ECOCYCLET®
A new Green Paradigm for Water Reuse
David Del Porto

ABSTRACT
The discharge of partially treated wastewater to receiving waters, be they groundwater or surface waters, is increasingly unacceptable due to the presence of man-made chemicals and pharmaceuticals.

The use of wastewater to grow valuable plants safely, be they for biofuels, flooring, or just landscapes for aesthetic value, is the highest use for the nutrients, organics, and water in what used to be called ‘wastewater’. This new Green Paradigm combines pollution prevention, economic savings, and energy production in one innovative concept.

One technology, specifically used for growing plants, is the patent-pending Ecocycl**ET** (ET stands for evapo-transpiration) and is based on the premise that effluent can be:

- stored
- recycled
- aerated
- transferred to a lined bed planted with valuable plant species and evapo-transpired
- or disinfected for non-potable reuse

The plant bed size and plant species are designed so that all the wastewater will be ultimately evaporated and transpired. Any excess effluent not used up is returned to an appropriately sized storage/recirculation tank or disinfected and transferred to a holding cistern to be used for non-potable purposes.

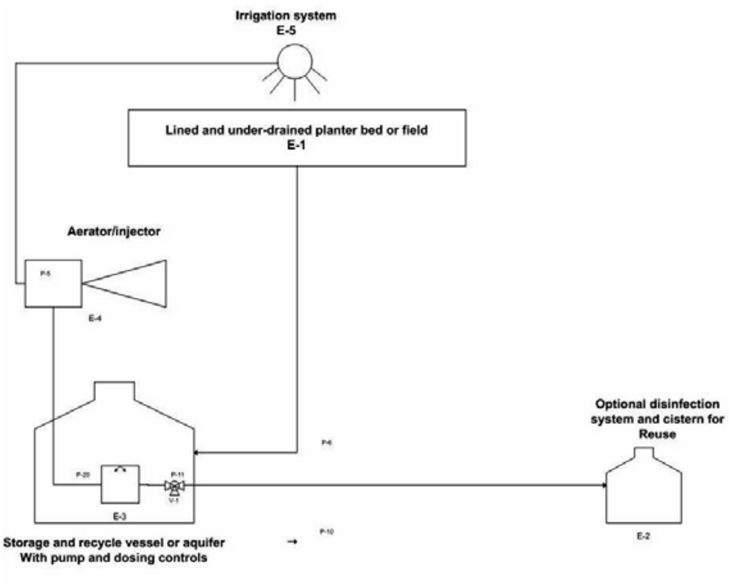
Because there is a separate cistern containing disinfected and treated effluent, the product completely avoids the need for a back up disposal field. The latter application is called the Ecocycl**ET** Wisconsin Reuse System because it was first approved in the state of Wisconsin, USA as a graywater reuse product to be installed where soils are too marginal to be considered for a soil absorption system. See Wisconsin Department of Commerce Product File Number: 20080446

An impervious liner forming the planting bed ensures that no effluent can enter the subsurface environment, or nearby receiving waters. Zero-discharge is the ultimate protection of the environment and growing valuable plants ensures that it is likely to be the most cost-effective on a life-cycle basis.

These systems can either be in sheltered or unsheltered environments depending on the local weather conditions. Storage in subsurface tanks or constructed aquifers holds the greatest promise for on-site applications. One unique unsheltered application is to store the effluent either in the recirculation tank or a subsurface constructed aquifer beneath the planting bed during cold winter months, and use it up during the plant growing season. Larger applications will more resemble farms for production of biofuels and other valuable crops such as bamboo flooring.

THE TECHNOLOGY

The patent-pending Ecocycl**ET** is based on the premise that effluent can be accumulated, stored, recycled, aerated, and transferred to a lined bed planted with valuable plant species. The plant bed size and plant species are designed to insure that all the wastewater will ultimately be transpired. Any excess effluent not used up is returned to an appropriately sized storage/recirculation tank or disinfected and transferred to a holding cistern to be used for non-potable purposes.



EcocyclET General Arrangement

Evapo-transpiration revisited

While evapotranspiration systems are not new, they have been appropriate only for climates with high temperature and low humidity. This EcocyclET technology seeks to broaden the application to all climates by adding new components such as storage, specially selected plants, aeration, and disinfection that are not in traditional ET system of past years. The seminal research on cold-climate evapotranspiration beds using wastewater from more than 100 on-site buildings and confirmed by careful laboratory analysis, was conducted primarily by Dr. Alfred Bernhart, Professor of Engineering, at the University of Toronto, Canada. At several sites, the summer rate of evapotranspiration without precipitation was measured at 0.29 gpd/sf (11.8 L/ m^2/d). The plants were primarily grasses, flowers, and small shrubs (Bernhart, 1985).

Water evaporates from the soil as well as from the plant itself. Transpiration is the plant's mechanism for evaporating excess water through openings in the leaf call stomata. Evapo-transpiration recognizes that water is evaporated from the soil as well as transpired. Maximal transpiration is the "unimpeded intensity of evaporation from plants under the regularly occurring conditions of evaporation in their natural habitat" (Larcher, 1995). The maximal transpiration, or uptake, rate is a function of many variables that interact and co-evolve over time. Factors include, but are not limited to:

- surface area of the stem and leaf system (leaf area index)
- ambient temperature and moisture content of planting bed, and air,
- plant species and variety
- recycle/dosing rate
- dissolved oxygen
- maturation of the phytosphere (which includes the bioplex in the rhizoplane of the planting bed
- light levels and phototropic issues

- influent nutrient characteristics
- general health and maintenance of the system (Del Porto, 2002).

Salt Accumulation and Removal

There has been concern that when wastewater is evapo-transpired, salts, especially sodium chloride, will remain in the bed and become toxic (O'Leary, 1984). To resolve this problem we specify the inclusion of excretive halophytes in the planting plan. Excretive halophytes transport the sodium and chloride ions to special glands in the leaves and there excrete the salt as a solid. Removing the leaves has the effect of mining the salt from the bed. Ion excretors include:

> Saltwater cord grass (*Spartina*), Amshot grass (*Echinochloa stagnina*), Salt bush (*Atriplex*), Salt cedar (*Tamarix L.*), Suaeda vera Forsk (*Suaeda fruticosa*), Goosefoot (Chenopodium *spp*), Summer Cyprus (*Kochia spp*), Saltwort (*Salicornia spp*), Russian Thistle (*Salsola spp*), Sea Blite (*Suaeda spp*).

Leaf area matters

While certain plants such as Salix spp (Willow) have a reputation for large ET rates; typically it is the leaf area index plus heat and humidity that are the primary variables in evapotranspiration. When large plants such as willows, poplars, and bamboo are used, the aim is to move as much water through them as possible so that they take up as much of the contaminants as possible. In 1991 the Miami Conservancy District Aquifer Update, No. 1.1 reported that a single large weeping willow tree transpired over 19 cubic meters of water (5,000 gallons) on a hot summer day. One hectare of the herbaceous halophyte plant *Spartina alterniflora* (saltwater cord grass) evapotranspires up to 80 cubic meters (21,000 gallons) of water per day. (Henchman et al, 1998).

We have not yet utilized large trees in our systems but rather shrubs and vines as most of our systems to date have been residential. We are presently designing a system to productively utilize the filtrate from a biogas facility in Canada. We will use the willow shrub *Salix viminalis L.,* as it has been very successful in Denmark removing (evapo-transpiring) all the sewage from many residences (Gregersen, 2001 and Brix (2004). The harvested willow will be chipped and used for fuel.

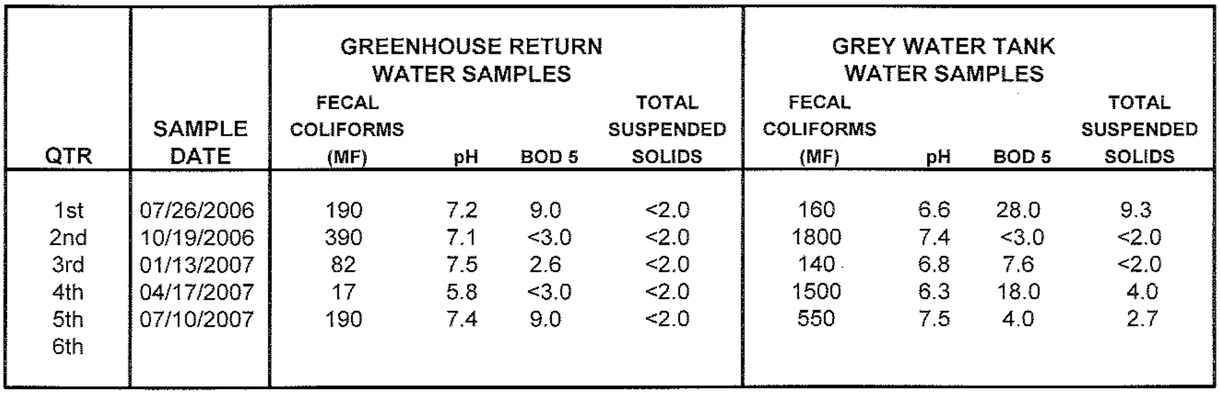
Performance

First, many variables influence the long-term acceptance rate (LTAR) of ET systems. In my early writings, I was referencing a compendium of ET rates based on studies by Alfred Bernhart and early data from systems we designed based on his work. When I changed the model to the present patented one with separate storage, recycle and aeration with optional disinfection for reuse; we began to see an annual average LTAR of 0.2 - 0.4 gpd/f2. In my opinion, the recycle rate, and the increased dissolved oxygen has the most influence after the leaf area, temperature and the plant species. We are now adding vines with a very large leaf area index to increase the LTAR in cold or temperate climates. Data from four three-bedroom residences and one fire-fighting station monitored by the Massachusetts Environmental Protection Agency (MADEP) indicate that an annual average LTAR of 10 L/m^2 per day (0.245 gpd/sf) of evapo-transpiration can be achieved in sheltered and seasonal unsheltered systems. These data were derived by metering the incoming water, minus metered water used for outdoor purposes, divided by the area of the plant growing bed (MADEP Reports). Initial piloting approval for these systems in Massachusetts was based on the data from the work of Dr. Alfred Bernhart (Bernhart, 1985).

Wastewater Evapotranspiration (ET) Performance Summary

Source data	ET (Annual average L/ m^2 per day)
University of Toronto (Bernhart)	10.3 - 11.8 (0.25 – 0.29 gpd/sf)
Massachusetts (in greenhouses)	8.15 – 12.2 (0.20 – 0.30 gpd/sf)
Denmark with *Salix viminalis L.* (Basket Willow) (Uncovered w 700 mm/year precipitation and 1200 – 1500 mm evapotranspiration)	3.3 - 4 .11 (0.08 – 0.10 gpd/sf)

The following is a summary of graywater treatment data required by the Massachusetts Department of Environmental Affairs 18 month piloting program. These are data from a three bedroom home with a detached greenhouse that contains the planted ET bed.These data were sampled and analyzed by a Massachusetts independent certified laboratory. It must be noted that this system does not have a disinfection system for reuse and evapo-transpired all the graywater. The grey water tank receives graywater from the house and also receives the filtered effluent from the planter bed under drain. In this case the bed functions as a recirculating sand filter, as well as an aerated planter bed. The original laboratory reports are appended as exhibits A - E.



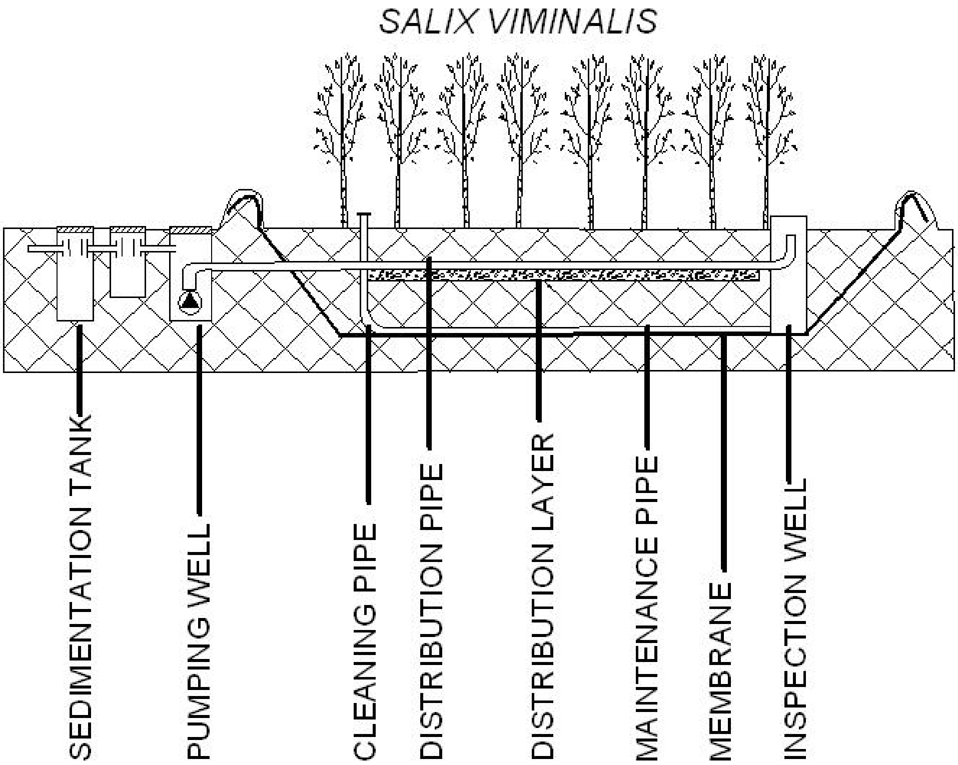
QTR	SAMPLE DATE	GREENHOUSE RETURN WATER SAMPLES FECAL COLIFORMS (MF)	pH	BOD 5	TOTAL SUSPENDED SOLIDS	GREY WATER TANK WATER SAMPLES FECAL COLIFORMS (MF)	pH	BOD 5	TOTAL SUSPENDED SOLIDS
1st	07/26/2006	190	7.2	9.0	<2.0	160	6.6	28.0	9.3
2nd	10/19/2006	390	7.1	<3.0	<2.0	1800	7.4	<3.0	<2.0
3rd	01/13/2007	82	7.5	2.6	<2.0	140	6.8	7.6	<2.0
4th	04/17/2007	17	5.8	<3.0	<2.0	1500	6.3	18.0	4.0
5th	07/10/2007	190	7.4	9.0	<2.0	550	7.5	4.0	2.7
6th									

Security

Because there is a separate cistern containing disinfected and treated effluent, it completely avoids the need for a back up disposal field. We call the latter application the Ecocycl**ET** Wisconsin Reuse System because it was first approved in the state of Wisconsin, USA as a graywater reuse product to be installed where soils are too marginal to be considered for a soil treatment system. Approval of this system was based on data from similar systems in Massachusetts and Ontario, Canada.

Protecting the soil

An impervious liner forming the planting bed insures that no effluent can enter the subsurface environment or nearby receiving waters. Zero-discharge is the ultimate protection of the environment and growing valuable plants ensures that it is the most cost-effective on a life-cycle basis.



Danish Willow ET bed with winter soil storage

Storage is the key

Storage in subsurface tanks or constructed aquifers holds the greatest promise for on-site applications. Storage allows the effluent to accumulate during cold periods when plants are dormant and shift the evapo-transpiration to the warmer growing season. One unique unsheltered application is to store the effluent in a subsurface constructed aquifer beneath the planting bed during cold winter months and use it up during the plant-growing season. Hundreds of such systems have been successfully installed in Denmark since 1992. (Brix, 2004)

Greenhouse-based systems

In cold climates, these natural systems are often, but not necessarily, housed in contained environments that provide more environmental stability and protection for operators and the public. They must allow daylight to ensure photosynthesis by the resident flora, so they are often covered with glass or high-transmissivity plastic. Solar energy, normally vented, can be collected and reclaimed, offsetting purchased energy costs. For more photos, see Appendix

Where are the pollutants transformed into safe forms?

The rhizosphere is that area that surrounds and includes the roots of plants, the soil, and, significantly, the microcosm of bacteria, algae, fungi, actinomycetes, worms, and other organisms. This area appears to be simply soil and roots; however, it is more than meets the eye (Kent and Triplett, 2002). The rhizosphere is teaming with life that includes plant cell detritus that is food for bacteria and nematodes, and exuded sugars and proteins from the roots that nourish the bacteria and other organisms. Protozoa and other organisms feed on the bacteria. The fungi and actinomycetes produce antibiotics such as penicillin and streptomycin that contribute to the health of the plant by suppressing disease (Getha et al, 2005). The rhizosphere is so dynamic and complex that only with the aid of microscopy can these interdependent systems be investigated and understood (Kent and Triplett, 2002).

The rhizosphere is a living and non-living factory where water, nutrients and minerals in the soil are prepared for absorption by the roots to support the plant. In order to support the microorganisms that support the plant; the plant sends down oxygen and nutrients via the roots, which supports the microbes. In ecology, this synergy is call commensalism. Balance is assured by predation and antagonism of the competing living members of this community.

This complexity informs ecological wastewater engineers to use the root zone to treat polluted water and to harvest toxic metals from contaminated soils. Wastewater passes through constructed and sequenced ecologies containing plants. Bacteria transform the constituents in the wastewater as well as complex enzymes produced by organisms, from pollutants to more benign compounds and gases such as carbon dioxide, nitrogen, and water vapor. The roots, in order to support the growth of the plant, absorb the water and transform nutrients and minerals. This is phytoremediation. (Henchman et al, 1998). I recommend that all who are interested in ecological design familiarize themselves with the system ecology of the root zone, which I have called “Rhizospherics”, as it will be the treatment “plant” of the future (Del Porto, 1999).

Costs

With the exception of the living plants, greenhouse, and/or a carport-style shelter, the costs are comparable to those of a recirculating sand filter (RSF) with a larger bed area. Costs have a wide variation driven by site constraints, excavation charges and whether or not a greenhouse or carport-style shelter is needed. A simple uncovered system needs the following components:

1. Two-chambered septic tank with effluent filters
2. Piping from the source to the bed and from the bed back to the storage/recirculation tank
3. Distribution/irrigation piping in the bed
4. High-head recirculation pump
5. In-line air injector
6. Insulation and liner for the planter bed
7. Media in the planter bed
8. Cistern with contact chlorinator for disinfection
9. And living plants

Depending on construction constraints, climate and precipitation, an open carport type canopy or a heated greenhouse can add significantly to the cost.

Estimated initial 200 gpd EcocyclET process equipment unit costs, installed, and including 600sf planting bed, living plants, piping, aeration system, sand and gravel media, two-chambered septic tank with outlet filter for pretreatment, pump, disinfection system, control and alarm, and valves. Not including greenhouse or shelter.	$18,500
Estimated Equipment repair/replacement costs, estimated at $25/year (pump repair/replacement). Not including living plants.	$2.08/month
Estimated O&M (does not include periodic plant replacement), with a maintenance contract of $200/year (system checks and maintenance performed twice annually) 4 hrs. @ $25/hour * 2.0, including taxes, overhead, profit, and including pump/controls servicing.	$16.67/month
Estimated Septage pumping once every 5 years	$2/month
Estimated pumping power costs (using 0.33 kWh/day energy use @ $0.15 kWh	$1.49/month
Total Operation and maintenance costs	**22.24/month**

Biomass economics

A study analyzing the costs and benefits of harvesting willow for biomass grown with wastewater established that the production costs were negative when costs were off-set by the economic value of environmental services (no conventional wastewater treatment, no fertilizer or irrigation water was required) were compared to the costs associated with willow cultivation. (Borjesson, P. and Goran, B., 2006)

Extrapolating from that study, we estimate that the life-cycle cost of the EcocyclET will be low compared to conventional water reuse technology. The primary reason is that the EcocyclET has few parts that need to be replaced unlike more complex systems such as membrane filtration technology. In addition, other issues that lower the life-cycle costs (Steinfeld and Del Porto, 2008) include (Hopkinson, 2007):

- Factoring in the avoided costs of pollution prevention, such as pumping holding tanks where the land cannot be used for soil absorption systems, is the most significant savings factor
- The harvesting of solar energy from greenhouses through the sale of marketable plants for uses such as energy production may offset some or all of the operation and maintenance costs.

Why are they good neighbors?

a. Attractive

We all like to be in the presence of living, green and often colorful, pleasant-scented plants. Humans have evolved in these surroundings and we all have a natural affinity for them. Unlike conventional systems, natural systems tend to avoid the Not in My Back Yard (NIMBY) problem because they are an amenity for the community instead of an eyesore.

b. No odor

Green plants purify the air and remove the odors associated with conventional systems. Smells of the woods and flowering plants replace the foul odor of conventional wastewater treatment facilities.

c. Educational opportunities

Teachers from 8th grade through graduate school bring their classes to natural treatment facilities to teach the application of systems ecology for solving pollution problems. Further, these systems demonstrate that human excreta need not be considered a pollutant; the nutrients and water in treated effluent can be a resource. The noted environmental educator, David W. Orr, calls these natural treatment systems “crystallized pedagogy” (Orr, 2002).

Recycling is not enough

Arid regions are increasingly looking to wastewater recycling as the answer to a secure water supply. While recycling wastewater is an important step in the conservation of fresh water, it is technologically complex, expensive, and unacceptable to many communities. As with desalinization, it is expensive and energy intensive to remove vast amounts of minute particles and bacteria from enormous volumes of wastewater so that it is safe for direct human contact. The practice of centrally collecting combined effluents—including excreta, toxics, pharmaceuticals and heavy metals—from a wide variety of sources, and then treating them with end-of-pipe solutions with advanced ultra filtration will not be feasible for many cities, especially those in developing countries. This approach has evolved to avoid the complexity of using many smaller, more local and effluent-specific strategies. Yet nature’s model shows us that local complexity is the best way to manage resources. The principle objective of this technology is the utilization of water and nutrients by plants i.e. bio-mimicry. (Del Porto, 2006).

Too valuable to waste

Wastewater's content of nutrients, organics, and a large volume of water makes it an ideal and valuable resource for growing plants. If those plants are not to be eaten, then the wastewater does not have to be treated to potable quality. These point to an opportunity, as laws require cleaner discharges to lakes, rivers, oceans and for indirect potable reuse

No upgrading treatment plants

We can avoid upgrading to advanced tertiary treatment of wastewater if we direct wastewater treated only to advanced primary or secondary standards to nearby barren lands to grow non-edible oil plants for refinery or cellulosic grasses for ethanol.

Use barren land unfit for human food agriculture

Instead of investing billions of dollars in wastewater pollution prevention and remediation, we can invest in the distribution system necessary to transport wastewater from existing treatment plants and animal feedlots to arid farmlands, deserts, and polluted brownfields to grow biologically based petroleum alternatives on land marginal for food crops. Because the nutrients and organics will be used by energy plants, the wastewater does not have to be treated to tertiary standards

This is the new Green Paradigm©, a model that calls for using the resource productively instead of improving disposal. Growing away our wastewater can reduce or eliminate the purchase of imported fossil natural gas and petroleum within the next few growing seasons by through production of growing oils, algae, grains and grasses that can be processed to replace imported petroleum (Del Porto 2005 and 2007).

This vision is not new. Automaker Henry Ford, invested heavily in soybean research and, in 1942, manufactured a Ford concept car with most of its components made from materials produced by American farmers. We now add to this vision by growing these materials and chemicals with what was called ‘wastewater’ instead of polluting receiving waters (Del Porto, 1999).

Why is it important to safely use sewage to grow biofuels? There is a growing need to protect receiving waters, mitigate effects on the economy, promote energy independence, reduce air pollution from power plants, minimize fertilizer use (through maximum efficiency), create new jobs for farmers, and substitute plant derived chemicals for petroleum derived chemicals. For example:

- Wastewater from Las Vegas, Nevada is currently being dumped into Lake Mead, Nevada, which flows into the Colorado River and then through Phoenix, Arizona;, San Diego, California and on to Mexico. Lake Mead and the Colorado River are drinking water sources for millions of people. The Mohave Daily News (2008) recently wrote *“the Clean Water Coalition proposed (and is now planning) to dump more than 180 million gallons of wastewater each day to the bottom of Lake Mead near Hoover Dam. The Clean Water Coalition consists of the Clark County Water Reclamation District and the cities of Las Vegas and Henderson. The population of Las Vegas is projected to be more than 3.1 million by 2035. By 2050, more than 400 million gallons of wastewater could be dumped each day into Lake Mead from Las Vegas. Arguments against the project claim the treated wastewater containing pharmaceutical drugs would go through Hoover Dam and contaminate the (Colorado) river downstream”.*

- In 2005, a preliminary estimate suggested that the wastewater from Reno and Las Vegas Nevada could produce more than 10 million barrels of palm oil per year. It would be piped to nearby barren lands instead of disposed into sensitive surface waters. (Del Porto, 2005). Based on the Las Vegas population projections, it should yield significantly more biofuel by the year 2050.

- Farmers are in need of new crops to replace tobacco and other crops that compete with foreign imports. Many farmers are paid via government subsidies to not grow crops at all. Growing petroleum alternatives creates more jobs in areas where employment is needed without threatening existing farming communities (Karg, 2000).

- One of the obstacles to growing petroleum alternatives is the cost of fertilizer, which requires a natural gas and petroleum to produce. According to John Sawyer, associate professor of agronomy at Iowa State University, the majority of nitrogen fertilizer sold in the Midwest is either anhydrous ammonia, or products made from anhydrous ammonia (urea, ammonium nitrate, and urea-ammonium nitrate solutions) (Sawyer 2005). Natural gas is a major component of ammonia production for both energy and supply of hydrogen (H) in ammonia (NH3). Therefore, the ammonia production cost is closely tied to the price of natural gas. Natural gas accounts for more than 85 percent of the total ammonia production cost. When the price of natural gas increased in 2004, the cost of nitrogen fertilizer also increased dramatically (Sawyer, 2005).

- There are hundreds of millions of acres of unusable land in the world that could be farmed to grow petroleum alternatives crops with the water and nutrients in wastewater. The Government owned barren land managed by The Bureau of Land Management has more than 258 million acres that could be used to grow biofuels with wastewater from nearby treatment plants. (BLM 2009)

CONCLUSION

Using the EcocyclET and Green Paradigm to manage wastewater eliminates pollution of receiving waters, avoids the need to upgrade plants to advanced secondary or tertiary, and reduces dependence on imported fossil fuel. What's more, growing away wastewater with plants and using energy from plants sequesters carbon. Biofuels made from *current* photosynthesis-derived carbon instead of *ancient* fossil carbon will slowly reduce the impact of global warming as biofuels replace fossil fuels.

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www.ecological-engineering.com/delporto.pdf

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