MEMORANDUM

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RE: **PSC 320: Living Machine Project Proposal**

Executive Summary

With increasing domestic and commercial demand, rising temperatures and unpredictable extreme weather patterns and natural disasters, potable water is becoming a precious resource more and more every day. In the Cal Poly Strategic Plan, there is indication of interest in producing recycled water, suggesting that an on-campus water recycling project could be feasible for future Cal Poly infrastructure. Water recycling is a topic that needs the full attention of students and researchers across campus and is an opportunity for many areas of expertise to come together and design a multidisciplinary solution. Cal Poly could provide students with research opportunities in water resources and wastewater treatment by opening a water research facility on campus. A water research facility could combine three water treatment and recycling techniques (Living Machine, Greywater Recycling System, and Rainwater Catchment and Water Filtration System) to allow student research and analysis on the processes and resulting water quality. This project could be a valuable education opportunity for Cal Poly students, and an exhibition of the water recycling technology that could be used at a large scale to solve California's water crisis.

Background

For years we have heard the phrase "California is in a severe drought." As citizens, we have adapted. We have opted to take shorter showers, turned off the faucet when we brush our teeth, switched our home landscaping from green lawns to drought-resistant plants, and made every effort to be conscious consumers and educate ourselves on how to be stewards of the environment. All this, because we were told that if every one of us did our part to conserve water, we could alleviate the drought.

In 2014, nearly 60% of California's land was affected by exceptional drought, (level D4, the highest level of drought) according to the National Integrated Drought Information System (NIDIS). The timeline of California's drought since 2000 to present is shown in Figure 1.

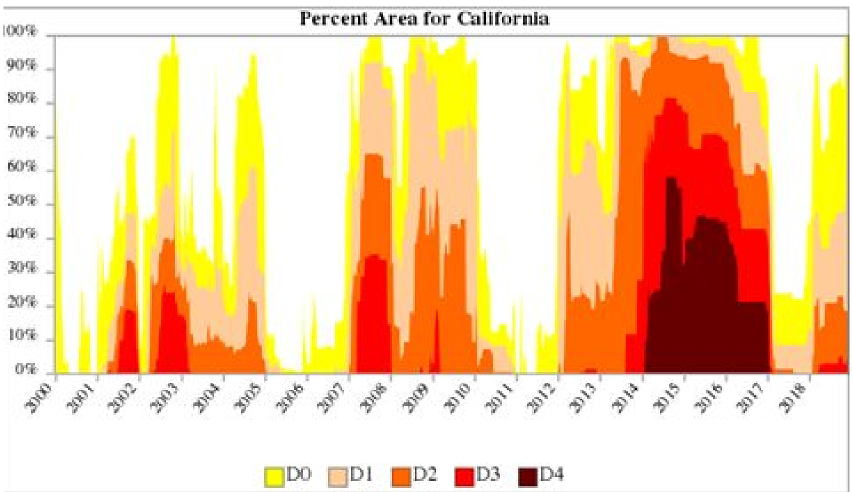


Figure 1. This graphic, from NIDIS's U.S. Drought Monitor, shows the percent area of California affected by drought over time. The U.S. Drought Monitor started in 2000. Since 2000, California is currently experiencing the longest duration of drought (D1-D4), which as of November 27th, 2018 has lasted 362 weeks beginning on December 27, 2011. The most intense period of drought occurred the week of October 28, 2014 where D4 affected 58.41% of California land.

With increasing domestic and commercial demand, rising temperatures and unpredictable extreme weather and natural disasters, water is becoming a precious resource more and more every day. But as we have seen the true story unfold, the solution is not shorter showers-- it is rapid action taken by our government and institutions. We need to be actively changing the way we view our resources and take water recycling solutions seriously. On Cal Poly's administration and finance website, under Water Conservation, it states "Cal Poly is also collaborating with the City of San Luis Obispo to evaluate opportunities to procure or produce recycled water for use on landscape and agricultural land." This indication of interest in producing recycled water suggests that a water recycling project would be feasible for future Cal Poly infrastructure. Water recycling is a topic that needs the full attention of students and researchers across campus and is an opportunity for many areas of expertise to come together and design a multidisciplinary solution. There are many solutions already being implemented in the residential and commercial building industry that recycle greywater, use composting toilets to treat wastewater, and collect and filter rainwater for potable use. Cal Poly could provide students with research opportunities in water resources and wastewater treatment by opening a water research facility on campus.

Proposed Research Facility

A water research facility could combine three water treatment and recycling techniques to allow student research and analysis on the processes and resulting water quality. The three main portions of the facility would include:

1. A Cal Poly Living Machine
2. A Greywater Recycling System
3. A Rainwater Catchment and Filtration System

The Living Machine is a patented technology, consisting of a series of tanks teeming with live plants, trees, grasses and algae, koi and goldfish, tiny freshwater shrimp, snails, and a diversity of microorganisms and bacteria. Each tank is a different mini-ecosystem designed to eat or break down waste. The process takes about four days to filter water to an acceptable level for irrigation. It is chemical-free, odor-free and, compared to conventional waste treatment, it costs less financially and ecologically. A schematic of a Living Machine Design is shown in Figure 2.

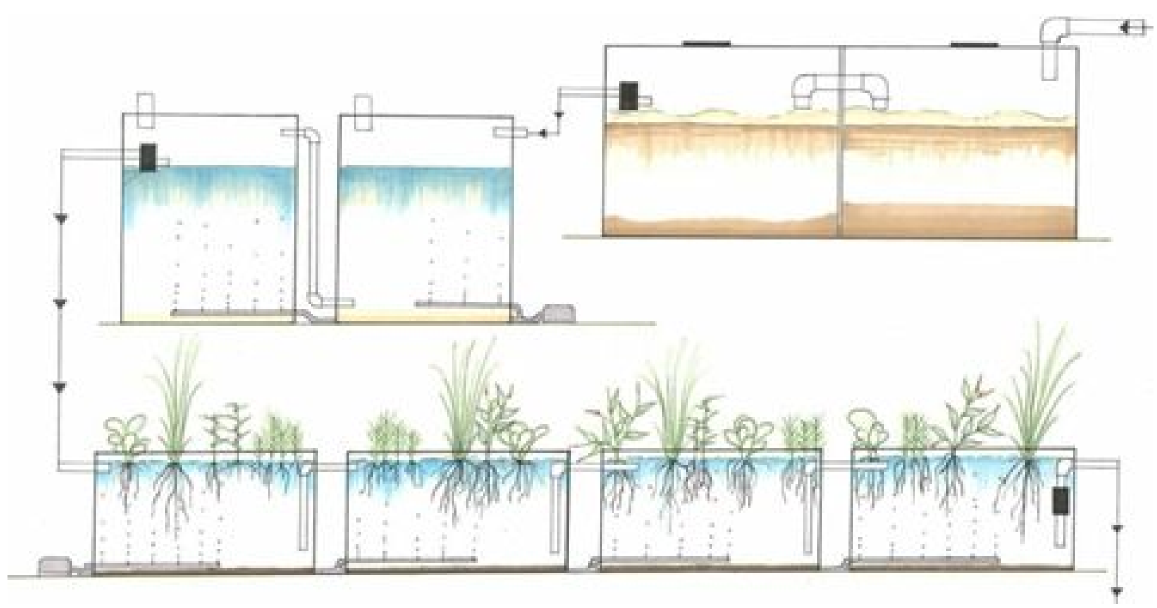


Figure 2. A Living Machine system design pumps wastewater through a series of ecological ecosystems to filter it to an acceptable water quality for irrigation.

The Greywater Recycling System would use a simple slow-sand filtration system, which would be made up of roughing filters that remove large particles from the water supply by washing water upwards through the gravel in the tank. The effluent water would then go through slow sand filters that remove pathogens and fine particulates from the water. The slow sand filter medium consists of gravel, coarse sand, and fine sand. These filters develop a natural biofilm of predatory bacteria on the top layer of fine sand that biologically remediates bacteria in the water, such as E. coli.

The rainwater filtration system for potable use would be made up of the standard sedimentation tank, activated carbon filter and UV sterilization. This proven technology could provide students with experimentation opportunities to optimize the filtration system.

For the purpose of our PSC 320 project, we will focus on the proposed Living Machine. The Living Machine portion of the Cal Poly Water Factory would need to be in a climate-controlled greenhouse, to accommodate the tropical plants that are used in the filtration pools. A possible site for the Living Machine could be in the existing Cal Poly Aquaponics greenhouse, located in the Cal Poly Experimental Farm.

This project would be multi-disciplinary and promote sustainability, while providing project experience for many different majors. Research opportunities in engineering include wastewater, water filtration, heating and cooling (greenhouse climate control), controls (filtration system DDC), and piping systems. Design opportunities in Architecture include greenhouse form/structure, interior design, and interior and exterior landscape. Research opportunities in agriculture/plant sciences include hydroponics/aquaponics, greenhouses, fish farming and more. This project could be a valuable education opportunity for Cal Poly students, and an exhibition of the water recycling technology that could be used at a large scale to solve California's water crisis.

Aquaponics

Aquaponics is the combination of raising fish and soilless growing plants to form a ecosystem to give a symbiotic relationship and provide filtered water. The main part of this system is that it is fully enclosed to provide the efficiency of water consumption to at the least 90%. So the simple definition of Aquaponics is the mixture of hydroponic and aquaculture.

- Hydroponics: Hydroponics is the growth of plants without the use of soil. It almost seems unreasonable but it works so well because their is always a "growing medium" with the delivery of a solution in the roots. The pH of this soluble solution allows the plant to take and process the solution as food with little effort. The less energy the plant has to uptake in the root to grow the higher the efficiency of the plant. Most people think that the growing medium is soil but in hydroponics it can be a plethora of things leading to a wide range of growth. Most are Rockwool, gravel, and sand.
- Aquaculture: or has the nickname "farmed seafood" which is a perfect representation of what it is. According to the NOAA Fisheries website, "the breeding, rearing, and harvesting of animals and plants in all types of water environments". Just like hydroponics aquaculture is very efficient and supplies 50% of all seafood for human consumption.

Now for the last piece of the puzzle in aquaponics: Microbes. They provide the most important part that saves peoples lives. This very important part is the conversion of ammonia ($NH4+$) to nitrates ($NO2$ or

NO3). According to the aquaponic source, “nitrates are the form of nitrogen that plants can uptake and use to grow”

Different Types of Aquaponics

1) Deep Water culture

a plant’s roots are suspended in a well-oxygenated solution composed of water and nutrients through small holes in a raft to anchor the roots in the deep water.

2) Media based
The growing of plants in a container filled with gravel or perlite which is the media and anchored to the roots.

3) Nutrient Film

This uses the method of constant flow of water to allow for more oxygen and supply of nutrients through narrow channels.

4) Vertical Aquaponics

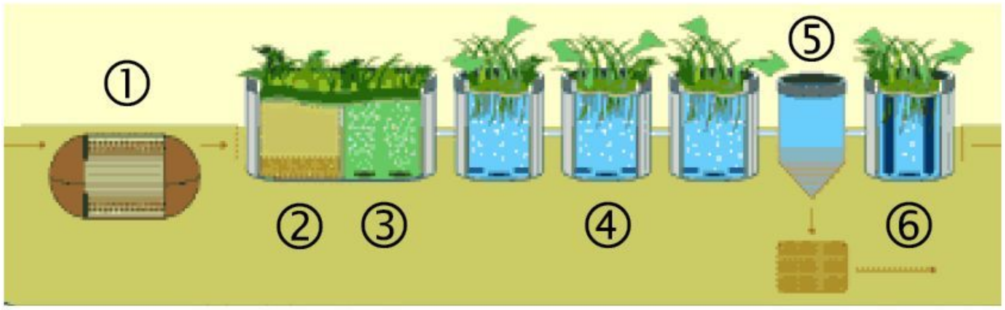
These systems have grown popular in many cities with skyscrapers due to their “vertical” and upwards system where plants are growing on top of each other.

Living Machine Feasibility Study

There are many types of wastewater produced by modern society. These wastewater types include sewage, industrial, agricultural, and leachate (liquid from landfills). The conventional wastewater treatment process goes through the following steps:

1. Phase Separation: removes solids and reduces biochemical oxygen demand.
2. Oxidation: converts organic compounds (impurities) into carbon dioxide, water, and biosolids. Chemical oxidation is widely used for disinfection.
3. Polishing: carbon filtering adjusts pH and alkalinity.

In a living machine, the wastewater treatment process uses multiple natural components to filter wastewater to an acceptable level for irrigation. The components of a living machine are shown in Figure 3.



Source: Living Machines Inc., 2001.

Figure 3. The components of the Living Machine include (1) anaerobic reactor, (2) anoxic reactor, (3) closed aerobic reactor, (4) open aerobic reactor, (5) clarifier, and (6) ecological fluid bed [5].

The function of each component is listed below:

1. Anaerobic Reactor: like phase separation, biochemical oxygen demand
2. Anoxic Tank: promotes microorganism growth to reduce biochemical oxygen demand. Plants above filter to remove odor.
3. Closed Aerobic Reactor: reduce biochemical oxygen demand, remove odors, stimulate nitrification
4. Aerobic Reactors: (complete nitrification) Plants promote microbial growth and nutrient uptake
5. Clarifier (Settling tank to separate any remaining solids): Often covered in duckweed
6. Ecological Fluidized Beds: (like polishing) Inner and outer tanks filter through gravel

Two examples of successful Living Machine implementations are in Frederick, MD, which processes 40k gallons of wastewater per day (gal/day), and Burlington, VT, which processes 80k gal/day. We can use these two examples as case studies to compare conventional wastewater treatment to a Living Machine wastewater treatment plant (WWTP).

The average cost of a 1 Mgal/day Living Machine and its associated greenhouse is $9.23 million. We'd need 4.5 of these to treat SLO's wastewater, which flows at 4.5 million gal/day. In contrast, a 1 Mgal/day conventional system costs $8.58 million.

From our research, we found that more work needs to be done to improve the efficacy of Living Machines, as the two examples provided and an EPA study show varying results. The Frederick plant discharged effluent of nonattainment status (Table 1). Cost reduction and improvement of treatment processes would increase the overall efficacy of the Living Machine as a WWTP.

Table 1: Effectiveness of two example Living Machine WWTPs compared to EPA effluent discharge goals.

Parameter	Effluent (mg/L)	% Removal (Frederick)	Effluent (mg/L)	% Removal (Burlington)	Effluent Goal

BOD_5	4	97	5.9	97	<10
COD	21	94	35.9	94	--
TSS	2	97	5.3	98	<10
NH_3	1.2	94	0.4	98	<1
NO_3	10	52	4.9	69	<5
Total N	11	75	5.6	81	<10
Total P	6	45	2.0	67	<3

Economics

Using a Living Machine system to treat wastewater and reuse the water for irrigation has many environmental benefits and provides educational opportunities for students on campus, but the biggest question remains: is it economically feasible on a large scale? We sought to show through case studies that this technology can be implemented on a large scale to replace conventional wastewater treatment systems. A published cost-benefit analysis from a Swedish university of agricultural sciences shows that this technology can be profitable over a conventional system under the base and best case scenarios, but not the worst. A cost benefit analysis was performed using data from Fors WWTP in Haninge in Sweden, based on valuation studies, and reports from hydroponic WWTPs in Sweden and abroad. The results of their study show a positive net present value of a hydroponic treatment plant in the base- and best case scenarios, but a negative in the worst case scenario. A summary of the costs associated with a hydroponic plant relative to a conventional plant over a 50 year life cycle (assuming a discount rate of 3.4%) are presented in Table 2.

Table 2. Cost Benefit Analysis Results of a Hydroponic WWTP Relative to a Conventional WWTP over 50 years

	Quantity	(USD/quantity)	Cost (USD)
Capital Investment (USD)	17.5	$ (110,000)	$ (1,925,000)
Labor (hours)	680	$ (759)	$ (515,900)
Heating and Lighting (MWh)	217	$ (3,014)	$ (654,060)
Operation (MWh)	-240	$ (3,014)	$ 723,360
Nutrient Reuse-N (tonnes)	13.5	$ 24,208	$ 326,810
Nutrient Reuse-P (tonnes)	0.14	$ 55,000	$ 7,700
Sludge production (tonnes)	-440	$ (1,344)	$ 591,140
Emission- N (tonnes)	-13.5	$ (92,147)	$ 1,243,990
Emission- P (tonnes)	-0.14	$ (3,094,929)	$ 433,290
Gas Production (1000 m^3)	-33	$ (360)	$ 11,880
Total			$ 243,210

From this analysis, one can see that over 50 years, the hydroponic system saves almost $250,000 in operational and emission costs over the conventional WWTP, proving that these systems can be a viable option to reduce the load on central municipal WWTP and treat wastewater locally while saving money.

Conclusion

Wastewater treatment is an immensely important process in order to reduce the stress that humans pose on their surrounding environment. As population grows and the detrimental effects of insufficient treatment becomes better understood, the demands on WWTPs increase. A Cal Poly water research facility could combine three water treatment and recycling techniques to allow student research and analysis on the processes and resulting water quality. This project would be multi-disciplinary and promote sustainability, while providing project experience for many different majors. This project could be a valuable education opportunity for Cal Poly students, and an exhibition of the water recycling technology that could be used at a large scale to solve California's water crisis.

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