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Water Leaders Course

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A Circular Bioeconomy as Applied to Wastewater Infrastructure

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Circular Bioeconomy Approaches to Wastewater Treatment

Learning Objectives

- What is a circular bioeconomy?
- Why should a water utility or municipality care about it with regard to wastewater treatment?
- How can it complement or even replace conventional wastewater infrastructure to increase resilience, lower costs and multiply benefits?

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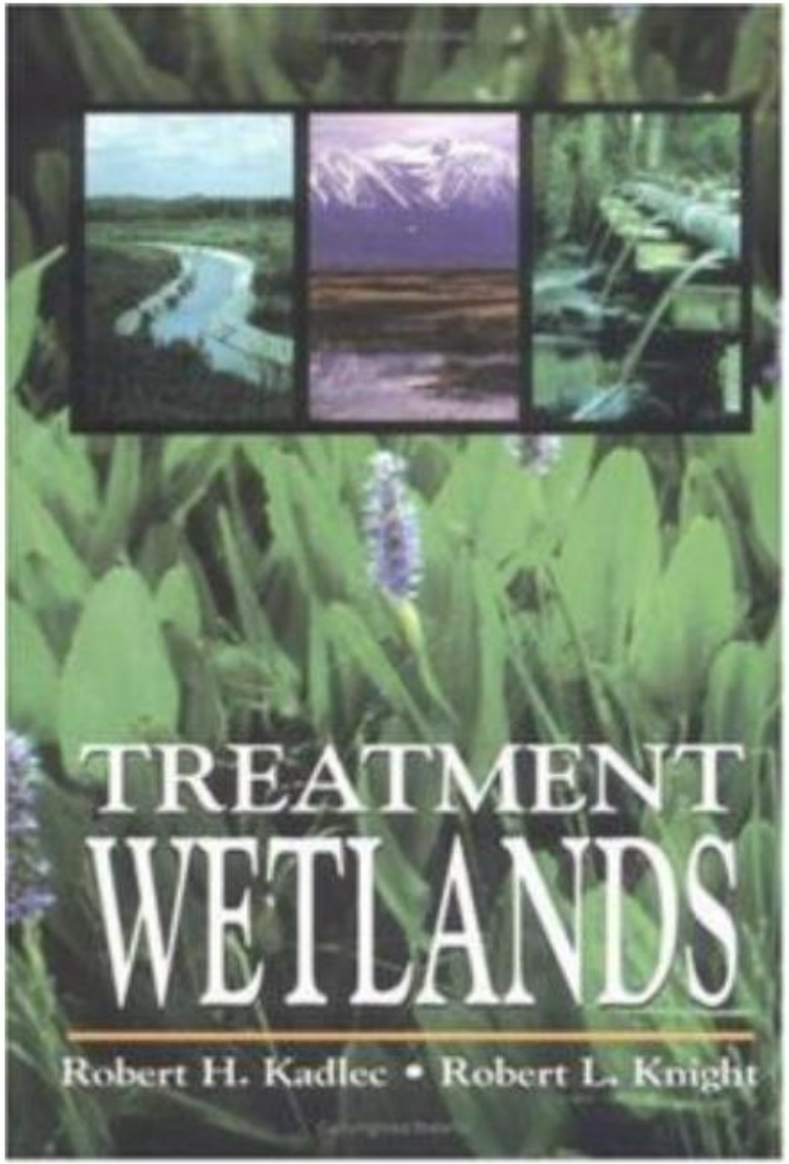
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Small Scale Living Machine (above), Large Scale Algal Turf Scrubber (below) and the reference text for Treatment Wetlands (right)





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What is a Circular Bioeconomy?

"The circular economy aims to eliminate waste and pollution, circulate products and materials and regenerate nature. While the circular economy reduces waste and extends product life cycles, the bioeconomy focuses on replacing fossil inputs with renewable or biological ones." **United Nations Trade and Development, UNCTAD**

Combining the principles of a circular economy with the bioeconomy is **an economic model** that combines the principles of sustainability, resource efficiency, and renewable biological resource use. It **seeks to maximize the value derived from natural materials** by keeping them in use for as long as possible, **minimizing waste, and reducing environmental impacts**.

Bio.org

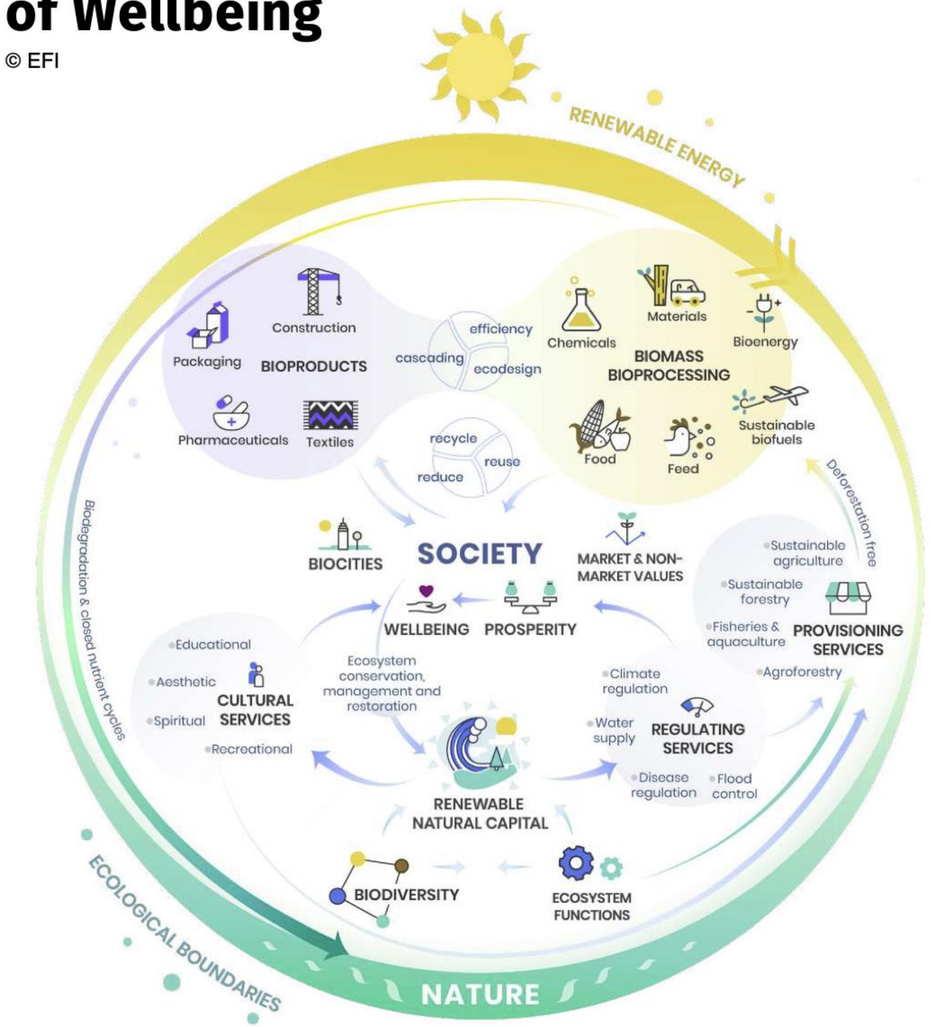
By integrating the circular economy and the bioeconomy, **countries can power [re]development**, curb waste and **use natural resources more sustainably**. This maximizes the efficient use of biomass through circular economy principles such as reuse, waste reduction and **recycling of biomass such as nutrient rich wastewater streams**.

UN Trade and Development, UNCTAD

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CIRCULAR BIOECONOMY ALLIANCE

THE CIRCULAR BIOECONOMY ALLIANCE WAS ESTABLISHED IN 2020 BY HIS MAJESTY KING CHARLES III AS THE PRINCE OF WALES.



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What are example wastewater treatment ecotechnologies that have circular bioeconomic characteristics?

Living Machines





Constructed Treatment Wetlands



Algal Turf Scrubbers

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A Different Way of Thinking About Wastewater Treatment

Why should water utility and municipal managers care and how does a traditional approach compare to a circular bioeconomic one?

Waste becomes a resource

Conventional Wastewater Infrastructure	A Circular Bioeconomic Wastewater Treatment Approach
Centralized and very expensive	Easily decentralized and can be large or small scalable while lower cost to build and operate
Fossil fuel energy intensive with a heavy carbon footprint	Uses more renewable and “free” energies (sunlight, gravity, photosynthesis, microbes) carbon sequestering
Expands grey engineered capacity unaesthetic	Increases the capacity of green, natural systems an aesthetic enhancement
Solves one problem at a time, wastewater treatment	Delivers multiple benefits with one investment, enhanced water treatment, aesthetics, wildlife use, potential food production, educational and a tourist attraction
Complex and easily disrupted, very costly to rebuild & requires high expertise	Simplified and resilient to disturbance, can be easily and less costly to rebuild with less expertise

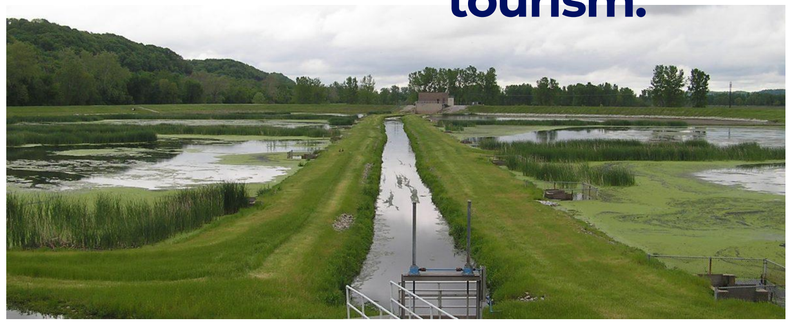
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How are wastewater treatment ecotechnologies supporting a circular bioeconomy? All are driven by the sun...and have beneficial by-products



Living Machines, housed in greenhouses in temperate climates, have visual aesthetics and the potential for some fruits & vegetables, cut flowers and aquaponics production. Anaerobic digestion of biosolids creates a methane biofuel.

Living Machines are a fascinating educational tool and often used in “green” tourism.



Treatment Wetlands have visual aesthetics and can support a large array of fish and wildlife. Evapotranspiration can create a cooler microclimate in urban areas. Anaerobic digestion of biosolids creates a methane biofuel.

Treatment Wetlands are magnets for the “birding” tourist economy.



Algal Turf Scrubbers as tertiary treatment require algal biomass to be regularly harvested, with the algae able to be used as a natural fertilizer, a composted soil media, a high protein livestock feed amendment.

Anaerobic digestion of biosolids creates a methane biofuel and at very large scales a potential algal biomass biofuel, i.e. bioethanol, biobutanol.

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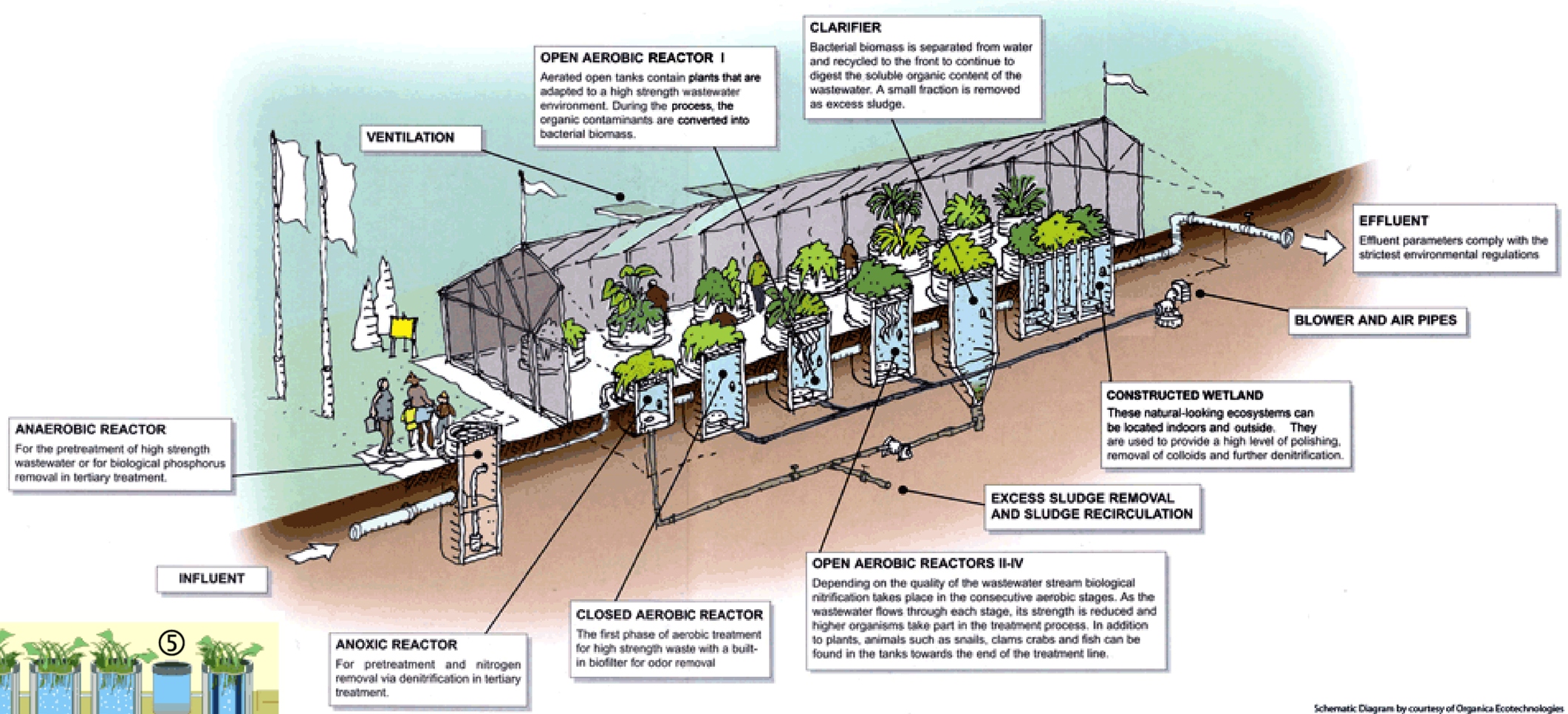
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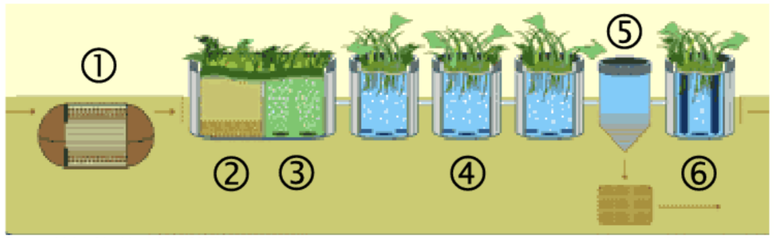
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Living Machines:

A Different Way of Thinking About Wastewate

Waste becomes a resource





Source: Living Machines Inc., 2001.

FIGURE 1 THE COMPONENTS OF THE LIVING MACHINE®: (1) ANAEROBIC REACTOR, (2) ANOXIC REACTOR, (3) CLOSED AEROBIC REACTOR, (4) OPEN AEROBIC REACTORS, (5) CLARIFIER, AND (6) "ECOLOGICAL FLUID BED"

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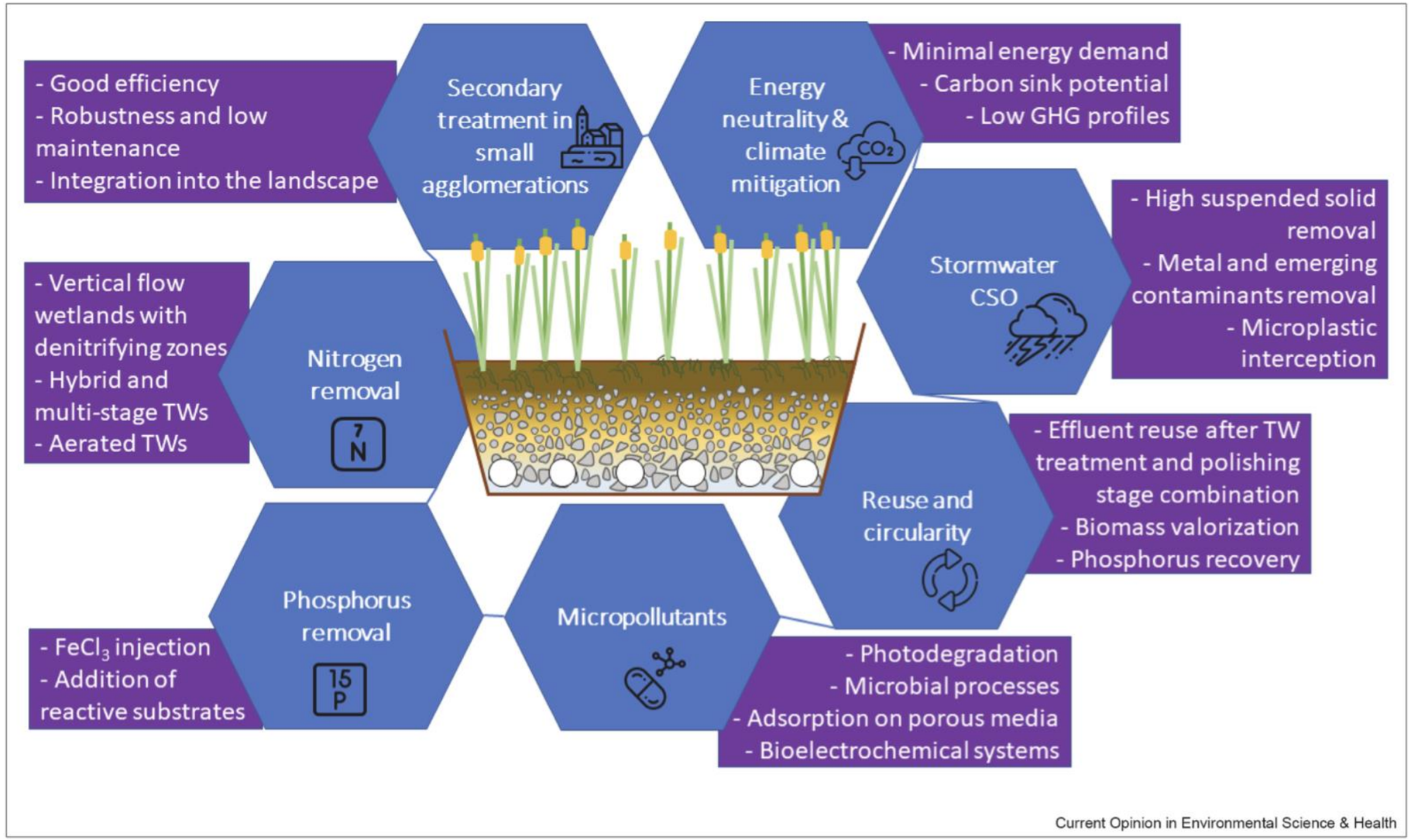
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Treatment Wetlands:

A Different Way of Thinking About Wastewater

Waste becomes a resource



The alignment of the key contributions of treatment wetlands with some of the regulatory priorities from the EU Urban Wastewater Treatment Directive 2024/3019. EU, European Union. (GAUTIER, 2026)

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Algal Turf Scrubbers:

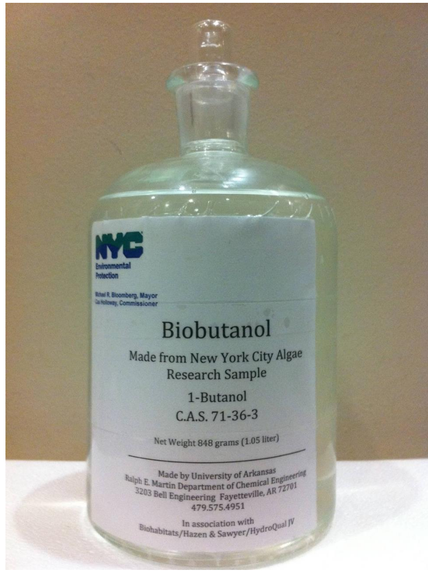
A Different Way of Thinking About Wastewater

Waste becomes a resource















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A Circular Bioeconomy using Wastewater Ecotechnologies

Scaling the Circular Bioeconomy: Unlocking Biobased Industries with Wastewater Treatment (Circular Bioeconomy Alliance, April 2026, CBA White Paper)

“The circular bioeconomy presents one of the greatest business [and governmental resource management] opportunities of the 21stcentury. It represents a systemic alternative to the current extractive, linear, fossil-based economy and offers holistic solutions to pollution, climate change and biodiversity loss as well as to resource security and economic prosperity.”

Treatment wetlands in the framework of the revised European Union Urban Wastewater Treatment Directive 2024, (Mathieu Gautier, 2026, Current Opinion in Environmental Science & Health 49:100702)

“The revised European Union Urban Wastewater Treatment Directive 2024/3019 introduces significant changes to the urban wastewater management framework across the European Union. Among its most notable developments are reinforced requirements for nutrient removal, the treatment of micropollutants, the management of urban stormwater, and broader ambitions for energy neutrality and water reuse. In this context, nature-based solutions appear increasingly relevant. Treatment wetlands including vertical flow and hybrid and bioelectrochemical systems offer solutions aligned with these objectives. ”

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Implementing a Circular Bioeconomy of Wastewater Treatment Using Ecotechnologies

Technical
Ecological



Economic
Social

- Doing more with less, saving up front capital and long-term operations & management costs with multiple increased benefits
- Provide on site tours of functioning systems to engineers, politicians and civil managers to see first-hand operations
- Engage with the firms that design and build these systems to compare costs of starting conventional vs ecotechnological
- Emphasize the small to large scalability and distributed vs a centralized model that is more resilient to disturbance

Interdisciplinary practitioners need to collaborate better and earlier

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Case study: Budapest, Hungary Living Machine Wastewater Treatment





OUTSIDE VIEW OF AN 80 000 M^3 / DAY ORGANICA FACILITY IN EUROPE



- Tertiary treatment of 80,000 m3/day
- 300,000 resident's sewage treated
- Built in 2012
- Open to the public for tours
- Designed and built by the firm Organica Water

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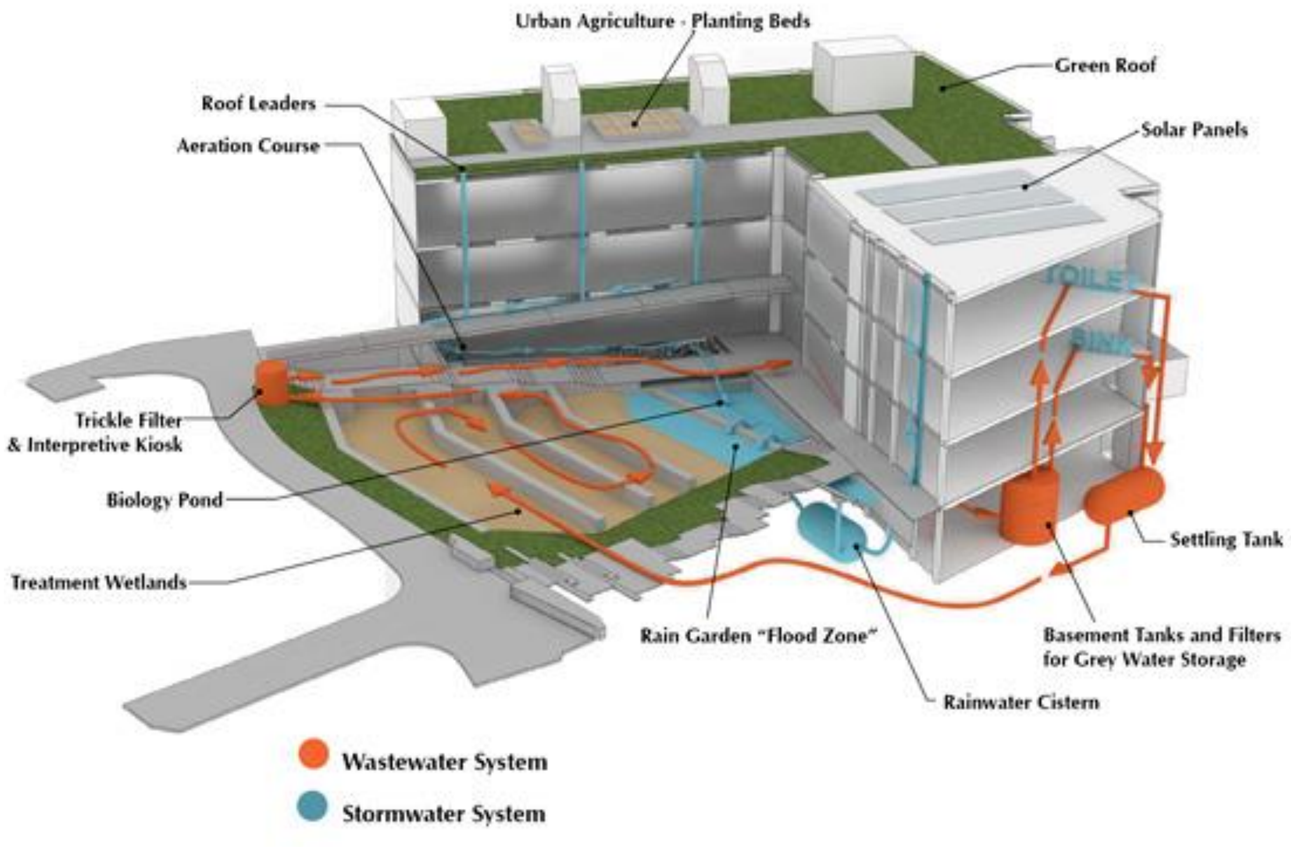
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Case study: Washington, D.C. Sidwell Friends School Treatment Wetland





The Sidwell Friends Middle School uses a subsurface flow treatment wetland, biofilm trickle filter, sand filter and UV disinfection to clean its sewage waste on site reusing the water in school toilets saving over 771,000 liters/year.

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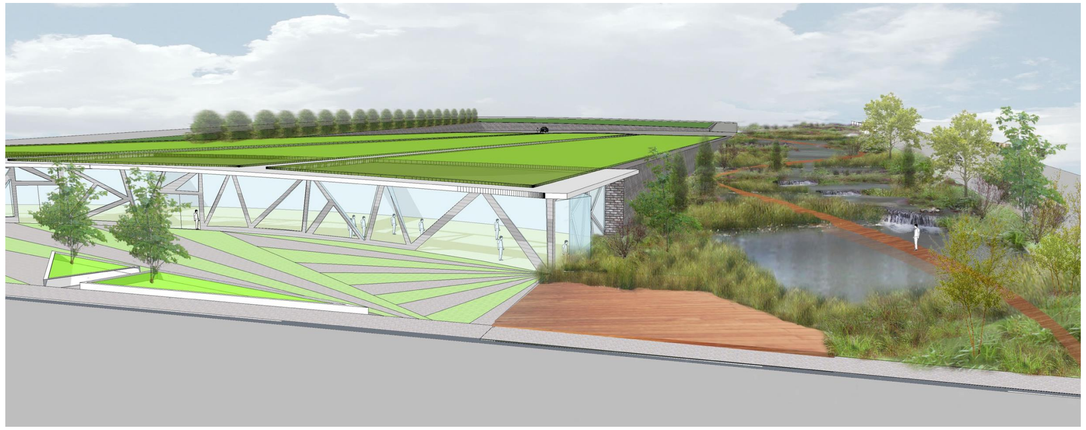
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Case study: New York City Algal Turf Scrubber Tertiary Wastewater Treatment

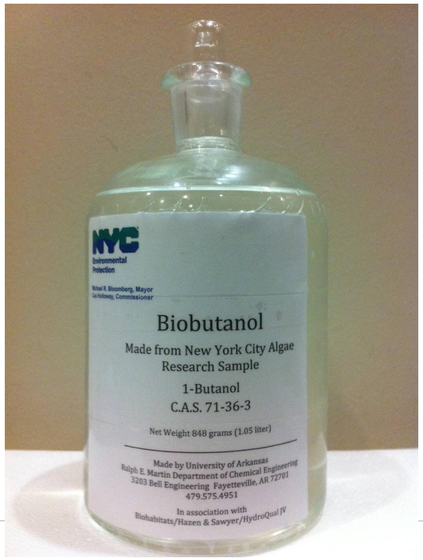








A NYC Department of Environmental Protection pilot with a plan for a 2 hectare community Ecopark and biofuel production next to the Rockaway Water Pollution Control Plant (100,000 m3/d)



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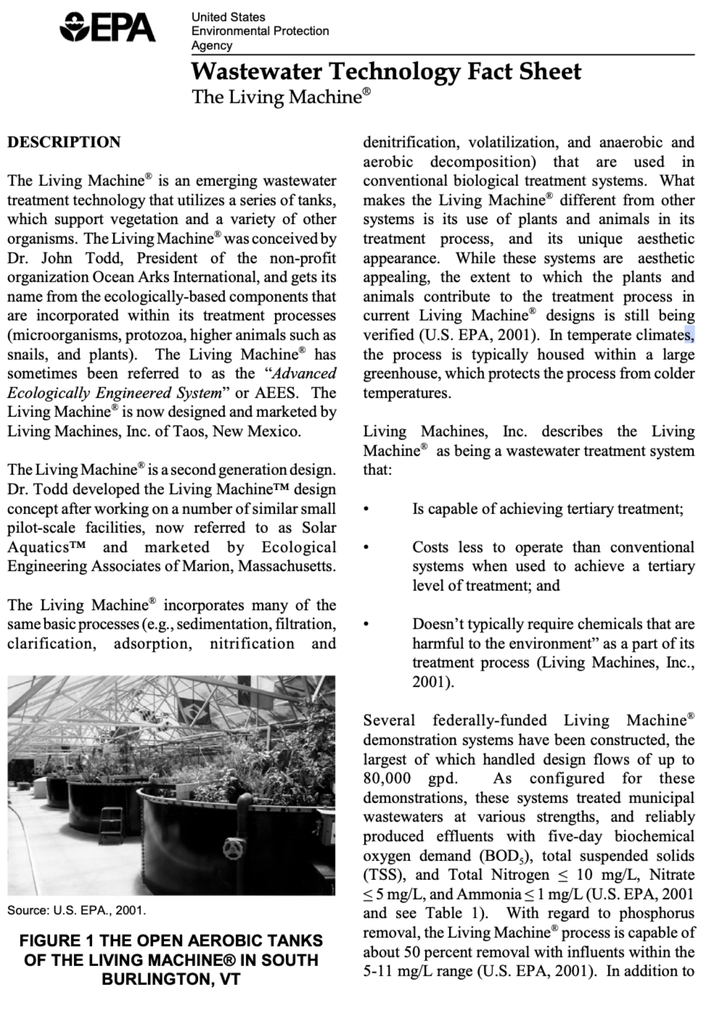
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Wastewater Ecotechnology Resources



United States
Environmental Protection
Agency

Wastewater Technology Fact Sheet
The Living Machine®

DESCRIPTION

The Living Machine® is an emerging wastewater treatment technology that utilizes a series of tanks, which support vegetation and a variety of other organisms. The Living Machine® was conceived by Dr. John Todd, President of the non-profit organization Ocean Arks International, and gets its name from the ecologically-based components that are incorporated within its treatment processes (microorganisms, protozoa, higher animals such as snails, and plants). The Living Machine® has sometimes been referred to as the "*Advanced Ecologically Engineered System*" or AEES. The Living Machine® is now designed and marketed by Living Machines, Inc. of Taos, New Mexico.

The Living Machine® is a second generation design. Dr. Todd developed the Living Machine™ design concept after working on a number of similar small pilot-scale facilities, now referred to as Solar Aquatics™ and marketed by Ecological Engineering Associates of Marion, Massachusetts.

The Living Machine® incorporates many of the same basic processes (e.g., sedimentation, filtration, clarification, adsorption, nitrification and denitrification, volatilization, and anaerobic and aerobic decomposition) that are used in conventional biological treatment systems. What makes the Living Machine® different from other systems is its use of plants and animals in its treatment process, and its unique aesthetic appearance. While these systems are aesthetic appealing, the extent to which the plants and animals contribute to the treatment process in current Living Machine® designs is still being verified (U.S. EPA, 2001). In temperate climates, the process is typically housed within a large greenhouse, which protects the process from colder temperatures.

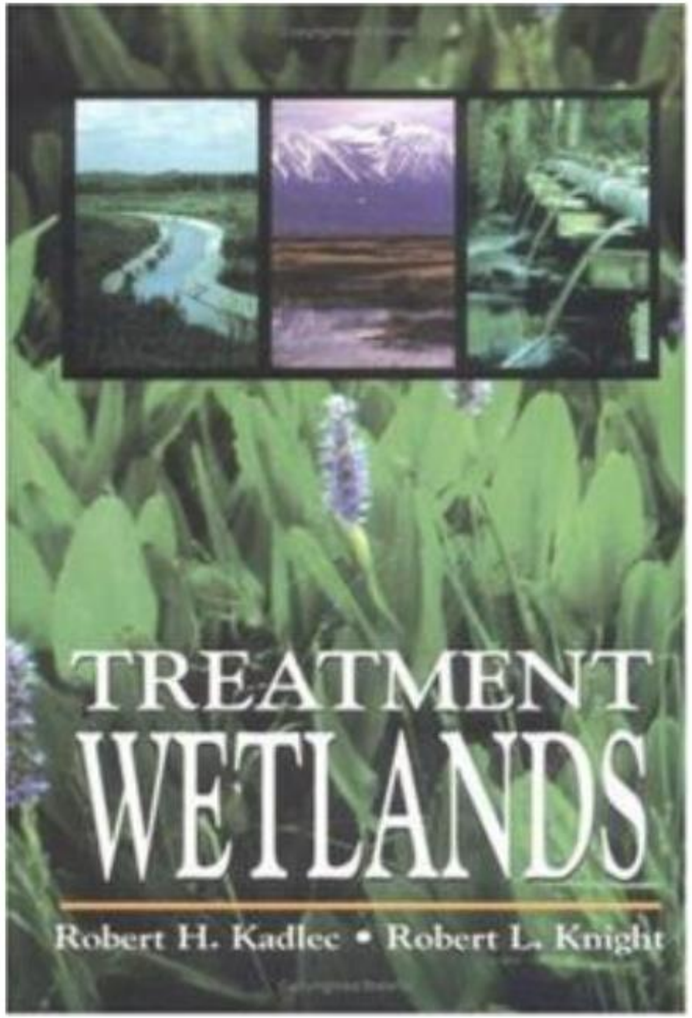
Source: U.S. EPA., 2001.

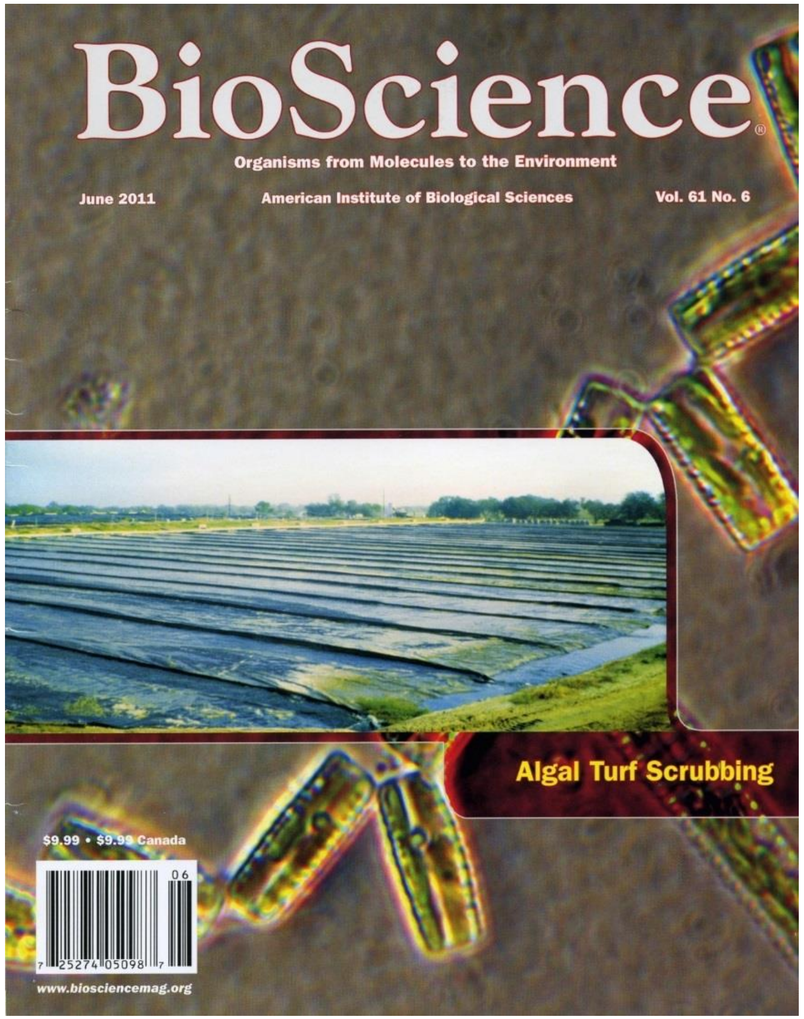
FIGURE 1 THE OPEN AEROBIC TANKS OF THE LIVING MACHINE® IN SOUTH BURLINGTON, VT

Living Machines, Inc. describes the Living Machine® as being a wastewater treatment system that:

- Is capable of achieving tertiary treatment;
- Costs less to operate than conventional systems when used to achieve a tertiary level of treatment; and
- Doesn't typically require chemicals that are harmful to the environment" as a part of its treatment process (Living Machines, Inc., 2001).

Several federally-funded Living Machine® demonstration systems have been constructed, the largest of which handled design flows of up to 80,000 gpd. As configured for these demonstrations, these systems treated municipal wastewaters at various strengths, and reliably produced effluents with five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L (U.S. EPA, 2001 and see Table 1). With regard to phosphorus removal, the Living Machine® process is capable of about 50 percent removal with influents within the 5-11 mg/L range (U.S. EPA, 2001). In addition to





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