoms (oxygen, hydrogen, carbon) we can express the above equation in a convenient unit of measure, say a kilogram*(kg) which will help us calculate and compare the amount of CO_2 that is released during the treatment of wastewater in both mechanical and natural wastewater treatment systems.

* Kg amounts are the same as the respective molecular weights times the number of molecules involved.

Photosynthesis:

$$264\text{kg of } CO_2 + 108\text{kg of } H_2O \xrightarrow[\text{chlorophyll}]{\text{☼ Sun's Energy}} 180\text{kg } C_6H_{12}O_6 \text{ (Glucose)} + 192\text{kg } O_2 \quad \text{(Eq. 2)}$$

Respiration:

$$180\text{kg } C_6H_{12}O_6 \text{ (Glucose)} + 192\text{kg } O_2 \longrightarrow 264\text{kg of } CO_2 + 108\text{kg of } H_2O + \begin{matrix}\text{Living}\\ \text{Energy}\end{matrix} \quad \text{(Eq. 3)}$$

The basic photosynthesis equation can be used to make a comparison of how much CO_2 is released by either a natural wastewater treatment system that relies on plants and a mechanical treatment system that relies on fossil fuels for it operation. For this exercise we will assume a residential type wastewater that has a biological oxygen demand (BOD) of 250 mg/l with a daily flow of 200 m^3/day (53,000 gallons/day). A system of this size contains approximately 50kg/day or about 18,250 kg/year of BOD.

When BOD is broken down by the bacteria in a wastewater treatment system our equation on the previous page moves to the left. Carbohydrates (chains of glucose and other sugars) are broken down, releasing CO_2 to the atmosphere in the process. If we look at our equation with the weights we can see that for every 180 kg of glucose that is broken down there are 264 kg of CO_2 released (a ratio of 1:46). So if our hypothetical treatment system is breaking down 18,250kg/yr of BOD (carbohydrates/sugars) then we are releasing 26,767kg of CO_2 to the atmosphere in the process (18,250 kg x 1.46 = 26,767kg). This release of CO_2 will take place in both a natural and/or a mechanical treatment system. Because natural wastewater treatment systems use plants as the foundation of their treatment engine, they remove about as much CO_2 from the atmosphere as is released by the breakdown of the BOD in the wastewater they treat.

Here in the Caribbean an indigenous wetland grass, Caribegrass (*Eriochloa polystachya*), would be planted to a natural treatment system called a "Vegetated Sand Filter" (VSF). Caribegrass would produce over 220 metric tons/ha/yr of biomass (wet matter) or about 42 tons/ha/yr of dry matter. A VSF sized to treat our hypothetical 200 m^3/day of flow would require 4,100 m^2 of area and would produce approximately 17,117 kg of dry matter annually.

As plants in a VSF grow, our equation (#1) on the previous page moves to the right and CO_2 is removed from the atmosphere. We can also see that for every kg of sugar that is produced on the right hand side of the equation, 1.46 kg of CO_2 (246 ÷ 180 = 1.46) is removed from the left hand side of the equation (the atmosphere). So when our hypothetical 4,100 m^2 VSF produces 17,117 kg/yr of dry matter in year, it has also removed 24,990 kg of CO_2 from the atmosphere, which will almost completely offset the 26,767 kg of CO_2 that is released from the wastewater being treated. This exercise only includes the above ground biomass produced by the plants. When root biomass production is added in, the CO_2 offset is greater than 100%. What is important to remember here is that our hypothetical VSF not only provides a 100% carbon offset, but each year it also produces 18,258 kg of oxygen that is added to the atmosphere (right hand side of the equation).

Mechanical treatment systems by comparison are net CO_2 producers because they rely exclusively on fossil fuels for their operation. Although there are many different types of mechanical treatment technologies with different operating efficiencies, a good rule of thumb is that for every kg of BOD that is treated approximately 2.65 kWh of electricity are consumed. For each kWh of electricity that is consumed 0.97 kg of CO_2 are released to the atmosphere from the power plant providing the electricity. This of course doesn't include the CO_2 produced from the sewage breakdown itself.

We can calculate the total amount of CO_2 that will be released by a mechanical treatment system treating our hypothetical 200 m^3/day of flow by summing the two CO_2 sources. As was stated earlier, a daily flow of this volume would produce approximately 18,250 kg/year of BOD. The breakdown of this amount of BOD releases 26,767kg of CO_2 to the atmosphere, the same as the natural treatment system. An additional 46,911 kg CO_2, however, are also released by the production of the electricity needed to operate the mechanical treatment facility (18,250kg BOD x 2.65 kWh/kg BOD x 0.97 kg CO_2/kWh = 46,911 kg CO_2). It should be noted that the 46,911 kg of CO_2 released from the production of electricity to operate the treatment facility does not account for all of the additional CO_2 released during the extraction, transportation, and refining of the fossil fuel used to generate the electricity.

A CO_2 scorecard for the two methods of treating wastewater is shown below:

	Natural	**Mechanical**
CO_2 Released (kg/yr)		
BOD Removal	26,767 kg	26,767 kg
Fossil Fuel Use	0 kg	46,911 kg
Total CO_2 Released/yr	**26,767 kg**	**73,678 kg**
CO_2 Removed/yr		
Plant Biomass	**24,990 kg**	**0 kg**
Net CO_2 to Atmosphere/yr	**0 kg**	**73,678 kg**
O_2 Produced (kg/yr)		
Plant Photosynthesis	**18,258 kg**	**0 kg**
O_2 Loss	**0 kg**	**18,258 kg + elec.**

International realization that ever increasing releases of CO_2 to the atmosphere by human populations presents a global environmental threat have precipitated a classification of CO_2 as an atmospheric pollutant by the US Environmental Protection Agency and a call for both an international carbon tax on fossil fuels and a carbon credit system for technologies that are CO_2

neutral. Municipalities and developers with an eye on the future can permanently decouple the cost of operating their wastewater treatment systems from the volatile and continually rising fossil fuel market by utilizing natural treatment technologies. In doing so they are also positioning their natural treatment system to benefit from an income revenue stream derived from the carbon credit system once it is in place.

Conclusions:

If one considers the 300 million people living in the USA, with 75% of them connected to municipal wastewater treatment plants, the tons of CO_2 being produced each day is staggering. To make matters worse, the practice of chlorinating the partially treated effluent discharge produces trihalomethanes that are recognized cancer producers in people, to say nothing of what they do to the ecology of the rivers and lakes that they dump into. Considering that most rivers quickly transport their fresh water into the nearest sea or ocean, when wastewater treatment plants discharge their freshwater effluents into the same rivers it’s a quick one-way trip to the “salty sea”. According to USEPA, the household, municipal, and institutional potable water consumption in the USA is about 100 gallons per capita per day. Multiply that by 300 million people and it represents more than 30 billion gallons of wastewater effluent each day that gets “flushed to the sea”. If we add in another 1400 gallons per capita per day for agricultural and industrial consumption the numbers become staggering.

Of course this technology comparison would not be complete without pointing out that VSFs are typically designed as “green space” or “eco park” areas where the water can be recycled onto the land, and where the plant product can typically be used as animal food. If the nations wastewater effluent went to corn production we might even be able to convert sewage to ethanol. Feces to fuel! Now that’s a novel idea!!

About the authors:

Dr. Ronald Lavigne holds graduate degrees in Plant and Soil Sciences, Public Health, Environmental Sciences and Environmental Engineering. He has more than 35 years of Environmental Technology Research and writes regularly for Boating on the Hudson. Your comments can be directed to newswet@aol.com. **All comments will be responded to.**

Kelly Gloger holds graduate degrees in architecture and fisheries and wildlife. He is based in the US Virgin Islands, works as an environmental consultant throughout the Caribbean, and manages a solar technology company.