An Investigation into Phosphorus Recovery Technology

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Abstract

This report investigates the available phosphorus recovery technologies for the UBC Farm new building centre in the form of Triple Bottom Line Assessment. The technology should be ideally low budget, low tech and sustainable, this means that it should be either zero net or positive. The main phosphorus recovery technologies investigated in this report are chemical precipitation, struvite precipitation, and the Pearl Process. Other technologies exist and are briefly mentioned in the report.

Ecologically, building a phosphorus recovery technology can eliminate the excess phosphorus that is sent to the ocean by the wastewater created from human and livestock excrement. Economically, a phosphorus recovery plant overall is quite feasible taking into account the long run at looking at things. It is concluded that it would be economically feasible to construct a wastewater treatment plant first than add a phosphorus recovery process to it in the future. Socially, implementing a phosphorus recovery technology onto a small scale like the UBC Farm can set an example for larger scale applications like the municipal wastewater treatment plant. This in the long run can solve the society's phosphorus scarcity problem that the world is facing.

In conclusion, phosphorus recovery technology is economically, socially and ecologically viable option for the UBC Farm building centre.

Lists of Illustrations

Glossary

Eutrophication – The response of the ecosystem to artificial or natural substances to an aquatic system.

Phosphate – An inorganic chemical compound that is a salt of phosphoric acid. As phosphorus does not exist in nature by itself, they have to be extracted from phosphate compounds. It is important to note that fertilizers are phosphates and not pure phosphorus.

Phosphorus – A chemical element that is never found as a free element on Earth due to its highly reactivity. Most phosphorus compounds exist as fertilizers and are essential to plant growth. It is essential for life.

Sludge – A semisolid residue left by sewage treatment processes as water is filtered out.

Struvite – Phosphate mineral formed from urine of animals. Struvite presents a potential problem to wastewater treatment plants as struvite builds up within pipes and clogs the system. Phosphorus may be recovered from struvite through treatment of the wastewater.

Triple Bottom Line Assessment – In sustainability, refers to environmental, economic, and social assessments of a system.

Wastewater – Water that has been affected by the actions of humans, including discharges from domestic, commercial, agricultural, and industrial buildings.

List of Abbreviations

P - Phosphorus

WWTP – wastewater treatment plant

LCA – Life Cycle Analysis

~~1~~ INTRODUCTION

As one of the world's largest growing and leading farm in sustainable agriculture, UBC Farm is currently in the process of building an iconic new farm building centre. The main purpose of this new centre is to set a pioneering example of regenerative building, and a living lab where building functions are integrated into the farm's core sustainable food production operations and serve as educational demonstrations of how careful design and construction can improve ecological health. As part of the building project, UBC Farm is considering implementing a waste water treatment facility that will capture storm, grey and black water to process and use as resources for sustainable and organic agriculture. This report will focus on the feasibility of applying phosphorus recovery technology to treat wastewater, using the triple bottom line assessment.

1.1 PHOSPHORUS

Phosphorus (P) is essential for life and especially for life in the agriculture industry. As a growing concern, phosphorus is becoming a scarce element on this planet and the importance of phosphorus recycling and recovery in our food system is becoming that much more important. The combination of three factors makes phosphorus a nutrient of concern in most ecosystems: (http://www.cliffsnotes.com/study_guide/The-Phosphorus-Cycle.topicArticleId-23791,articleId-23786.html)

- Most soils have only small amounts from the weathering of disjunctly distributed rocks.
- Phosphorus is more insoluble than other nutrients and less mobile, hence less phosphorus travels in the soil solution; roots generally must grow into a zone of phosphorus availability. Additionally, it helps encourage growth, photosynthesis, and cell division within plants.
- Phosphorus that drains from the land to the ocean is used by organisms in the surface waters, but a considerable amount is lost to the sediments in the shells and bones of marine organisms and by precipitation and settling of phosphates.

Without phosphorus, foods like chicken, beef, and even chocolate cannot be made. The creation of organic phosphorus can take up to millions of years to process, because of how they are naturally formed, known as the phosphorus cycle. See Figure 1 below.

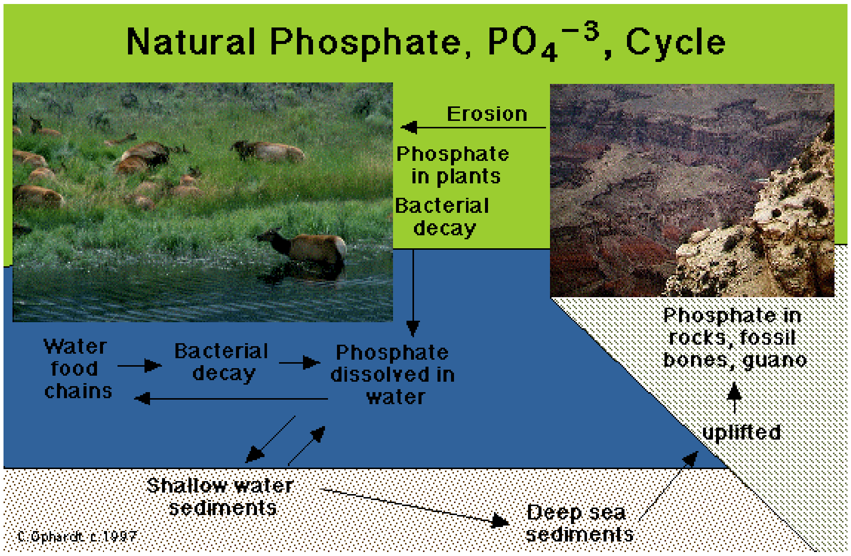


Figure : The Phosphorus Cycle

(From: http://www.elmhurst.edu/~chm/vchembook/308phosphorus.html)

However, using recovery technology we can extract phosphorus from sources like detergents, pesticides, grey water and more which is commonly found in the sludge of pipes.

P is considered a non-renewable resource as its formation and life cycle is one of the slowest biogeochemical cycles (Van Vuuren et al, 2010). In order for P to become a renewable resource, the treatment and sewage sludge will need to have P recovery technology. The life cycle of phosphorus is presented below, showing the life cycle of P from beginning to end as a non-renewable resource.

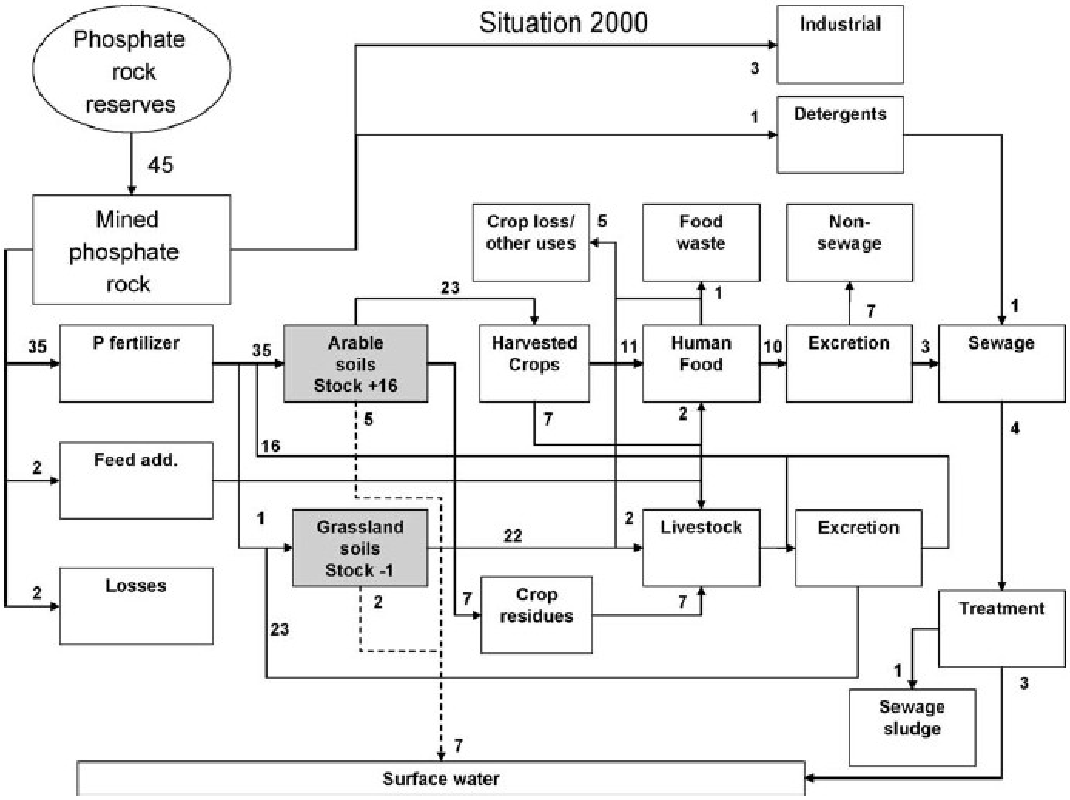


Figure : Life cycle of phosphorus

From: *Phosphorus Demand for the 1970-2100*, Van Vuuren et al. (2010).

According to Molinos-Senate et al. (2011), by 2050, the world would be consuming 70 million tons of P per year. If the world continues its consumption of P at this rate; P reserves would be depleted within sixty to seventy years. These findings are concurrent with other studies done on P depletion, such as a study conducted by Van Vuuren et al. (2010). As high grade P mines are concentrated in a select few countries. Canada is not one of these countries and must import P unless there is a method to recover P from current sources, such as wastewater.

1.2 PHOSPHORUS RECOVERY TECHNOLOGIES

The following is contains brief descriptions of some phosphorus recovery technologies currently used in large scale operations. A complete chart of process summaries of different P removal technologies is given in the appendix but most are still in the research stages.

1.2.1 CRYSTALACTOR®/CHEMICAL PRECIPITATION

Chemical precipitation is a simple process of adding a metal salt to wastewater to create precipitation. This results in a metal phosphate that settles and can be removed from the wastewater. The chemical precipitation process is the most common process used for phosphorus recovery in wastewater today (Morse et al, 1997). The result of wastewater going through a process is a metal phosphate and not pure phosphorus. While it has value to agriculture, Morse et al. (1997) determined that its bioavailability is still inconclusive. The Crystalactor technique builds on the concept of chemical precipitation.

A phosphorus recovery plant designed by DHV Consultancy and Engineering, the crystalactor has been implementing phosphate recovery technology since 1985 (Giesen, 2009). The system works by implementing a fluidized bed reactor and creating compact, high purity pellets that may be removed and used in fertilizer or for usage in other phosphate products. As calcium phosphate is the same as mined phosphate, it is possible to recycle calcium phosphate (Woods et al, 2010). The Crystalactor works as an add-on to existing wastewater treatment plants (WWTPs). Additionally, degasification is required to reduce carbonates within the Crystalactor and filtration is required for low phosphate concentrations in the resulting effluent. Currently, Crystalactor wastewater treatment facilities are being used in the Netherlands and Japan. A crystalactor is shown below.

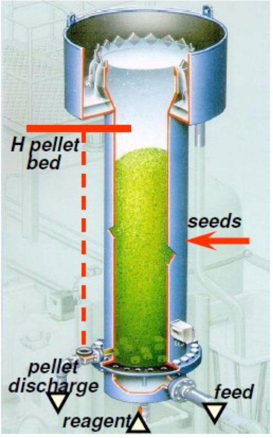
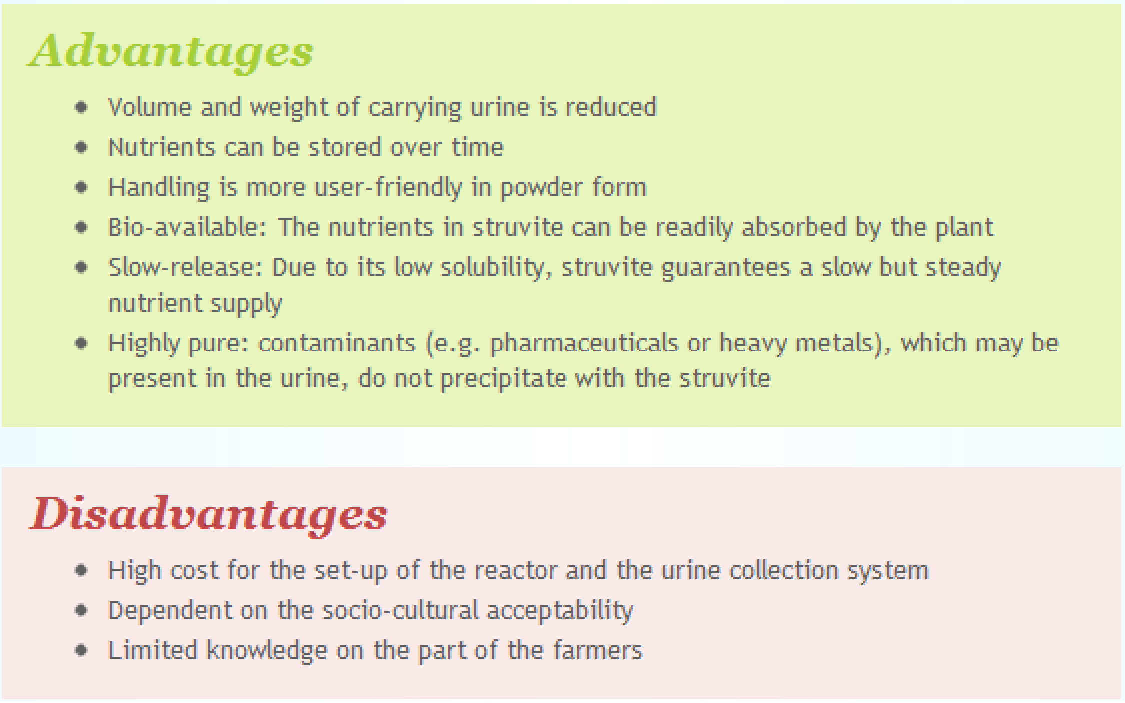


Figure : Crystalactor

From: *P recovery with the Crystalactor,* Giesen, A., 2009)

1.2.2 STRUVITE PRECIPITATION

Struvite, sometimes also called Magnesium Ammonium Phosphate Hexahydrate (MAP), has many of the fertilising properties of urine with a few advantages which includes volume and weight reduced and easily storable. Struvite is a naturally occurring precipitate in aged urine. The struvite molecules are formed through a combination of dissolved magnesium, ammonium and phosphate ions (Miso, 2009). As difficulty is concern, producing struvite is the most technologically accessible as it does not need any sophisticated apparatus. Using struvite has many advantages and disadvantages, see figure below.



Advantages

- Volume and weight of carrying urine is reduced
- Nutrients can be stored over time
- Handling is more user-friendly in powder form
- Bio-available: The nutrients in struvite can be readily absorbed by the plant
- Slow-release: Due to its low solubility, struvite guarantees a slow but steady nutrient supply
- Highly pure: contaminants (e.g. pharmaceuticals or heavy metals), which may be present in the urine, do not precipitate with the struvite

Disadvantages

- High cost for the set-up of the reactor and the urine collection system
- Dependent on the socio-cultural acceptability
- Limited knowledge on the part of the farmers

Figure : Advantages and disadvantages of struvite precipitation

(From: http://www.sswm.info/category/implementation-tools/reuse-and-recharge/hardware/reuse-urine-and-faeces-agriculture/fertili)

1.2.3 PEARL® PROCESS

The Pearl Process technology is owned by the company Ostara. It resolves the problem of the formation of obstructive struvite scale in pipes, pumps and valves resulting in severe impacts to plant reliability, efficiency and operating and maintenance costs. The Pearl process is a specialized approach to nutrient management. Nutrient rich sources are fed into the Pearl fluidized bed reactor after being combined with chemicals such as magnesium chloride and sodium hydroxide. Within the Pearl reactor, 'seeds' of struvite begin to form. These struvite grains are grown under special conditions until they have attained the desired size of 1-3.5mm in diameter. Using the Pearl process, up to 90% of the phosphorous contained in the wastewater sludge can be extracted in the form of these struvite grains. See Figure below (Ostara, 2011).

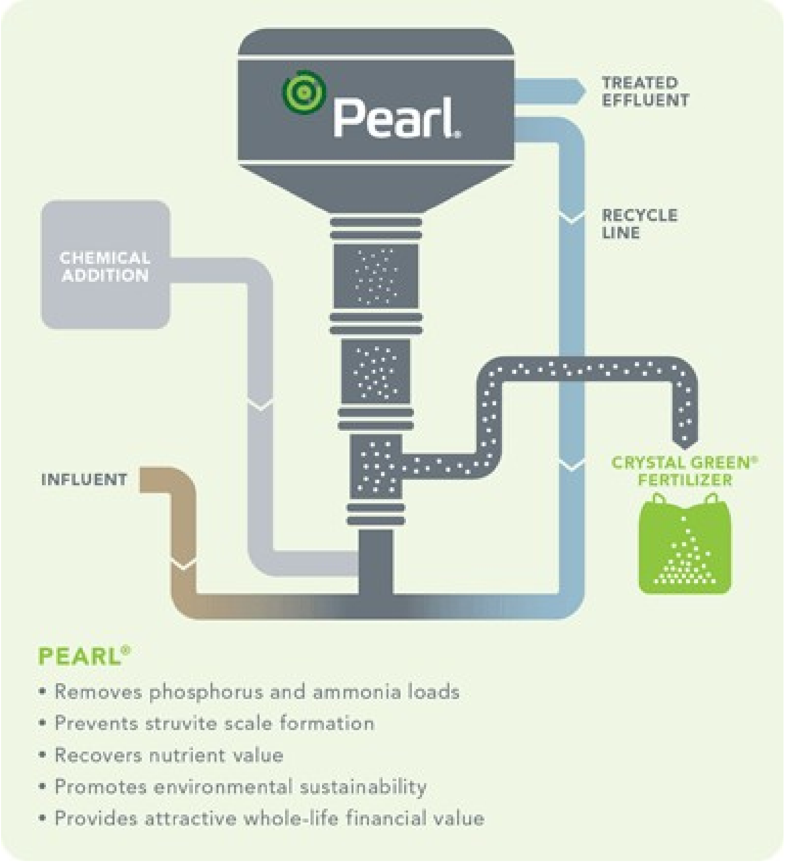


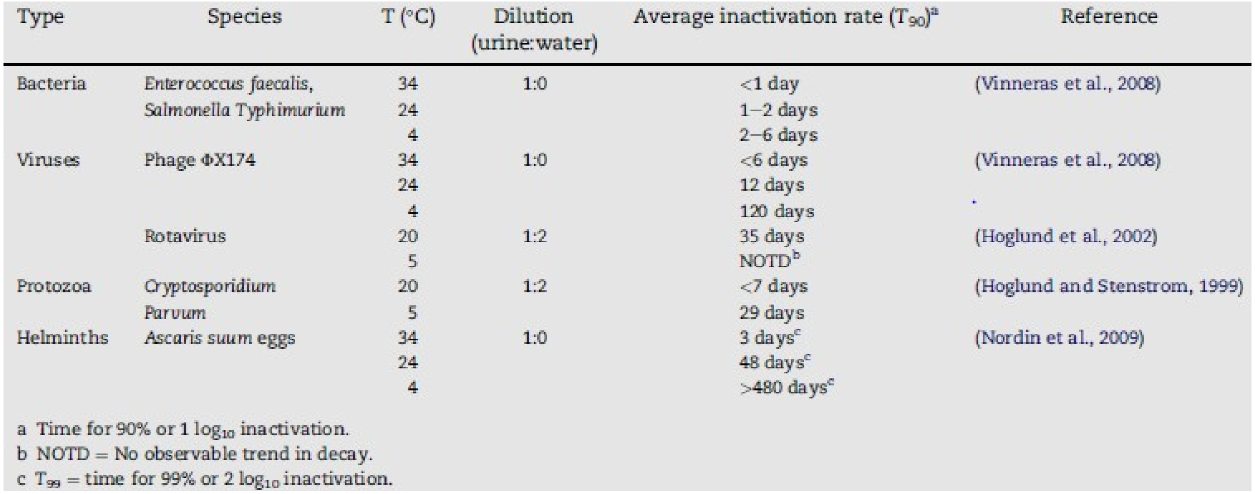
Figure : Pearl Process
From: *Pearl Technology*, Gromji, 2009

~~2~~ ECOLOGICAL ANALYSIS

Phosphorus recovered from wastewater is an organic resource that can be used to produce fertilizer for the agriculture sector. This application of phosphorus indirectly affects our food system, thus a thorough investigation into the health and safety of the end products must be conducted. Also, recovering phosphorus from wastewater helps sustain the environment by saving non-renewable phosphate rocks being exhausted for commercial fertilizers. Lastly, phosphorus recovery technology as a solution for the hazard of excessive phosphorus in wastewater entering lakes, streams, and oceans will be discussed. Ecological assessment of the phosphorus recovery technology is based on three major indicators: health and safety, sustainability, and water quality.

2.1 HEALTH AND SAFETY

Phosphorus is recovered from wastewater in the form of a phosphate mineral called struvite, which is used to produce sustainable fertilizer. Excrement takes up a significant portion in wastewater, therefore some health concerns on obtaining struvite from wastewater need to be discussed. Struvite formation may incorporate some constituents that can be found in excrement such as pathogens, pharmaceuticals, and heavy metals. It has been proven through experiments that only a small fraction, less than 2%, of pharmaceuticals and heavy metals in wastewater were incorporated into struvite. Also, concentration of heavy metals in struvite formed from wastewater is far lower than commercial fertilizers. In contrast, pathogens in struvite present a much more significant health threat than pharmaceuticals and heavy metals do. Two of the most common pathogens found in excrement are phage ΦX174 and Ascaris suum eggs. Concentration of phage is approximately the same in both struvite and wastewater, and Ascaris suum eggs (parasitic roundworms) tend to accumulate during the filtration and precipitation process. Therefore, proper procedures must be carried out to inactivate these pathogens. Specific air-drying condition of the struvite filter cake can effectively inactivate the pathogens to reduce their infectivity. The following table shows the inactivation rate of different pathogen types.



Type	Species	T (°C)	Dilution (urine:water)	Average inactivation rate (T_{90})[a]	Reference
Bacteria	*Enterococcus faecalis,*	34	1:0	<1 day	(Vinneras et al., 2008)
	Salmonella Typhimurium	24		1–2 days	
		4		2–6 days	
Viruses	Phage ΦX174	34	1:0	<6 days	(Vinneras et al., 2008)
		24		12 days	
		4		120 days	
	Rotavirus	20	1:2	35 days	(Hoglund et al., 2002)
		5		NOTD[b]	
Protozoa	*Cryptosporidium*	20	1:2	<7 days	(Hoglund and Stenstrom, 1999)
	Parvum	5		29 days	
Helminths	*Ascaris suum* eggs	34	1:0	3 days[c]	(Nordin et al., 2009)
		24		48 days[c]	
		4		>480 days[c]	

a Time for 90% or 1 $\log_{10}$ inactivation.
b NOTD = No observable trend in decay.
c T_{99} = time for 99% or 2 $\log_{10}$ inactivation.

Figure : Inactivation rate of different pathogen types

From: Loı¨c Decrey, Kai M. Udert, Elizabeth Tilley, Brian M. Pecson, Tamar Kohn. 2011. Water Research.

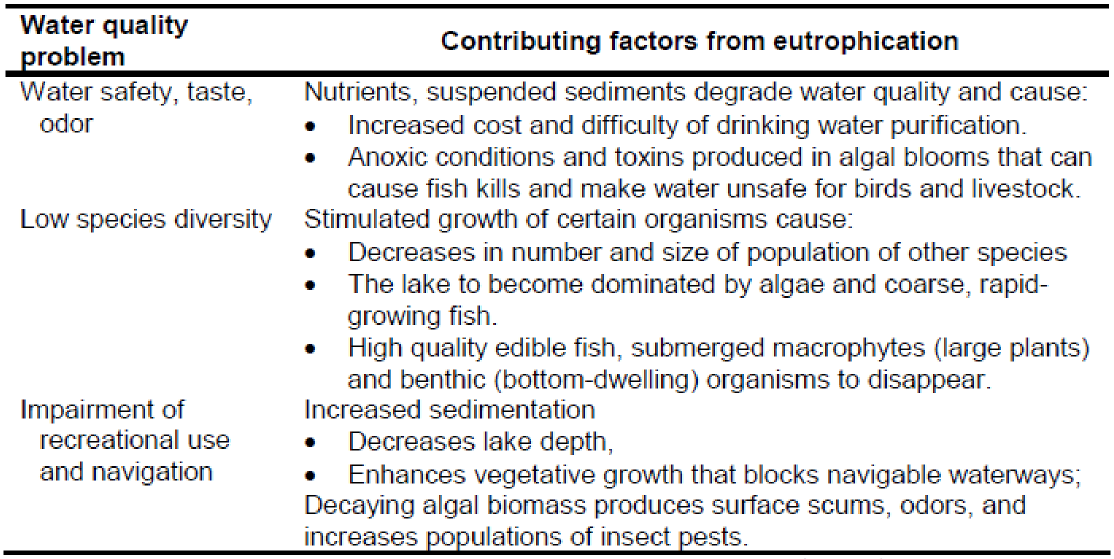
The recommended measures to reduce the threat of pathogens are drying the struvite filter cake at high temperature and/or low humidity, and create thin struvite filter cakes that allow for a short drying phase. While it is ideal to use either high temperature or low humidity for drying to inactivate viruses, Ascaris suum eggs inactivation require high temperature combined with low humidity. When proper measures are taken to inactivate the pathogens, the health risk they present will be kept at minimal.

2.2 SUSTAINABILITY

Commercial fertilizers are made from nonrenewable phosphorus extracted from phosphate rocks that are mined in a limited number of sites around the world. These phosphate rocks would soon be exhausted if there are no other methods to obtain phosphorus. The result of this would be mass decrease in global agriculture output which then lead to wide spread hunger. It is ironic how the phosphate rocks are facing exhaustion while the world is filled with excess phosphorus that we cannot recover. The phosphorus recovery in wastewater is the perfect solution to retrieve the excess phosphorus in nature and turn it into organic fertilizer. The organic fertilizer produced from phosphorus recovered from wastewater offers better quality than commercial fertilizers. Therefore, phosphorus recovery technology has the potential to eventually eliminate the need to extract phosphorus from phosphate rocks to produce commercial fertilizers. Phosphorus recovery systems should be deployed in as many places in the world as possible to completely satisfy the agriculture need for organic fertilizer, and then there would be no reason to mine phosphate rocks for production of the less desirable commercial fertilizers.

2.3 WATER QUALITY

A form of water pollution occurs when excessive nutrient is added into a body of water causing increased biological productivity of the water. Addition of nutrients such as nitrogen, phosphorus, and carbon to surface water stimulate the growth of algae. If excessive nutrient enters the water, large algal bloom may result and cause serious water quality problems. When algae die, their decay release more nutrients and depletes the concentration of dissolved oxygen in water. This process will eventually starve the water body of oxygen causing the disappearance of most species in the ecosystem. This phenomenon in aquatic ecosystems is called eutrophication. Eutrophication can decline water quality to a level where the water is not acceptable for any use. The table shows some of the main water quality problems associated with eutrophication.

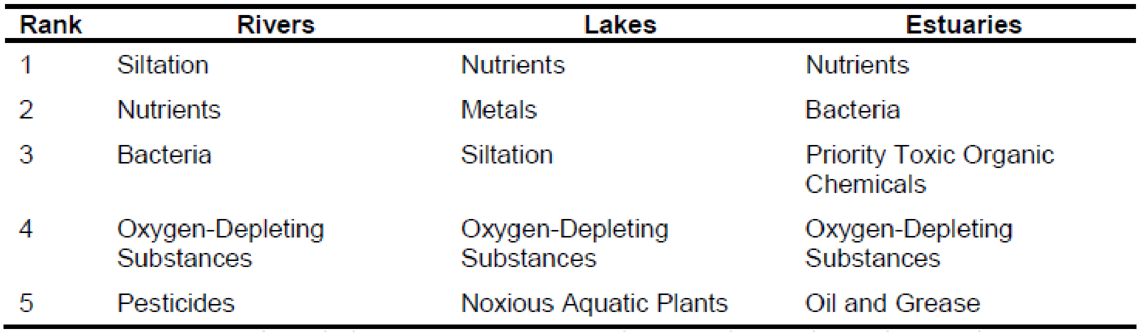


Water quality problem	Contributing factors from eutrophication
Water safety, taste, odor	Nutrients, suspended sediments degrade water quality and cause: • Increased cost and difficulty of drinking water purification. • Anoxic conditions and toxins produced in algal blooms that can cause fish kills and make water unsafe for birds and livestock.
Low species diversity	Stimulated growth of certain organisms cause: • Decreases in number and size of population of other species • The lake to become dominated by algae and coarse, rapid-growing fish. • High quality edible fish, submerged macrophytes (large plants) and benthic (bottom-dwelling) organisms to disappear.
Impairment of recreational use and navigation	Increased sedimentation • Decreases lake depth, • Enhances vegetative growth that blocks navigable waterways; Decaying algal biomass produces surface scums, odors, and increases populations of insect pests.

Figure : Water quality problems associated with eutrophication

From: Pierzynski, G.M., J.T. Sims, and G.F. Vance. 1994. Soils and environmental quality. CRC Press, Inc., Boca Raton, FL. p.14.)

The following figure ranks the leading causes of water quality problems discussed above.



Rank	Rivers	Lakes	Estuaries
1	Siltation	Nutrients	Nutrients
2	Nutrients	Metals	Bacteria
3	Bacteria	Siltation	Priority Toxic Organic Chemicals
4	Oxygen-Depleting Substances	Oxygen-Depleting Substances	Oxygen-Depleting Substances
5	Pesticides	Noxious Aquatic Plants	Oil and Grease

Figure : Leading causes of water quality impairment

From: U.S. Environmental Protection Agency. 1996. The quality of our nation's water: Section 1: National summery of water quality conditions. 1996 Report to Congress. Office of Water. U.S. Gov. Print. Office, Washington, DC.

It is statistically proven that excessive nutrient addition is among the leading causes of impairment of water bodies. Therefore, if the amount of nutrient, especially phosphorus, entering water bodies can be controlled, water quality problems can be greatly reduced.

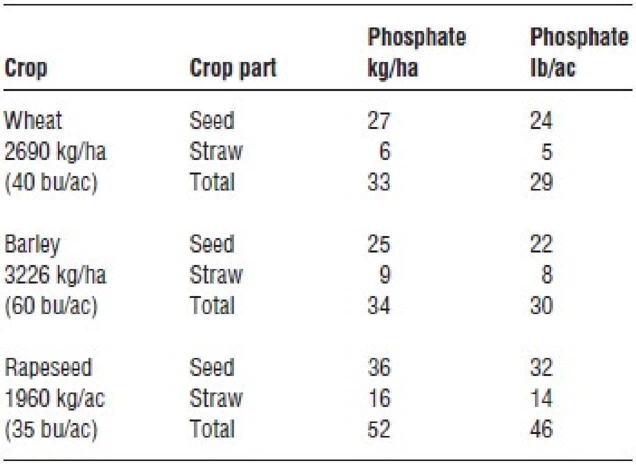
The majority of excessive phosphorus that leads to eutrophication comes from agriculture production runoff water. The fertilizers being used on crops usually supply an amount of phosphorus that is much more than needed for crop production. The excess phosphorus from fertilizers combined with phosphorus contained in livestock manure make the runoff water from agriculture operations highly concentrated with phosphorus. An indicator of how much phosphorus is in a crop is called the Soil Test Phosphorus (STP) level. Scientists agree that there is no agronomic reason for STP levels to be greater than 80 to 100 pounds per acre. A suggested upper limit for STP level is 300 pounds per acre. It is very difficult to control the concentration of phosphorus in crops and stop phosphorus from incorporating itself in runoff water. Therefore, phosphorus recovery from wastewater is the ideal solution to stop the flow of excess phosphorus into water bodies. Depending on the scale and geography of the agriculture operation, different methods of phosphorus recovery must be designed to achieve maximum efficiency. In the case of UBC Farm, there is no large scale agronomic activities, thus there probably will not be serious eutrophication effect. However, UBC is located right beside the ocean; therefore human and livestock excrement in wastewater may bring excess phosphorus into the ocean and cause a minor degree of eutrophication in the estuary. This problem can be completely eliminated with phosphorus recovery solution implemented in the UBC Farm.

~~3~~ ECONOMIC ANALYSIS

In order to be economically sustainable, the wealth and capital of a society should not decline as time passes. However, this is not possible to achieve. In the case of the UBC farm, the goal becomes finding and constructing the most sustainable wastewater treatment plant (WWTP) on that is financially feasible. This section will explore the economics of phosphorus (P) as well as provide life cycle analysis (LCA) of P recovery technologies. An analysis on the economic feasibility is presented at the end.

3.1 CONSUMPTION OF PHOSPHORUS ON FARMS

Consider the chart below, where a comparison of phosphate requirements for different crops is given.



Crop	Crop part	Phosphate kg/ha	Phosphate lb/ac
Wheat	Seed	27	24
2690 kg/ha	Straw	6	5
(40 bu/ac)	Total	33	29
Barley	Seed	25	22
3226 kg/ha	Straw	9	8
(60 bu/ac)	Total	34	30
Rapeseed	Seed	36	32
1960 kg/ac	Straw	16	14
(35 bu/ac)	Total	52	46

Figure : Phosphorus requirements for common farm produce

From: *Phosphorus Fertilizer Application in Crop Production,* Alberta Agriculture and Rural Development, 1997

The US consumption of P fertilizer was also considered. In 2010 alone, 1,933 thousand metric tonnes of phosphate was used to grow corn, 139 thousand for cotton, 552 thousand for soybeans, 458 thousand for wheat, and 1017 thousand tonnes for other produce (US Economic Research Service, 2011). Through calculations, it can be determined that the amount of P per square feet required should at least be 0.19lb, or 3,754.11 kg per acre. As the UBC farm is 60 acres, then 225,246 kg of phosphate will be consumed every time the farm is fertilized. It should be noted that the amount of P required for each crop is not set. Factors such as region and climate will also affect the amount required. The amount of P required for optimal yields also depends on the crop.

3.2 COSTS OF PHOSPHORUS

The following chart looks into average costs of phosphate fertilizers in the US per ton (US Economic Research Service, 2011).

Year	2008	2009	2010	2011
Super-phosphate (44-46% phosphate)	$800/ton	$639/ton	$507/ton	$633/ton
diammonium phosphate	$850/ton	$638/ton	$508/ton	$703/ton

Figure : Price of phosphate fertilizers in US for past 4 years, in USD per ton

From: Fertilizer Use and Price. (2012, January 5). In *US Economic Research Service.* Retrieved March 15

If the UBC farm wishes to use phosphate fertilizers, it will cost the farm around $142,580.72 USD for super-phosphate or $158,347.94 for diammonium phosphate to fertilize a 60 acre farm. However, the usage of P fertilizer may be reduced through control of plant nutrition and recycling P. Ultimately the price will be depend on the farm's management techniques. Note that the costs are based on US data. As the US produces phosphate rock and P, the costs may be lower in the US compared to Canada.

The price of phosphate is not set and fluctuates often. It depends on quality and demand, as well as politics and stock markets. In 2006, the price of phosphate was below $50,000 USD / kg but fluctuated to above $300,000,000 USD / kg in 2008 (Schaum et al, 2009). However, as phosphorus is a non-renewable resource that will eventually be depleted, the price of phosphorus will slowly rise.

3.3 LIFE CYCLE ANALYSIS (LCA)

Only methods that have been tested in large scale situations are considered. As these facilities operate on a larger scale then what would be constructed at the UBC farm, the price of construction for the plants will differ. The following section looks into the construction, operation, and retirement of a WWTP and compares Crystalactor with the Pearl Processes.

3.3.1 CONSTRUCTION

The cost of building a new WWTP will depend on the budget as well as the company's asking price. As an innovative learning centre that promotes sustainability, such a facility would not only add value to the UBC farm but to UBC and to Canada. Direct, indirect, and induced impacts will also influence the construction of a WWTP. The economic value of a P recovery WWTP may increase as society moves towards sustainability and green technology. Environmental or Government factors such as regulations and taxes will also influence and affect the economic value.

The Crystalactor needs to be fitted to existing WWTPs as an add-on. However, in the case of the UBC farm, a new WWTP is required. The farm would be required to build a conventional WWTP then apply Crystalactor technology to the plant. Also, the application of Crystalactor facilities requires the addition of pre-degassification and post-filtration components (Morse et al, 1997).

The Pearl process is also applied to existing WWTPs, meaning a WWTP will need to be built first on the farm. Unlike the Crystalactor, however, the Pearl system does not require additional add-ons. In terms of material, the Pearl process will be more economically feasible.

3.3.2 OPERATION

As many methods of P recovery are still in the research stages, there may be additional costs of hiring specialized employees for nonstandard processes. The wealth (price of property, business output) of such a facility has to be considered. As the UBC farm is planning a WWTP as part of the new farm centre, there isn't an alternative to what the land may be used for. Property value of the plant will depend on how innovative and efficient the facility is, as well as current laws and regulations. The business output of a P recovery WWTP will also depend on what method has been chosen, as the end product of each process may be different.

The end result of the Crystalactor produces 40-50% calcium phosphate along with additional material (Morse et al). However, in order to profit from the pellets, the UBC farm would have to sell or treat the pellets as well as deal with the additional waste. The cost of a conventional chemical phosphorus removal plant is compared with a plant using Crystalactor in the figure below.

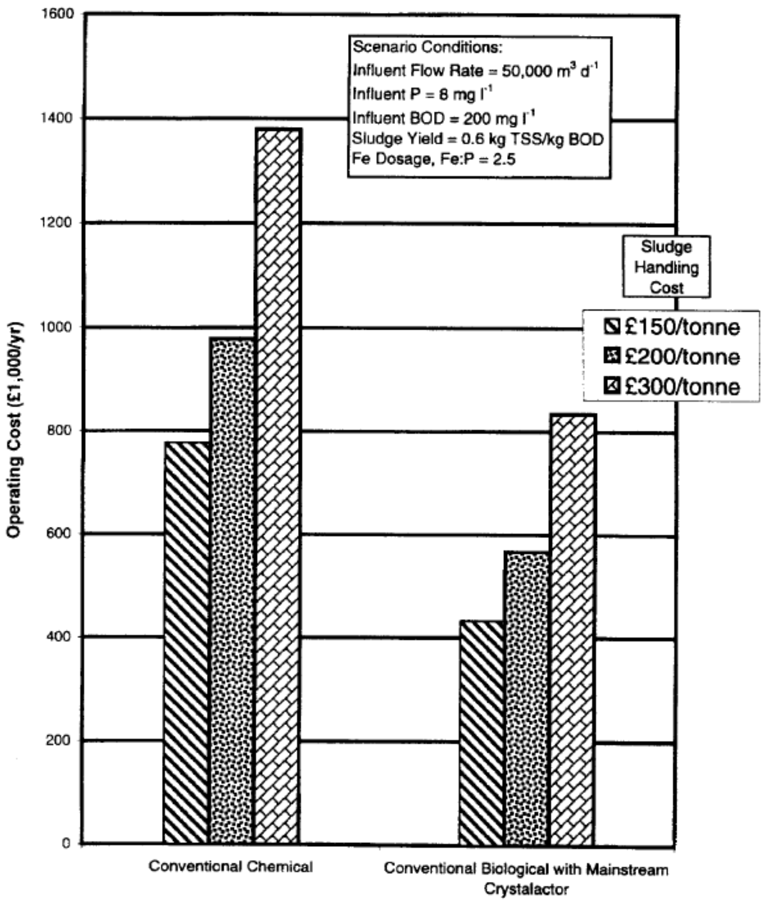


Figure : Operating costs of conventional and Crystalactor plants
From: Woods, N. C., Sock, S. M. & Daigger, G. T. (2010). Phosphorus Recovery Technology Modeling and Feasibility Evaluation for Municipal Wastewater Treatment Plants. *Environmental Technology, 20(7), 663-679*

For the Pearl Process, the end products results in pellets of fertilizer instead of crystal phosphate compound pellets. The fertilizers can then be sold or used on the UBC farm. Both these techniques do not produce sludge, thus saving sludge handling costs of a conventional WWTP.

3.3.3 RETIREMENT

At the end of its economic life, the building should be able to be sold for its salvage value. As the building is planned to be sustainable, it can be assumed that the plant will operate long enough to recover its construction and operation costs. The phosphorus recovery WWTP's value at retirement should be similar to that of a conventional WWTP entering retirement as both the Crystalactor and Pearl Processes work as add-ons.

3.4 ANALYSIS OF ECONOMIC FEASIBILITY

The costs of P recovery and struvite production will also depend on the amount of effluent and the amount of chemicals used (Le Corre et al, 2009). To be profitable, the WWTP will have to generate enough phosphate. If the amount generated is not enough to supply the farm to a break-even point, then P recovery technology is not economically feasible. If the phosphate is to be sold, then the economic feasibility of the plant will depend on the price of phosphate. Ultimately, the economic profitability of phosphate will depend on the world's consumers.

There may be a decline of P consumption, resulting from the knowledge that P is a limited resource and will eventually run out (Van Vuuren et al. 2010). This seems unlikely today, but within the next few decades movement towards green technology and sustainability may impact the way society behaves. In this case, the costs of phosphorus or phosphate will likely drop, making phosphorus treatment technology will be economically unfeasible.

As current processes for phosphorus recovery requires the processes be added onto existing WWTPs, the UBC farm will be required to build a plant before adopting P recovery technology. This may not be economically feasible in the short run. If a new, innovative method of P recovery technology is used, it may be more expensive.

The main benefit of P recovery methods economically is the savings generated from no sludge buildup in the WWTP. This saves the plant cleaning and maintenance costs of up to $100,000 USD per year (Schaum et al, 2009). Issues such as laws and regulations will also affect the economic feasibility of a phosphorus recovery plant, as P recovery systems reduce phosphorus release into the environment. From this point of view, P recovery technology is economically feasible.

~~4~~ SOCIAL ANALYSIS

As mentioned in the previous sections, there are tremendous positive impacts on adopting phosphorous (P) recovery methods to the UBC farm wastewater treatment plant (WWTP). The implementation will bring major benefits to the economic and environmental aspect of the community. However, there are a few social concerns that need to be addressed before giving the ruling that the system is beneficial (Stark, 2005). Many people have problems adjusting to consuming P recovered from wastes. Hygienic and health factors are major problems that consumers are coping with as people fear that the sanitary level of the retrieved products is not too high (Stark, 2004). Therefore, the government have to make laws and put up regulation to monitor the recovered P to provide confidence and certainty to the consumers (Stark). Once the UBC farm adopts P recovery technology into their WWTP, it might give the government the confidence to implement the technology into the municipal water treatment plant. Not only will the implementation aid Canada economically and environmentally, it will also resolve the society's P scarcity crisis (Ashley et al, 2011).

4.1 AWARENESS

Society is well aware of the oil insufficiency catastrophe as the gasoline price continues to rise and eco-friendly campaigns promote their beliefs. While phosphorous, like many other resources such as gasoline, is irreplaceable, it has not been prioritized proportionally to its importance (Mavinic, 2011). Since P plays an essential role in the food production industry, as population grows, the demand for P will continue to increase.

Unfortunately, the general public is not familiar with the fact that P supply is currently running low while demand rises (Ashley et al, 2011). As the world's P resource becomes scarce, it is important for people to understand the significance of using recycled P (Stark, 2004). According to our survey located in the appendix, about 56% of the participants claim that they are aware of sustainability and believe it is important. At the same time, about 62% of the participants responded they consume bottled water. The responses given demonstrate that people's awareness towards sustainability is not sufficient for them to act accordingly. The main reason why the participants acted differently to their understanding of sustainability is that most people are unaware of the level of severity the damage they are doing to the environment when a bottle is consumed. From the survey we can see that only about 10% of the participants have been to the UBC farm. This indicates that the awareness level of the farm is too low and might result in the lack of development in the community. Therefore it is extremely important to raise alertness in the negative impact of P scarcity, because without P, life forms will not be able to sustain on earth (Ashley et al, 2011).

Once awareness is raised, the society will become more cautious with the conservation of P. Then, people will willingly look pass hygienic issues surrounding recovered P (Stark, 2004). Being the world's leading farm in sustainable agriculture, if the farm decides to adopt a P recovery WWTP will have significant impact upon the community. With UBC's reputation, it might have an influential effect on the provincial government, which will lead to incorporation of P recovery technology into the municipal WWTPs.

4.2 SANITARY ISSUES

Obtaining P via waste such as sludge and animal manure is the only method to ensure P sufficiency for the near future (Cordell et al, 2011). However, it will require society to overcome the hygienic and pride issues regarding the consumption of what was once waste (Wzorek et al, 2007). For P recovery systems to be implemented, the general public have to recognize the desperation for the resource of phosphorous (Cordell et al, 2011).

According to our survey, about 48% of the participants stated that they are indifferent on the usage of recovered P in food production as long as they are not constantly reminded. At the same time, around 31% of the surveyed population are fully supportive to P recovery systems, while about 15% of the participants responded negatively towards the usage of recovered P in food production. The statistics demonstrate that most of the survey participants are able to accept the implementation of P recovery systems in their water treatment plants as long as they are not reminded of their source.

In order for the consumers to gain confidence in the P quality, it will be a necessary for the company providing the recovery technology to come up with convincing methods to retrieving P (Wzorek et al, 2007).

4.3 GOVERNMENT INVOLVEMENT

Unfortunately, Canada does not have the geographic resource of phosphate rocks. With Morocco, China, South Africa, and the U.S containing 80% of the world's phosphate supplies, Canada's main source of phosphorous depends heavily on the U.S (Mavinic, 2011). In reality, the U.S phosphorous production has reached its limit and is expected to deplete within the next 20 years (Mavinic, 2011). To make matters worse, many experts have estimated that the world's demand for phosphorous will exceed its supply sometime between 2025 and 2030, and the supply of phosphate rock will run out completely by 2080 (Ashley et al, 2011). As a result, the Canadian government should begin assessing different P recovery systems in order to plan for the future.

In the most common retrieving process, struvite will be extracted from sludge (Stark, 2005). Since sludge is a product of wastewater, there exists both nutrients and pollutants in the P recovered (Stark, 2005). Therefore, it is essential that the government enforce strict regulations to create an acceptable standard for the retrieved P to be consumable without contaminants (Stark, 2004). Many European countries have already begun implementing various P recovery methods as their governments are being tremendously supportive in the process (Stark). With the government's support, the Netherlands is one of the first countries to have P recovery technology in the municipal WWTPs (Stark). In order to provide securities to the general public, the Dutch government have the strict regulations to ensure the P quality is up to the acceptable standards. Many European countries are beginning to realize the shortage of phosphate rocks, and their governments are resolving the issue of shortage by encouraging P recovery technologies (Stark, 2004).

~~5~~ CONCLUSIONS AND RECCOMENDATIONS

Ecological analysis is a crucial step in evaluating any technology to ensure no harm will be done to the environment and living beings. For phosphorus recovery technology, it offers a great benefit to the environment by turning excess phosphorus into a renewable source for fertilizers. Furthermore, phosphorus recovery from wastewater significantly reduces eutrophication problems by reducing the amount of phosphorus entering water bodies. However, one health concern on the phosphorus recovery technology is the infectivity of pathogens incorporated into struvite. This problem can be solved by specific struvite drying process to inactivate pathogens. Overall, phosphorus recovery is an environmental friendly technology that brings great benefits to both the environment and society.

Taking into account of the factors presented in the economic analysis section, a phosphorus recovery plant by itself is not economically feasible, especially on a small scale for the UBC farm. However, once external impacts (such as not having to deal with environmental laws from producing phosphorus discharge) are taken into account, the project becomes economically feasible overall. As current phosphorus recovery technology works as add-ons to existing WWTP, it may be wise to first construct a sustainable, economically feasible WWTP and add a phosphorus recovery process to the plant in the future.

There are still concerns on the social aspect of the phosphorous recovery technology. The society has to overcome the sanitary and pride issue in order for the system to work to its full potential. In order to give the general public more confidence in their systems, it might require the company providing the recovery technology to come up with convincing methods to retrieving quality phosphorous. Furthermore, as Canada does not have phosphate rock as a resource, it will be a good idea for the Canadian government become supportive to the adoption of phosphorous recovery systems. We believe through rising the awareness of phosphorous scarcity and importance, the society will become more concerned with the conservation of phosphorous, and these social issues can be easily be resolved.

There is no substitution to phosphorous as it plays an important role in sustaining all life forms and food production. With its supply running low, it is important to figure out an alternative to the limited resource of phosphate rock. Overall, our group is very optimistic about the potential that lies in the implementation of phosphorous recovery system on the UBC farm water treatment plant. Overall, our group is very optimistic about the potential that lies in the implementation of phosphorous recovery system on the UBC farm water treatment plant. As our report shown, there are many benefits in the economic and environmental aspect of the UBC farm. We believe the adoption of phosphorous recovery systems will bring prosperity to local communities and sustainability to the UBC ecosystem. Being the world's leading farm in sustainable agriculture, it is significant if the farm decides to adopt a phosphorous recovery system in the water treatment plant. With UBC farm's reputation, it might have an influential effect on the provincial government, which could lead to the execution of phosphorous recovery technology into the municipal water treatment plant.

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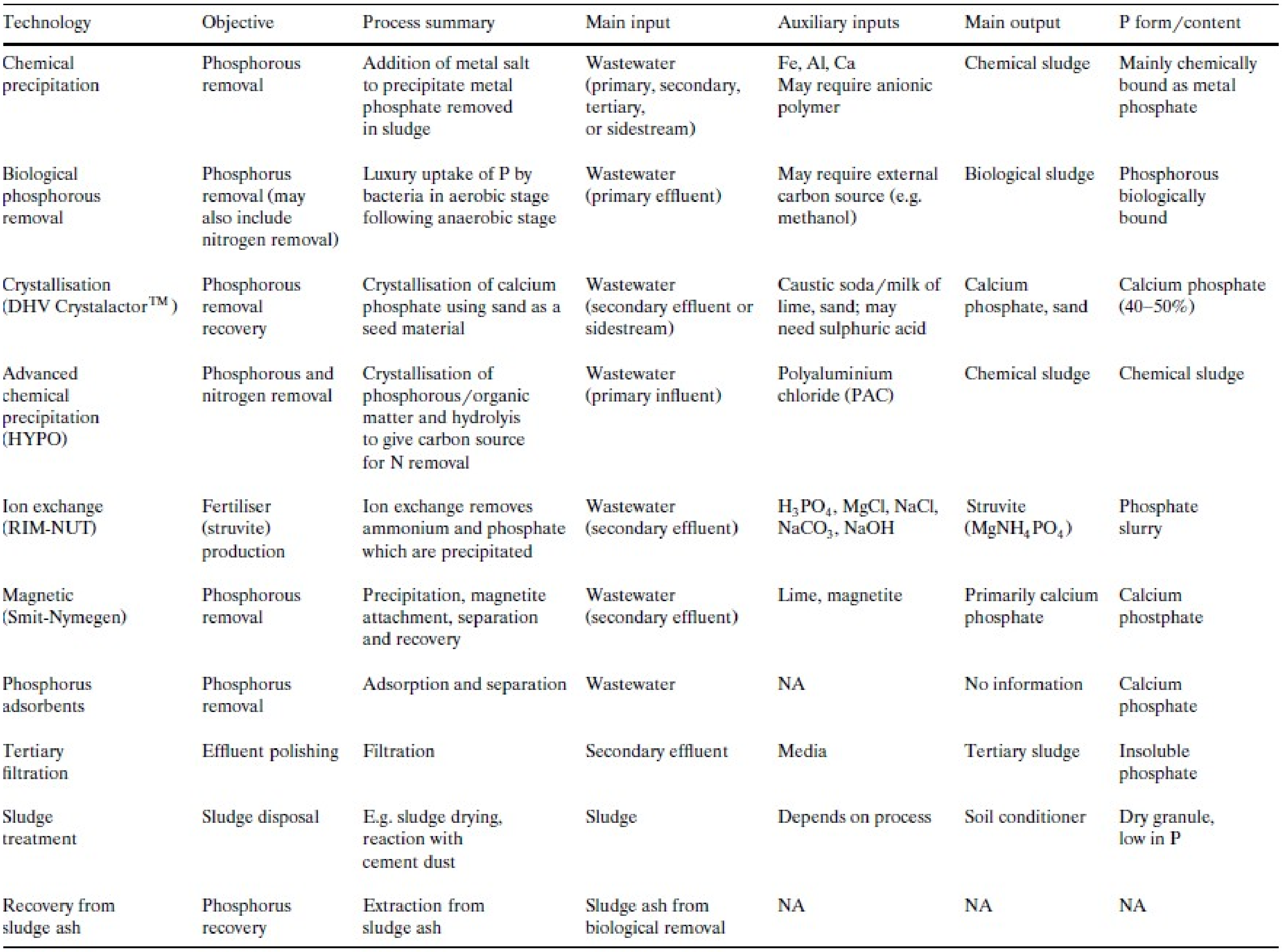
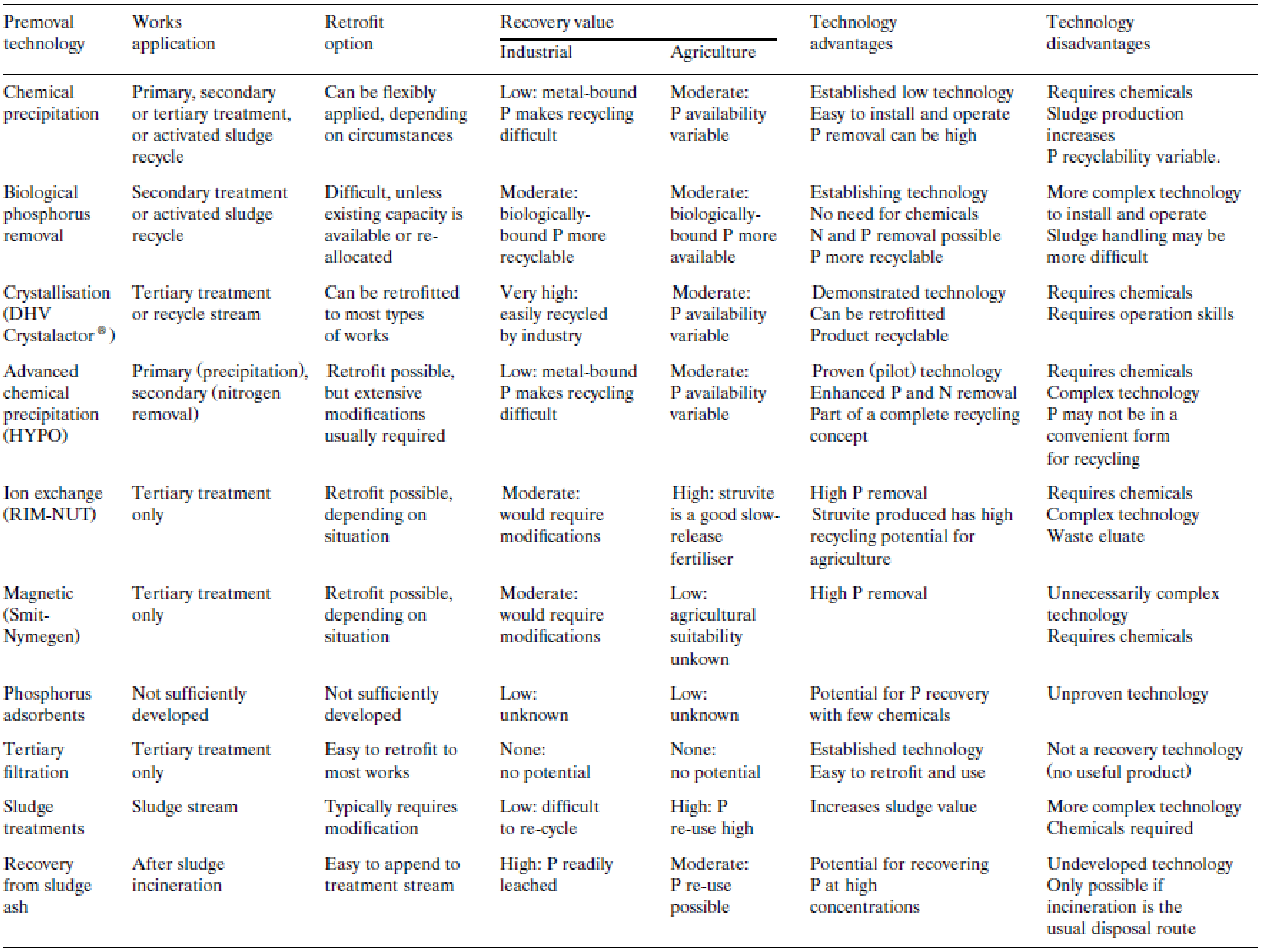
Appendix



Technology	Objective	Process summary	Main input	Auxiliary inputs	Main output	P form/content
Chemical precipitation	Phosphorous removal	Addition of metal salt to precipitate metal phosphate removed in sludge	Wastewater (primary, secondary, tertiary, or sidestream)	Fe, Al, Ca May require anionic polymer	Chemical sludge	Mainly chemically bound as metal phosphate
Biological phosphorous removal	Phosphorus removal (may also include nitrogen removal)	Luxury uptake of P by bacteria in aerobic stage following anaerobic stage	Wastewater (primary effluent)	May require external carbon source (e.g. methanol)	Biological sludge	Phosphorous biologically bound
Crystallisation (DHV Crystalactor$^{\mathrm{TM}}$)	Phosphorous removal recovery	Crystallisation of calcium phosphate using sand as a seed material	Wastewater (secondary effluent or sidestream)	Caustic soda/milk of lime, sand; may need sulphuric acid	Calcium phosphate, sand	Calcium phosphate (40–50%)
Advanced chemical precipitation (HYPO)	Phosphorous and nitrogen removal	Crystallisation of phosphorous/organic matter and hydrolyis to give carbon source for N removal	Wastewater (primary influent)	Polyaluminium chloride (PAC)	Chemical sludge	Chemical sludge
Ion exchange (RIM-NUT)	Fertiliser (struvite) production	Ion exchange removes ammonium and phosphate which are precipitated	Wastewater (secondary effluent)	H_3PO_4, MgCl, NaCl, $NaCO_3$, NaOH	Struvite ($MgNH_4PO_4$)	Phosphate slurry
Magnetic (Smit-Nymegen)	Phosphorous removal	Precipitation, magnetite attachment, separation and recovery	Wastewater (secondary effluent)	Lime, magnetite	Primarily calcium phosphate	Calcium phostphate
Phosphorus adsorbents	Phosphorus removal	Adsorption and separation	Wastewater	NA	No information	Calcium phosphate
Tertiary filtration	Effluent polishing	Filtration	Secondary effluent	Media	Tertiary sludge	Insoluble phosphate
Sludge treatment	Sludge disposal	E.g. sludge drying, reaction with cement dust	Sludge	Depends on process	Soil conditioner	Dry granule, low in P
Recovery from sludge ash	Phosphorus recovery	Extraction from sludge ash	Sludge ash from biological removal	NA	NA	NA

Figure : Methods of phosphorus recovery

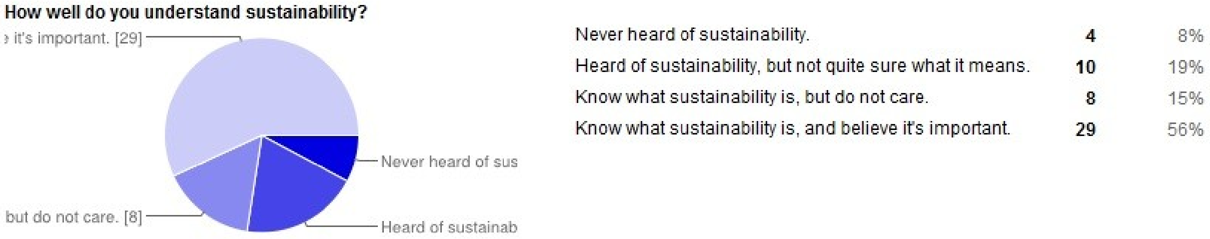
From: Morse, G.K., Brett, S.W., Guy, J.A. & Lester, J.N. (1998). Review: Phosphorus removal and recovery technologies. *The Science of the Total Environment*, *212, 69-81*



Premoval technology	Works application	Retrofit option	Recovery value		Technology advantages	Technology disadvantages
			Industrial	Agriculture		
Chemical precipitation	Primary, secondary or tertiary treatment, or activated sludge recycle	Can be flexibly applied, depending on circumstances	Low: metal-bound P makes recycling difficult	Moderate: P availability variable	Established low technology Easy to install and operate P removal can be high	Requires chemicals Sludge production increases P recyclability variable.
Biological phosphorus removal	Secondary treatment or activated sludge recycle	Difficult, unless existing capacity is available or re-allocated	Moderate: biologically-bound P more recyclable	Moderate: biologically-bound P more available	Establishing technology No need for chemicals N and P removal possible P more recyclable	More complex technology to install and operate Sludge handling may be more difficult
Crystallisation (DHV Crystalactor®)	Tertiary treatment or recycle stream	Can be retrofitted to most types of works	Very high: easily recycled by industry	Moderate: P availability variable	Demonstrated technology Can be retrofitted Product recyclable	Requires chemicals Requires operation skills
Advanced chemical precipitation (HYPO)	Primary (precipitation), secondary (nitrogen removal)	Retrofit possible, but extensive modifications usually required	Low: metal-bound P makes recycling difficult	Moderate: P availability variable	Proven (pilot) technology Enhanced P and N removal Part of a complete recycling concept	Requires chemicals Complex technology P may not be in a convenient form for recycling
Ion exchange (RIM-NUT)	Tertiary treatment only	Retrofit possible, depending on situation	Moderate: would require modifications	High: struvite is a good slow-release fertiliser	High P removal Struvite produced has high recycling potential for agriculture	Requires chemicals Complex technology Waste eluate
Magnetic (Smit-Nymegen)	Tertiary treatment only	Retrofit possible, depending on situation	Moderate: would require modifications	Low: agricultural suitability unkown	High P removal	Unnecessarily complex technology Requires chemicals
Phosphorus adsorbents	Not sufficiently developed	Not sufficiently developed	Low: unknown	Low: unknown	Potential for P recovery with few chemicals	Unproven technology
Tertiary filtration	Tertiary treatment only	Easy to retrofit to most works	None: no potential	None: no potential	Established technology Easy to retrofit and use	Not a recovery technology (no useful product)
Sludge treatments	Sludge stream	Typically requires modification	Low: difficult to re-cycle	High: P re-use high	Increases sludge value	More complex technology Chemicals required
Recovery from sludge ash	After sludge incineration	Easy to append to treatment stream	High: P readily leached	Moderate: P re-use possible	Potential for recovering P at high concentrations	Undeveloped technology Only possible if incineration is the usual disposal route

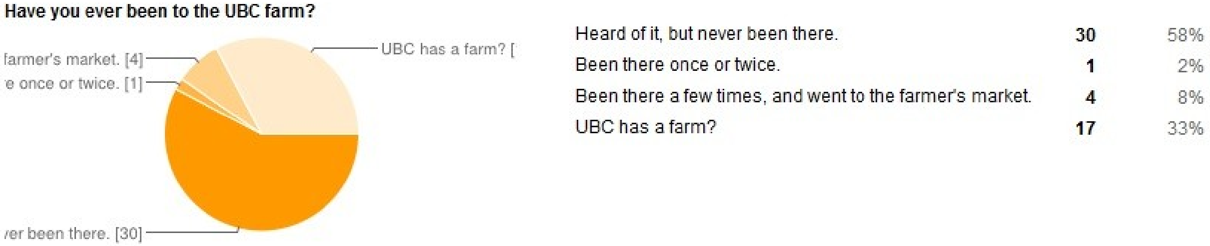
Figure : Methods of phosphorus recovery continued

From: Morse, G.K., Brett, S.W., Guy, J.A. & Lester, J.N. (1998). Review: Phosphorus removal and recovery technologies. *The Science of the Total Environment*, *212, 69-81*



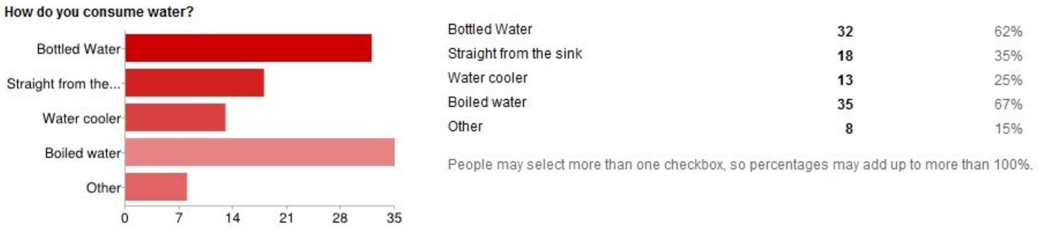
How well do you understand sustainability?

Never heard of sustainability.	4	8%
Heard of sustainability, but not quite sure what it means.	10	19%
Know what sustainability is, but do not care.	8	15%
Know what sustainability is, and believe it's important.	29	56%



Have you ever been to the UBC farm?

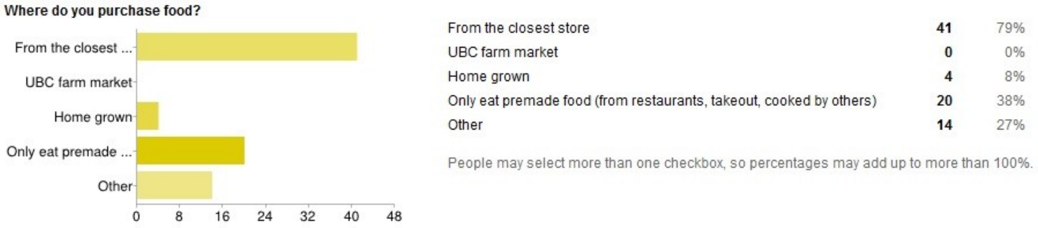
Heard of it, but never been there.	30	58%
Been there once or twice.	1	2%
Been there a few times, and went to the farmer's market.	4	8%
UBC has a farm?	17	33%



How do you consume water?

Bottled Water	32	62%
Straight from the sink	18	35%
Water cooler	13	25%
Boiled water	35	67%
Other	8	15%

People may select more than one checkbox, so percentages may add up to more than 100%.



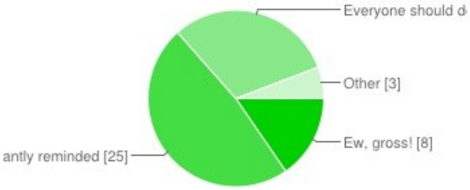
Where do you purchase food?

From the closest store	41	79%
UBC farm market	0	0%
Home grown	4	8%
Only eat premade food (from restaurants, takeout, cooked by others)	20	38%
Other	14	27%

People may select more than one checkbox, so percentages may add up to more than 100%.

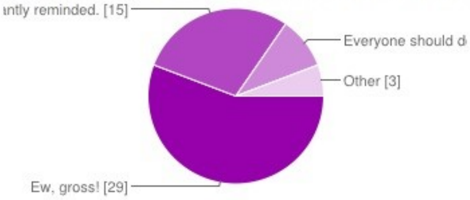
Figure : Group initiated survey

What do you think of using nutrients or minerals retreived from wastewater in the food production process, knowing the substances has already been treated?



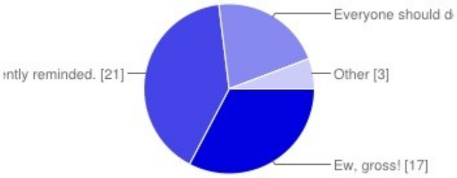
Ew, gross!	**8**	15%
Indifferent as long as you aren't constantly reminded	**25**	48%
Everyone should do it.	**16**	31%
Other	**3**	6%

What do you think of resusing wastewater for drinking and cooking actual food, knowing the wastewater has already been treated?



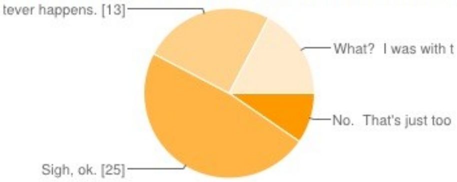
Ew, gross!	**29**	56%
Indifferent as long as you aren't constantly reminded.	**15**	29%
Everyone should do it.	**5**	10%
Other	**3**	6%

What do you think of using nutrients or minerals retreived from animal manure in the food production process, knowing the substances has been treated?



Ew, gross!	**17**	33%
Indifferent as long as you aren't currently reminded.	**21**	40%
Everyone should do it.	**11**	21%
Other	**3**	6%

If the world's water supply runs out, would your views above change?



No. That's just too disgusting.	**5**	10%
Sigh, ok.	**25**	48%
Indifferent to whatever happens.	**13**	25%
What? I was with this already.	**9**	17%

Figure : Group initiated survey continued