COMPARISON OF URINE DIVERTING TOILET SYSTEMS TO CONVENTIONAL WASTEWATER TREATMENT AND ASSESSMENT OF THE FEASIBILITY OF REPLACING THE LATTER WITH THE FORMER

by

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ABSTRACT

Comparison of Urine Diverting Systems to Conventional Wastewater Treatment and Assessment of the Feasibility of Replacing the Latter With the Former

Nathan Krebs

Developed and developing nations alike face challenges around the seemingly disparate issues of water shortages, energy consumption, water pollution and shortage of agricultural inputs. Conventional sanitation systems in industrialized societies are expensive to build and maintain, consume large amounts of energy, lead to extensive water use because they require water as a transport medium and, because wastewater contains large amounts of plant nutrients, wastewater is implicated as a major source of water pollution. In less developed areas of the globe, human excreta often causes major health and environmental problems when it is directed untreated into water ways. Agriculture worldwide requires fertilizer inputs to maintain the fertility of soil. While these concerns are widely studied by researchers in distinct disciplines, a cooperative and interdisciplinary approach may arguably be more effective at adequately handling these problems than the piecemeal offerings of individualized fields of study.

Urine diverting toilet systems represent a rather revolutionary departure from status quo sanitation systems. Such systems treat human excreta as a valuable reusable resource rather than a waste. The sanitation system becomes a means of not only sanitizing human excreta, but also a means of capturing a resource to be directed back to agriculture as a fertilizer. However, as these systems have only been implemented on relatively small scales, their overall feasibility remains unproved. The research presented here seeks to compare conventional systems to alternative urine diverting systems, analyzes the potential feasibility of the alternative technology both from a technical aspect and also from the standpoint of the potential perception and acceptance of the technology by the anticipated users.

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Section 1- Introduction

Interdisciplinary approaches are gaining popularity and recognition for their essential role in finding solutions to growing environmental problems. Specialized fields of study have long been important for providing understanding of the physical world and developing ways that societies may benefit from natural systems. However, the interface of human societies and their environment takes place on a complex and interconnected front. In many human interactions with the natural world, a lack of a comprehensive understanding of natural systems' roles lead to ventures that are successful in some regards, but complete failures in others.

For instance, hindsight shows that society and environmental systems may have been better served had engineers working on the construction of dams in the Pacific Northwest during the middle of the last century stepped outside of their tidy professional boundaries to discuss means to mitigate the potential harmful impacts of dams with fishery scientists and biologists. These massive construction projects were generally quite successful in providing irrigation water and electricity, but also resulted in widespread destruction of habitat for salmon and other wildlife native to impacted riverine habitats. The impacts of the decisions made decades ago continue to carry, in many ways, a damaging legacy to cultural, environmental, and economic systems in the region.

Since the middle of the twentieth century, human food systems have become increasingly complex and technical in many regards. Following World War II, western agricultural systems, largely influenced by specialized chemists, plant geneticists, and agricultural scientists, experienced a massive infusion of fertilizers and crop treatments.

These inputs were largely made possible through a heavy subsidization by fossil fuels and government policies and have allowed for tremendous increases in yields over past decades. The benefits of the increased yields are obvious. Food is generally more easily available and cheaper than it has ever been in history. However, the reliance of the food system on finite resources makes it vulnerable to market forces as those resources become depleted and costly.

Sanitation systems represent the other end of the existing" linear" agricultural system (i.e. this system has defined inputs and outputs, as opposed to a cyclical system in which outputs are recycled in some manner to become inputs into the system) . Human excreta, the primary component of concern in what is commonly known as "wastewater."By treating excreta as a waste it becomes essentially an externalized cost of producing and consuming food. Human excreta can be a public health concern due to the potential for disease transmission from contact with excreta. In the name of protecting public health, specialists such as wastewater engineers and public health officials, developed modern sanitation systems that have proved largely successful at limiting human contact with excreta, but require large, expensive and technologically advanced systems to move vast quantities from points of potential contact between individuals and excreta to large treatment facilities.

In the process, large quantities of energy, water, and other resources are needed to treat the water that is, due to its role as a transport medium, intentionally polluted by the system. The system is then tasked with handling vast quantities of sludge removed from water. Due to the presence of various pollutants present in the wastewater stream, and especially due to the presence of large quantities of plant nutrients present in excreta, this waste product often becomes an environmental pollutant in itself. Indeed, the current widespread consideration and treatment of human excreta as a waste product has presented environmental problems not easily solved by existing systems.

In addition to the large amounts of inputs, the agricultural system, and in turn sanitation system, can be critiqued based on its linear nature. The system in many ways is weakened by its distinct inputs and outputs. The inputs (fossil fuels, mined resources, water, infrastructure, etc) are in many cases finite or limited in their availability. The outputs are largely implicated as pollutants of land, air and water.

Myriad technologies have long been in existence that could allow the closure of the resource "loop" with regard to the inputs to the agricultural system and the outputs of the sanitation system. One such system is urine diverting (UD) technology. This system allows for the sanitary capture and reuse of urine (a fraction of the wastewater stream of high importance for nutrient reuse and sequestration) in agriculture. These alternative systems are designed to not only effectively remove pathogenic organisms and pollutants that cause environmental and human health problems, but also to capture the plant nutrients that are found in human excreta in order to make them available for reuse in agriculture. This paper will seek to examine the issues surrounding the choices societies make with regard to managing their waste/resource streams and consider issues regarding the feasibility of shifting from a system of sewered "wastewater" systems to urine diverting systems.

In order for this technology to become widely adopted, there are many potential barriers. Some of these barriers are technological. There are concerns about whether urine collection and storage technology can be scaled up to function in the context of large towns and cities. Technology to transfer urine-sourced fertilizer resources to agriculture and means of application are still largely unproven.

In addition to the technological barriers, there are many barriers based on the perception of the technology by a wide variety of stakeholders. Human excreta is a taboo topic in many societies. There are many reasons, some of them being quite reasonable, that using fertilizer products sourced from excreta to grow food gives many people pause. There are also many rather irrational and emotional reactions that factor in. In addition to the difficulty many individuals have regarding the mental problem of using sewage for fertilizer, there also are challenges that arise when an attempt is made to replace or augment established systems and practices (e.g. infrastructure). In many cases these challenges arise from strong paradigmatic convictions held by key stakeholders. Finding a way to overcome or convince these convictions is often the challenge of a new technology, no matter how innovative or sensible it may be.

It is widely accepted that industrial agriculture is not currently on a sustainable path due to its linear nature, massive resource throughputs, irresponsible use and handling of plant nutrients, and the resultant environmental damage that stems from these attributes. Additionally, there are many concerns about the ability of sewer-based industrial wastewater systems to adequately and efficiently sanitize human excreta. Urine Diverting systems represent an alternative that may be capable of adequately collecting and sanitizing human excreta while also providing a reasonable means for reuse of the plant nutrients contained in excreta. However, these systems require a radical reconsideration of the meaning of human excreta and shift the value of it from being a valueless waste product to being a valuable resource. In so doing, the technology also essentially demands a reconsideration of the barriers that exist between existing disciplines. These technologies have the potential to dramatically increase the sustainability of both agricultural and sanitation systems. However, there exist technological and attitudinal barriers for the extensive implementation of these systems. These barriers and their interactions are the subjects of this paper.

Section 2- Background Information

Flush and Forget: Conventional wastewater treatment plants

The "flush and forget" (Langergraber & Muellegger, 2005) system of sanitation, based on vast networks of sewer pipes connected to centralized treatment plants, has long been considered the superior system for reducing the potential health threats posed by improperly handled human excreta. Sewer systems have existed for centuries and have flourished especially within the last two hundred years (Bracken, Wachtler, Panesar, & Lange, 2007). In response to the horribly unsanitary conditions that arose around industrializing towns and cities in Europe in the seventeenth and eighteenth centuries, systems were designed to minimize odor, filth and health concerns associated with human excreta. As indoor restrooms became more prevalent, especially in western industrialized countries during the nineteenth century, flush toilets and sewers came to dominate as the most common form of sanitation.

However, the construction of sewers and sewage treatment plants has proved insufficient to control water pollution, other associated environmental issues, and human health problems. In many cities, water treatment plants have become locations where concentrated wastewater is introduced into the environment. In the United States, the Clean Water Act of 1972 established a set of rules and regulations to govern the wastewater treatment industry. Many other counties have analogous legislation to regulate wastewater treatment and the subsequent return to the environment. However, as populations continue to grow, costs of operation increase, infrastructure ages, and the nature and quantity of contaminants change and increase, treating water to legally acceptable levels is proving more and more difficult (U.S. EPA, 2004).

Overview of Conventional Wastewater Treatment Plant Operation

Conventional wastewater treatment plants (WWTPs) are quite technologically advanced. Most of these systems use water as a medium to transfer excrement via pipes into networks of sewers, where toilet water (blackwater) mixes with other domestic wastewater (greywater), industrial wastewater streams and possibly stormwater runoff before arriving at centralized treatment facilities. Treatment facilities use myriad physical, chemical and biological treatment processes to bring water to some level of sanitization before it is returned to the environment. The following synopsis of the treatment processes at conventional WWTPs is based on the "Primer for Municipal Wastewater Treatment Systems," published by the U.S. Environmental Protection Agency (EPA) (2004).

In some systems solids are simply removed by a primary process of filtration and settling. This process first removes large objects such as sticks and rags that may be suspended in the wastewater stream by the use of screens and grates. Sand and gravel are then removed in sedimentation chambers. This step is very important to limit wear and tear on pumps and other machinery and is especially important in combined sewer systems where storm water runoff can contribute road debris when it is added to the wastewater stream. After the largest particles are removed, dissolved inorganic and organic material and suspended solids are still present. Additional solids may be removed by further gravity sedimentation, filtration or chemical coagulation. The sludge collected during primary processing is generally either hauled to a landfill or incinerated.

In the United States and many other industrialized countries, secondary treatment is required as a minimum level of treatment before wastewater can be returned to the environment. These more advanced systems use biological agents such as bacteria, algae and fungi to consume and remove additional organic materials from the water. Wastewater is passed through biologically active holding tanks utilizing either attached growth apparatus (where the biological agents are affixed to a stone or plastic media) or a suspended growth system. Both types of systems require the water to be continually aerated to ensure that the biological agents have plenty of oxygen to thoroughly remove dissolved organic matter. Secondary treatment potentially removes about 90% of suspended biodegradable matter.

For the approximately 70% of WWTPs in the United States employing secondary treatment, the final step in the process is to disinfect the wastewater before it is returned to the environment. This is generally done in one of three ways. The use of chlorine gas is very effective at killing bacteria and viruses, but the use of this method has declined in many areas because chlorine is also highly toxic to beneficial aquatic life. Therefore, if this method is employed, precise dechlorination processes are necessary before the water can be released. Ozone, an unstable molecule produced by exposing oxygen to very high voltage, is also very effective at sanitizing water. The gas readily breaks down to reform oxygen and leaves no harmful residue in the water. However, it is expensive to treat water with ozone due to the large amounts of electricity used. Ultraviolet radiation kills potentially pathogenic microorganisms by penetrating cellular tissues and damaging genetic material. UV treatment is quite effective and leaves no harmful residue in the out flowing water. However there are substantial energy penalties to this method of sterilization.

The other approximately 30% of WWTPs in the United States employs a third stage of treatment. Tertiary, or advanced treatment is necessary to further purify wastewater, and specifically to remove the plant nutrients nitrogen and phosphorus before the nutrients can be absorbed by aquatic vegetation. This is because the deleterious effects of excess nutrient loading of waterways are generally associated with high levels of algae and plant growth (e.g. Anderson, et al., 2008). Eventually the overgrowth blocks out sunlight at the surface, causing a die-off of the algae. As the algae decompose by natural biological processes, oxygen is consumed. The resulting low levels of dissolved oxygen can cause severe harm to aquatic systems and has been implicated in large-scale fish kills, marine mammal mortality, shellfish mortality, illness in humans from eating affected shellfish, and loss of certain types of aquatic vegetation (Anderson et al., 2008). In addition to pollution of aquatic environments, nitrogen groundwater pollution is another concern. Groundwater pollution is most often associated with agricultural sources of nitrogen. However, the connection between wastewater treatment processes and aquifer pollution can be quite direct in places that allow secondarily-treated wastewater to be used in irrigation.

Nitrogen often occurs in the wastewater stream in the form of ammonia. Ammonia can be directly poisonous to some aquatic life and can also stimulate the growth of algae. Nitrification is a process whereby toxic ammonia is converted into non-toxic nitrates by nitrifying bacteria. Once the toxicity of the ammonia is addressed, nitrogen removal from the wastewater stream typically takes place by biologically converting it to nitrogen gas. This is accomplished in an anaerobic environment where bacteria are forced to use the oxygen linked to the nitrates for their metabolic activity, which isolates nitrogen as nitrogen gas. The non-toxic gas is simply vented to the atmosphere.

Phosphorus, another plant/algae nutrient found in wastewater, must also often be removed prior to releasing the effluent to lakes, streams or estuaries. Such removal may be done through coagulation-sedimentation processes or by using biological nutrient removal systems. The coagulation-sedimentation process requires the addition of alum, lime, or iron salts to be added to the wastewater. These chemicals bond with phosphorus and, because the resulting particles are heavier than water, they fall out of solution as sediment. Up to 95% of phosphorus can be captured in this process. However, the resulting chemical sludge is fairly expensive to dispose of, making this process less desirable as an option for municipal wastewater treatment. In the biological nutrient removal system, bacteria and other microorganisms are supported on a suspended growth system. These systems generally treat nitrogen by converting it to nitrogen gas in a similar manner as the denitrifying systems described above. Phosphorus is removed in the solid material of the microorganisms collected from the effluent.

The solid portions, or sludge, of the wastewater stream are collected and generally are either incinerated, buried in landfills or applied to the land in some manner. The proportion of sludge that is disposed of or reused in some capacity varies widely. In some Swedish municipalities, for instance, nearly all of the sludge produced is spread on agricultural lands, while the national average is closer to about 30% (Kvarnstrom &

Nilsson, 1999). In the United States about half of the sewage sludge produced is applied to the land either as an agricultural soil amendment or as a soil conditioner in disturbed lands such as construction sites and strip-mines where vegetation re-growth is desired (U.S. EPA, 2004). Because sewage sludge may contain heavy metals, pathogens, and other pollutants, the use of sewage sludge is regulated in the United States by Federal Regulation 40 CFR Pert 503.

Problems Inherent to Conventional WWTP Operations

Modern sewage systems have done an admirable job of improving sanitary conditions for many populations globally. However, this benefit to society has not come without a price. Drawbacks to conventional sewer-based sanitation systems include high energy consumption, considerable usage of freshwater, economic costs and environmental pollution.

Energy Consumption

A substantial amount of energy is required in the process of purifying water that has been contaminated by human excreta. Depending on the location and design of a given system, electric pumps may be required to move large volumes of water to centralized treatment facilities. Massive mechanical apparatuses are also required at treatment plants to aerate water as it moves through the system. The energy costs of aeration alone in the United States accounts for at least one percent of all electricity consumption in the country (Rabaey, 2009). The handling of sludge at treatment plants accounts for at least as much additional energy use (Rabaey, 2009). Many other aspects of the process result in additional energy consumption. These range from the production of chemicals (e.g. chlorine) involved in the sanitation process, to the maintenance and manufacture of large machinery required for the treatment operations. The energy costs of pumping, storing, and treating the water used as flush water are also not accounted for here. Depending on what energy costs are included, it is possible to come to diverse conclusions about the energy costs of WWTPs. However, it is difficult to deny the large magnitude of energy used in treatment processes. According to a large study coordinated by the EPA "estimates the annual energy usage at approximately 100 billion kWh per year. At an average energy cost of $0.075 per kWh, the cost for providing safe drinking water and providing effective wastewater treatment is approximately $7.5 billion per year" (EPA, 2010).

Water Use

Because of the tremendous volume of water required by such systems, consumption of freshwater is a major concern, especially as shortages in per capita availability of freshwater become more prevalent in many areas around the globe. Jenkins (2005) states that “by some estimates it takes one to two thousand tons of water to flush one ton of human waste.” A study of water use in the United Kingdom found that around one third of total domestic water use is used for flushing toilets (Burkhard, Deletic, & Craig, 2000). This figure agrees with Vinnerås and Jönsson (2002), who state that in Sweden the average person uses about 59 m^3/yr, of which 19 m^3 is used for toilet flushing. The EPA estimates that Americans use about 4.8 billion gallons of water to flush toilets every day (“How to Conserve Water and Use It Effectively”, 2010). These statistics are concerning, as freshwater supplies around the world are in shorter supply every year. For instance, in the United States, groundwater use outpaces replacement rates by 21 billion gallons per day (Jenkins, 2005).

In addition to the sheer volume of water used by sewer-based sanitation systems, water used for flushing in most parts of the world is purified drinking water. This means that not only are freshwater supplies being depleted, but also that energy and other resources are invested into the purification of the water used for flushing, which is then to be polluted prior to anyone having had a chance to drink it.

High Cost of Maintenance and Operation

Because of the high levels of inputs, wastewater treatment systems have relatively high operating costs. The operation of sanitation systems in industrialized countries generally is the responsibility of municipalities. According to Langergraber and Muellegger (2005) "conventional systems are directly cross subsidized and the chances to ever become financially sustainable are low." In western, industrialized economies, wastewater treatment can require expenditures of 2% of Gross Domestic Product (Larsen & Gujer, 2001). The true costs of water supply and the resulting water treatment are rarely covered by the fees paid by consumers. On average, municipalities must pay 65% of the cost for treating wastewater that is not covered by user fees (Renzetti, 1999). In the U.S., a recent report by the U.S. Conference of Mayors, Mayors Water Council estimates that local governments spent $93 billion in 2008 to pay for water and wastewater infrastructure. It is estimated that about 60% of these costs go to operations and maintenance, with the approximately 40% of these funds going to new capital investment (Anderson, 2010).

A primary point made by this report is that the current level of funding dedicated to the existing water infrastructure is not sustainable. Additionally, due to the degeneration of the aging infrastructure, there are grave concerns about the ability of municipalities to pay for future maintenance, upgrades, and replacement of water infrastructure components that are coming to an end of their useful lives. The wastewater infrastructure alone in the United States is comprised of over 16,000 publicly owned treatment facilities, 100,000 pumping stations, 600,000 miles of sanitary sewers, and 200,000 miles of storm sewers (Anderson, 2010). The Congressional Budget Office predicts that between $13-20.9 billion (2001 $US) will need to be spent annually to repair the nation's wastewater treatment system in order to meet *existing* levels of service and comply with *existing* regulations. This expenditure is in addition to $20.3-25.2 billion annually for operation and maintenance costs and does not include increased costs associated with growing populations and tightening regulations.

Water Pollution

From an environmental perspective, perhaps the most significant concern regarding conventional sanitation systems is their management of plant nutrients, specifically nitrogen and phosphorus, and micro-pollutants, such as pharmaceuticals and endocrine disrupting compounds. Myriad studies have demonstrated that micro-pollutants are showing up in increasing concentrations in surface water, groundwater and drinking water (e.g. Winker, Faika, Gulyas, & Otterpohl, 2008).

Many pharmaceuticals that are introduced into the environment via WWTP outflow pipes are classified as endocrine disruptors. This class of chemicals can disrupt hormone development in aquatic organisms even at very low concentrations (Daughton & Ternes, 1999). Also, natural and synthetic hormones from anthropogenic sources have been implicated in the destruction of aquatic ecosystems, especially fish populations (Escher, Pronk, Suter, & Maurer, 2006). The toxic effects of the broad range of pharmaceutical compounds have only been studied for a relatively short period of time and they are still not well understood. However, according to Daughton and Ternes (1999) the drug interactions in aquatic environments that are understood "…are known to elicit subtle but dramatic effects on aquatic life at very low concentrations…" and "…may point to an ill-defined vulnerability in aquatic ecosystems". Conventional wastewater treatment systems are a primary route by which micro-pollutants enter the environment, but no widespread technologies have yet been introduced to conventional WWTPs that allow for the removal of micro-pollutants from the effluent stream (Larsen & Gujer, 2001).

In addition to their failure to handle micropollutants, many WWTPs globally and about 70% of those in the U.S. do not effectively remove biologically available nitrogen and phosphorus from the outgoing water. Nutrients not absorbed by the treatment processes are introduced into the environment where they can become pollutants if they are allowed to flow into naturally nitrogen- or phosphorus-limited bodies of water. In addition to the nutrients that escape from systems that are fully equipped to remove them, there are a great number of sewer systems around the world that dump sewage ranging from insufficiently treated to completely untreated into water bodies. In cities throughout the Southern hemisphere the high cost of implementing sewage treatment system has resulted in over 90% of effluent being left completely untreated (Drangert, 1998). Even in Europe, according to Lienert, Tove and Larsen (2009), “only 79 of 542 major cities have full (tertiary) sewage treatment.” Of those cities without full tertiary treatment, 223 rely on secondary treatment systems, 72 have only incomplete primary treatment, and 168 have “no or an unknown form of treatment for their wastewater” (Bracken et al., 2007).

In the United States, The American Society of Civil Engineers gave the country’s wastewater treatment system a grade of D- on their 2009 “Report Card for America’s Infrastructure” (ASCE, 2009). This low grade is based on the crumbling state of America’s wastewater treatment system, its antiquated equipment and especially on the fact that the overall system allows over 10 billion gallons of untreated sewage to be discharged into the nation’s surface waters every year (ASCE, 2010).

Consequent discharge of improperly treated sewage into the environment presents a serious health risk due the pathogens that can be found in human excreta. Also, as noted previously, pollution from nutrients that are allowed to flow through the treatment process and into marine environments and bodies of freshwater can result in eutrophication, the cause of significant ecological and economic losses around the globe.

The human disruption of the nitrogen cycle, a cycle largely driven through Earth's marine and aquatic ecosystems, over the last century has been tremendous. Through various activities such as burning fossil fuels, and fixing atmospheric nitrogen into synthetic fertilizers, humans produce roughly 160 million metric tons of biologically available nitrogen annually. This compares to between 90 and 120 million metric tons fixed by natural systems (Dybas, 2005). Of the additional nitrogen that humans add to the system, relatively small amounts are taken up by crops. The remaining nitrogen added to the system invariably ends up in aquatic ecosystems.

When nitrogen (and in some cases, phosphorus) are added in large volumes to aquatic ecosystems that are limited by these nutrients, large blooms of algae known as harmful algal blooms (HABs) can occur. In fact, the frequency, severity, and duration of HABs is expanding dramatically (e.g. Dybas, 2005). These blooms can have direct harmful effects on humans when toxins produced by harmful algae species are bioaccumulated into shellfish consumed by humans. More commonly and with more widespread harmful implications, the added nutrients are causing marine dead zones around the world caused by blooming and consequent oxygen-consuming decay of algae in marine environments. The occurrence of these situations, which cause large fish kills and areas of very poor ecosystem production, is expanding at an astonishing rate, with the waters affected by HABs doubling every decade (Dybas, 2005). Reducing the amount of nitrogen synthesized from atmospheric sources (perhaps by recycling nitrogen through the human food chain) could have a positive effect of reducing the over-addition of biologically available nitrogen to the system.

Concerns regarding conventional modern agricultural inputs

As the wastewater industry has sought technologically advanced methods for removing plant nutrients from wastewater, agriculture has relied on the production of synthetic fertilizers and mining of mineral fertilizers to replace the nutrients removed from fields when food crops are harvested. As societies have trended toward industrialization over the last century, negative flows of nutrients from agricultural lands have become more pronounced (Magdoff et al., 1997). Incidentally, the three main nutrients required for plant growth- nitrogen, phosphorus, and potassium- are all found in human excreta. Nitrogen and phosphorus supplies will be the emphasis of this paper.

Plants require nitrogen for protein synthesis and up to five percent of plant dry matter is nitrogen. Atmospheric nitrogen is quite abundant, constituting about 79% of the atmosphere. However, in general, plants have no way of absorbing nitrogen from the air for their own cellular use. Some plants (e.g. legumes) have developed symbiotic relationships with soil microorganisms that are capable of "fixing" atmospheric nitrogen. For plants that have this capability, it is an energy intensive process that ceases when just enough nitrogen is made available. Therefore, for many plants (nitrogen fixers and others) nitrogen is one of the primary factors limiting growth (Heinonen-Tanski & van Wijk-Sijbesma, 2005).

Phosphorus is a vital element in DNA, RNA and enzyme reactions that are necessary for plant growth. Although phosphorus is equally as vital as nitrogen, plants require about one tenth as much phosphorus as nitrogen to maintain growth (Heinonen-Tanski & van Wijk-Sijbesma, 2005). Different soil types have varying amounts of naturally available phosphorus. In most agricultural areas, phosphorus should be added once per growing season to ensure a sufficient supply to growing plants.

Historically, natural levels of phosphorus in soil were relied upon to supply plants with their requirements. Human excreta, animal manure and bone were sources of phosphorus that were used to supplement naturally occurring phosphorus. Over the course of history soil reserves were depleted and local contributions could no longer keep up with the demand for nutrients. In order to meet the needs of growing populations it became necessary in many areas to supplement naturally occurring phosphorus with imported fertilizer. When large guano deposits, which had accumulated over countless centuries off of the South American coast and in the South Pacific, were discovered, they provided the world with a steady supply of phosphorus. These limited supplies quickly became depleted though, and were exhausted around the end of the 19th century (Cordell, Drangert, & White, 2009).

Phosphorus in modern agricultural systems is primarily obtained from mined rock phosphate.   Global reserves of rock phosphate were once considered to be inexhaustible. However, after more than a century of intensive pressure, it is now widely recognized that global reserves of high quality rock phosphate are quickly being diminished and that they may be exhausted in the next 50-100 years (Cordell et al., 2009). There are currently no viable alternative sources that can replace the 20 million tonnes of rock phosphate that are currently mined each year (Cordell, et al., 2011).

A growing shortage, and the resulting price increase, of an essential agricultural input will inevitably lead to increased food prices, potentially lower yields, and decreased food security (Cordell et al., 2009). In fact "some researchers assume that within a century, the severity of the phosphorus crisis will result in increasing food prices, food shortages and geopolitical rifts" (Langergraber & Muellegger, 2005).

In addition to their declining availability, phosphate fertilizers from rock phosphate can have high levels of heavy metals, depending on the source of rock phosphate (Maurer, Pronk, & Larsen, 2006). As stocks of higher quality (lower heavy metal content) rock phosphate become depleted, stocks with higher levels of heavy metals will more extensively be brought to market. These heavy metals can be transmitted to agricultural lands, where they can accumulate and be taken up into food crops and on up the food chain into humans.

Nitrogen fertilizer does not face the same resource availability issues that phosphorus does per se, but there are some compelling reasons to reconsider the methods used to obtain plant-available nitrogen for agricultural purposes. The Haber process is the industrial process used to combine vast atmospheric stores of non-reactive nitrogen gas and hydrogen under high pressure into reactive ammonia. Ammonia produced by the Haber process can be used as a high nitrogen fertilizer, converted into other nitrogen-supplying compounds such as urea, ammonium nitrate and ammonium sulfate, or be combined into NPK combination fertilizers.

The Haber process produces each unit of nitrogen quite efficiently and therefore it can be argued, assuming that natural gas prices remain low, that there is little economic incentive to seek alternative sources of nitrogen fertilizer (Wilsenach & van Loosdrecht, 2006). However, because of the tremendous quantities produced worldwide, and the rate at which demand continues to grow, the production of nitrogen fertilizers constitutes a significant percentage of annual global natural gas consumption and accounted for approximately 1% of total world energy consumption in 2001 (Ramirez & Worrell, 2005). Annual applications of nitrogen fertilizers continue to grow at impressive rates. To this point that has meant a steady increase in the quantity of natural gas used for the production of nitrogen fertilizers (just less than 500 PJ in 1961 compared with just over 2500 PJ in 2001) (Ramirez & Worrell, 2005).

Natural gas is used in the Haber process both as means of providing heat, and also as a source of hydrogen as a raw material for the process (obtained by mixing methane gas with steam). With natural gas being one of the primary inputs to the Haber process, farmers have come to be at the mercy of fluctuating natural gas markets. For instance, an increase in the price of natural gas in 2003, and the resulting increase in the cost of fertilizer, was cited as the cause of the collapse of the largest farmer owned co-operative in the United States ("Expensive Fertilizer Blamed", 2003). The increase in cost of nitrogen fertilizers was around 32% between April 2007 and April 2008. Prices also rose substantially the following year (Huang et al, 2009). Although the price of natural gas has come down in recent years (due to new reserves becoming available by hydraulic fracturing) the point remains that the existing nutrient sources for the world food supply is inextricably linked to the ever-fluctuating whims of energy markets. All markets seek consistent estimates input costs. Given the inevitable uncertainty already faced by farmers from weather, pests, and market forces, the development of a more consistently priced source of nitrogen (e.g. from urine diverting systems) would likely be beneficial to agricultural systems.

In Ethiopia, the rising cost of energy and the fact of limited phosphorus reserves are causing annual price increases of up to 20% (Meinzinger, Oldenburg, & Otterpohl, 2008). There are additional signs of stress worldwide as farmers in the poorer nations of the world struggle to pay higher and higher prices for fertilizers (e.g. Cordell et al. 2009). As a result of rising costs for production inputs, among other factors, Mitchell (2008) notes that the price of fertilizer from 2002 to 2007 in $/acre of input has risen markedly for corn ($42.51 in 2002 to $93.96 in 2007), soybeans ($6.79/$13.94), and wheat ($17.71/$33.33).

The rising cost of farm inputs does not only affect farmers. As noted by R. Neal Elliott of the American Council for an Energy-Efficient Economy (ACEEE) in his testimony before Congress (2005)“negative economic impacts on the agricultural community ripple throughout the entire economy affecting every household because these increased farm energy costs are passed thorough to the consumer in higher food and agricultural product costs.” Although energy prices are just one factor that contribute to the price of food, the trend of rising food costs has become clear. Prices of internationally traded food commodities increased 130 percent from January 2002 to June 2008 and 56 percent from January 2007 to June 2008 (Mitchell, 2008).

Economic and ecological costs associated with nitrogen are not only attributable to fertilizer costs, however. As noted previously, an overabundance of nitrogen has been the cause of damage to fish populations, changes in levels of marine vegetation, beach pollution, damage to coral reefs, and ground water pollution (Heal, 2000). These deleterious effects are due to the fact that humans have, through the use of synthetic fertilizers, altered the global nitrogen cycle to the point that “the quantities of nitrogen added to the soil…now exceed the totals fixed through natural processes” (Heal, 2000). However, “less than half of the nitrogen added to the soil (in the form of synthetic fertilizers) is taken up by plants” and “nitrogen and its compounds are highly mobile, so the majority runs off into groundwater and ends up in lakes or the sea or seeps through the ground into aquifers” (Heal, 2000).

Plant nutrients available in human excreta

Human excreta contain many of the micronutrients required for plant growth and contain especially high levels of nitrogen and phosphorus. In fact, each person excretes plant nutrients each year approximately proportional to the nutrients required to grow the amount of food (in the form of grains) that that person will require in a year (Drangert, 1998). On average, humans produce about 500 kg of urine and about 50 kg of feces per year (Heinonen-Tanski & van Wijk-Sijbesma, 2005). Urine consists of approximately 93-96% water. Fecal matter contains a high proportion of water as well, typically between 70-85% . Because the kidneys are the primary excretion organs in the human body, the majority of nutrients are found in the urine portion. Of all the nitrogen in human excreta, about 90% is found in urine. Additionally, 50-65% of phosphorus and 50-80% of potassium are found in urine (Heinonen-Tanski & van Wijk-Sijbesma, 2005).

Agricultural nutrients in human urine are produced by the body in forms that are readily available to plants. The nitrogen, for instance, in urine is excreted as urea. Urea is one of the primary industrially produced forms of nitrogen fertilizer. In addition to having a high nutrient content, urine from a healthy individual is also generally free of pathogens when it leaves the body (Heinonen-Tanski & van Wijk-Sijbesma, 2005), although there are some diseases that may be spread through urine and it should be handled with care. Methods and technologies for ensuring the hygienic handling of urine will be addressed in another section of this paper.

Although fecal matter contains less of the three primary agricultural nutrients, it still has agricultural value as a nutrient rich form of soil-building source of organic material. The plant nutrients found in feces are not as readily available to plants as those found in urine. For instance, according to Vinnerås and Jönsson (2002), only about 50% of the nitrogen in feces is water soluble and therefore immediately available to plants. For this reason, properly processed/composted feces represent a kind time-release source of nutrients. Fecal material also represents a potentially valuable source of organic matter that can increase the humus content of soil, thereby increasing its ability to hold water and maintain fertility (Langergraber & Muellegger, 2005). Despite the potential benefits of feces, the reuse of feces will not be the primary focus of this paper.

Resources available for use from the waste stream

Urine represents only about one percent of the total wastewater volume (Maurer et al., 2006). However, blackwater (urine and feces combined) contributes up to 95% of the nitrogen content and 90% of total phosphorus in typical wastewater streams. Urine alone accounts for about 87% of the nitrogen and 50% of the phosphorus in the wastewater stream (Langergraber & Muellegger, 2005). When urine is diluted in a conventional toilet, it contaminates the water used to flush, thus increasing the "magnitude of the pollution by mixing relatively small quantities of potentially harmful substances with large amounts of water" (Chandran, Pradhan, and Heinonen-Tanski, 2009). In addition to contaminating large amounts of clean drinking water, conventional treatment systems move the valuable nutrients from a relatively concentrated form into a much more dilute form, thus making their reuse much more difficult.

When the urine/flush water solution reaches the sewer, the entire volume of water within the sewer becomes contaminated. If this water is destined for a treatment plant capable of tertiary treatment to remove the plant nutrients, because of the mixing of the water streams, a significantly higher volume of water must be treated that would not otherwise have required costly advanced treatment. Thus, a much larger treatment facility is required, causing higher construction and operating costs (e.g. more precipitation chemicals are required (Tidåker et al, 2007)). If the destination plant does not employ technology for nutrient removal, the nitrogen and phosphorus will be released back into the environment at the end of the pipe, leading to potential environmental degradation by misplaced nutrients. In addition to the possibility of small volumes of blackwater contaminating large volumes of wastewater, if nutrient recovery is an objective, other wastewater sources are often to blame for contaminating and diluting the nutrient-rich blackwater stream.

Many countries allow the use of sewage sludge as a soil amendment in various uses ranging from food production to forestry. In theory, this practice can be seen as a positive in terms of sustainable reuse of resources. However, sewer systems often divert runoff from stormwater drains, industrial effluent, greywater (water from all domestic drains other than toilets, e.g. sinks and showers), and toilet water into a single stream. It becomes very difficult, if not impossible to separate out heavy metals, micro-pollutants and chemicals prior to the sludge being dispersed as a source of agricultural nutrients. Therefore, the use of sewage sludge in agriculture is rightfully restricted and even banned by many government policies. For instance, the United States Department of Agriculture (USDA) Organic Standards prohibit the use of sewage sludge in the growing of organic food. In Switzerland consumer pressure convinced the government to issue a complete ban on the use of sewage sludge in agriculture (Lienert & Larsen, 2009). In 2002, a National Academy of Sciences panel concluded that the potential mix of biological and chemical wastes in sewage sludge represents such a complicated and unpredictable set of dangers. It therefore warned that existing management practices allowing the use of sewage sludge on agricultural lands do not protect public health (Snyder, 2005).

In addition to the various contaminants that are found in the wastewater stream, some “contaminants” that limit the use of sewage sludge in agriculture are added as part of the treatment process. For instance, phosphorous can be removed using chemical precipitation processes or by biological systems as outlined previously. In the case of the common chemical treatment for phosphorus, where iron and aluminum salts are added to the wastewater stream, the recovery of and reuse of phosphorus becomes impossible (de-Bashan & Bashan, 2004). Because of the cross-contamination of valuable nutrient-rich resources such as urine that occur in conventional wastewater treatment systems, if nutrient recycling from human excreta sources is desired, new treatment processes will be necessary.

In fact, technology already exists and is currently being deployed on varying scales around the globe. The various technologies and methods that exist for collecting and handling excreta are described in the upcoming chapter. Additionally, processes for treating excreta for reuse as nutrient fertilizers will be addressed.

Section 3- Urine Diverting Technologies

In response to the situations described above, many technical suggestions have been presented that allow human excreta to be used to supplement or replace synthetic fertilizers in agriculture and limit the negative consequences of conventional wastewater treatment. Some technologies remove both urine and feces from the wastewater stream. Also, because urine represents the largest portion of the nutrients of interest, many technologies have been devised to specifically remove urine from the wastewater stream before it arrives at the treatment plant. Additionally, technologies and methods have been devised to prepare and use collected excreta in agriculture

Collection Technologies

Feces and Urine Collecting Systems

In addition to the site-built and custom toilets of that have been built over the centuries, toilets that separate both urine and feces from the wastewater stream have been commercially available since at least the 1970s. These first source separating toilets were designed as *dry* toilets. Dry toilets do not use water to flush excreta into a sewer (although in some innovative toilets, such as the Aquatron toilet, discussed by Vinnerås and Jönsson (2002), a very small amount of water is used to clean the bowl, but is kept separate from the fecal matter as it enters the holding tank). In most dry systems, urine is diverted by a dedicated pipe into a holding tank. Feces pass, typically by gravity, into a separate holding compartment. The size of holding tank, depending on the size of the building it serves, is usually compact enough to fit in the basement or else can be buried. In some of the more advanced systems a source of carbon, such as sawdust, (proper composting requires a ratio of carbon to nitrogen of 20-35:1 (Jenkins, 2005)) is added to the high-nitrogen feces to allow composting to take place inside of the toilet. Additionally, depending on the level of sophistication, mechanisms to mix and aerate the composting material, fans to minimize odors, and dual holding tanks that allow one side to compost while the other collects new material may be included.

Both the feces and the urine storage tanks require periodic emptying, with the frequency being determined by the size of the holding tanks, the number of people using them, and the percentage of each user’s daily trips to the restroom that employ that holding tank (i.e. some people may use such a toilet at work or in public buildings, but have a conventional flush toilet at home). With proper treatment (options to be discussed in succeeding section), either in the holding tank or in a separate container, the feces and urine may be used as a nutrient source for agricultural purposes.

From the perspective of maximizing nutrient recovery, such systems would be the most ideal. However, implementing nutrient-recovering toilets into a system that is already embedded with water-based flush toilets and sewers will be a complicated matter. Capturing the feces portion of the waste stream presents additional complications. For instance, the feces portion must be moved by a mechanical method generally, as opposed to urine which, being a liquid, can be moved by pump or gravity feed. Feces are also more likely to be smelly and messy to handle. As such, this paper will focus primarily on the feasibility of recovery of urine.

Urine Collecting Systems

Many modern urine separating, or urine diverting (UD) toilets, (also referred to as NoMix, ecological sanitation, and EcoSan) represent a compromise between conventional flush toilets and full-capture composting toilets. Sweden has been the location of much pioneering effort regarding new urine separation technologies. Starting during the 1990s, “thousands were installed in pilot projects” (Larsen et al., 2009). Such pilot projects have also been undertaken in several other European and Asian cities.

Upon approach, a urine separating toilet will generally bear a strong resemblance to a conventional flush toilet. The main functional difference is that instead of having one large bowl and a single drain, there are two separate bowls with two separate drains. The front bowl is designed to catch the urine portion. In this bowl there is generally a very small amount of water (.1 l/flush) that is used for flushing. There is a dedicated flushing mechanism that is distinct from the mechanism for flushing the back bowl, which is intended for fecal matter. The back bowl is very similar to a conventional toilet and is usually plumbed into an existing sewer system.

Urine diverting systems only capture urine, while allowing feces to enter the wastewater stream. This is an improvement over conventional systems from an environmental and economic standpoint because, as discussed previously, urine contains a much higher percentage of the available nutrients. Keeping the nutrients in urine from entering the wastewater stream reduces the load that conventional WWTPs must handle. From a water conservation standpoint, there is also a significant savings in water over a conventional system, as typical urine separating toilets use only one tenth of a liter per flush (.1 l/flush) of water to flush the urine bowl, as opposed to four to six liters per flush for a conventional toilet (codes for water use by conventional toilets vary by location and only apply to newly installed toilets) (Vinnerås & Jönsson, 2002). In some toilets no water is used for flushing urine.

There are several methods used for relaying the urine to storage or treatment facilities. The most obvious is to use gravity to simply transport pure urine to a storage tank. Some toilets also add a small amount of flush water to the urine portion to aid in flushing. This makes the toilet function better and helps to meet the objective of reduced water consumption. There are many proprietary designs on the market that employ various valves and mechanisms to assist in flushing, odor control and reduction of precipitation and flocculation of urine in pipes. The Aquatron® is one such example of the myriad devices appearing on the market. This product allows the use of a conventional flush toilet, but allows the feces and urine/water portions to be separated. In this case the urine and about 98% of the water are diverted into a separate holding tank via an apparatus that operates on gravity and centrifugal force. The water/urine portion may enter a standard leech field or be stored as irrigation water. The feces are diverted to another holding tank for treatment by composting or vermiculture.

Treatment Technologies

Although UD toilets are useful for capturing nutrients, in most cases they must still be connected to a system that allows for the collected material to be sanitized in some way prior to use. Urine from a healthy individual is theoretically free of pathogens. However, in many cases it is not prudent to assume sterility and measures should be taken to ensure the safety of urine to be applied for agricultural purposes. This is because source-separated urine may be contaminated by fecal matter at the toilet. It is also the case that *some* pathogens, such as *Salmonella typhi* and *S. paratyphi*, *Salmonella* strains associated with typhoid fever, and *Schistosoma haematobium*, may be passed through the urine of an unhealthy individual (Vinnerås, Nordin, Niwagaba, & Nyberg, 2008). Feces may contain any number of enteric pathogens and bacteria. Additionally, while excreta are generally very low in pollutants such as heavy metals (Jönsson et al., 1997), in many societies they may contain high levels of micropollutants. The following are some potential methods and technologies for ensuring that excreta may be used safely.

Storage

The most straight-forward method of sterilization for pure urine, and the only method to have been used on any scale outside of laboratory experiments (Maurer et al., 2006) is to simply store the urine for a period of time prior to use. Length of storage time, pH level and temperature "are the critical factors affecting the survival of different enteric organisms" (Chandran et al., 2009). For many of the pilot projects underway in Sweden, storage has been the chosen method of hygienization. It is generally recognized that urine stored at 20°C for six months may generally be considered safe to use for agricultural purposes (e.g. Drangert, 1998 and Maurer et al. 2006).

The risk of urine-oral transmission of such bacterial infections as mentioned above is significantly lower than the risk from fecal-oral transmission. This is because most bacteria in urine are inactivated even after a relatively short storage time (Chandran et al., 2009). Chandran et al. (2009) studied the survival of enteric organisms (*S. enterica, E. coli,* and *Ent. faecalis*) and the coliphage MS2. The study sought to determine the survival rates at temperatures relating to temperate (15°C) and tropical (30°C) climates. The authors found that all of the micro-organisms and the virus survived for less than one week in urine stored at 30°C, at a pH of around nine. Thus, in warm climates, relatively short storage times are necessary. At 15°C, a temperature deemed representative of temperate climates, the study found complete die-off after nine weeks.

Vinnerås et al. (2008) also found temperature to be important to the die-off of studied micro-organisms and viruses, but also examined control samples with varying temperatures, but no ammonia concentrations (and therefore low pH). The same study "confirmed that the temperature works synergistically with NH_3 when threshold concentrations are reached." The study found that above 34°C, and with ammonia concentration of 40 mM, all micro-organisms and viruses studied showed rapid mortality. However, below 20°C, the study reports that "there ought to be restrictions on the use of urine as a fertilizer for food crops." These studies indicate not only that temperature plays an important role in the time it take for urine to become sterile, but also that the pH of the urine also plays a role. According to this research finding, it can be assumed that in cooler climates it may be necessary to add supplemental heat to storage tanks and/or place storage tanks in relatively warm locations such as underground parking garages if it is desired to use the urine within a shorter timeframe than mentioned by Maurer et al (2006).

Storage of urine presents several potential limitations. First, with long storage times being required in many cases, large volumes of storage are required. While it is quite conceivable for an individual household to store sixth months' worth of urine on site, it would be much harder to imagine a storage tank to contain all of the urine produced in six months by the tenants of a high-rise apartment building in a large city. Hence, space considerations may be a limiting factor for storage as a method of sterilization.

From a nutrient recapture perspective, storage tanks also may suffer from excessive nitrogen loss due to ammonia evaporation if they are left to vent to the atmosphere (Maurer et al., 2006). This problem may be alleviated by making the stored urine more acidic. This can be accomplished by dosing the storage tank with a supplemental acid as described in the next section.

Acidification

As mentioned previously, the addition of a strong acid can help to reduce loss of nitrogen by ammonia evaporation from urine storage tanks. The reduction in nitrogen losses is attributed to a reduction in ammonia produced. Under normal circumstances, shortly after leaving the body, pH levels in stored urine rise as urea undergoes chemical decomposition by hydrolysis to eventually form ammonia gas, which, given a pathway to the atmosphere, easily evaporates. Hellström et al. (1999) found that a one-time dosing of 60 meq of sulphuric or acetic acid to experimental 10 l cans of urine was sufficient to substantially inhibit the decomposition of urea to ammonia.

Acidification may also serve to sterilize stored urine. At a low pH, many bacteria are rendered unviable. Additionally, high pH levels may have a positive impact on pharmaceuticals found in stored urine. Maurer et al. (2006) report that Butzen et al. (2005) found an inactivation level between 50-95% for various antibiotic and anti-inflammatory drugs.

Evaporation

The reduction of nitrogen losses to ammonia evaporation by techniques such as acidification may be most helpful due to their role in other volume reduction strategies. In some areas of the world, for example, around many major cities, the cost of transporting large volumes of relatively heavy liquid urine to outlying agricultural lands will preclude the use of urine directly in agriculture. There are several methods for concentrating the nutrients in separated liquid urine and thereby reducing the volume and weight of the finished product.

Evaporation of the liquid is one obvious method of volume reduction. Potential issues with evaporation are energy use, loss of ammonia (and thereby valuable nitrogen) due to evaporation (Maurer et al., 2006), and sterilization. Evaporation does not, by itself provide any sterilization. However, if heat is applied to speed evaporation, the storage time required to sterilize can be reduced. Energy consumption can be minimized by employing energy recovery systems and losses due to ammonia evaporation can be minimized by acidifying the urine (Maurer et al. 2006 and Hellström et al., 1999).

Although there are situations where evaporation may make sense (e.g. dry warm climates), it is likely not a feasible method for large-scale volume reduction of urine for nutrient reuse. This is due in part to the potential nitrogen losses associated with the practice. Also, the large surface areas required to allow efficient water loss may preclude this as being a sensible concentration method in many locations.

Freeze/thaw

The repeated freezing and thawing of collected urine is another potential means of volume reduction. Studies have shown a concentration of 80% of nutrients in about 25% of the original volume (Maurer et al 2006). This method could potentially be used in certain climates if systems could be devised to recycle the inevitable heat that is produced/consumed by this system. If virgin energy is used, the energy inputs to this system would likely render this process cost prohibitive.

Struvite production

Another method of volume reduction and means of capturing nutrients in urine, especially phosphorus, is to facilitate the formation of the precipitate magnesium ammonium phosphate ($MgNH_4PO_4·6H_2O$), also known as struvite, MAP, and AMP (Maurer et al. 2006). Precipitation of struvite requires a molecular ratio of $1(Mg^{2+}):1(NH_4^+):1(PO_4^{3-})$ (de-Bashan & Bashan, 2004). The precipitation generally requires the supplementation of Mg, "usually in the form of MgO, $Mg(OH)_2$, $MgCl_2$, or bittern (a magnesium-rich brine from table salt production)" (Maurer et al. 2006). Finished struvite is a dry, granulized product that is very similar in appearance to conventional fertilizer.

Struvite is a very promising means to produce an effective fertilizer product as well as a method for limiting the release of plant nutrients and other pollutants into the environment. Lind et al. (2000) added MgO to fresh and synthetic urine containing 0.5 g P/l at a Mg:P ratio of 1.71:2.21. The resulting struvite (and other minor mineral crystals) resulted in the concentration of considerable percentages of available micronutrients as well as 100% of available phosphorus.

Struvite offers several major advantages as a means of volume reduction/nutrient concentration, sterilization, purification, and fertilizer production. From a nutrient recycling perspective, struvite provides a means of capturing phosphorus in the form of a slow-release fertilizer that has considerable market potential (Maurer et al. 2006). Because ammonium generally exists in urine at higher ratios relative to phosphorus, phosphorus recovery rates can be quite high (Ganrot, Z. et al., 2007). Some nitrogen and potassium, along with myriad other plant micronutrients have also been shown to be absorbed into struvite crystals (Lind et al., 2000).

Struvite production may also have the major benefit of removing the majority of micro-pollutants from urine. Escher et al. (2006) find that struvite production, “due to the formation of very clean precipitates,” removes 97% (±2%) of pharmaceuticals, and 98% (±2%) of estrogens. Ronteltap et al. (2007) confirm this research, finding that around 98% of tested hormones and pharmaceuticals remained in solution after struvite precipitation. Thus, as the micro-pollutants become highly concentrated in a solution with a volume much reduced from the original. Presumably, as technology advances process could be made to continue to further remove the micro-pollutants from the remaining contaminated water so that they could be disposed of in a responsible manner. Regardless of whether the struvite is destined to be used in agriculture, a strong argument can be made for urine separation and subsequent struvite precipitation if for no other reason than to remove micro-pollutants from the wastewater stream.

The fate of pathogens in struvite precipitated from urine is also of vital concern if struvite is to be used in agriculture. Decrey et al. (2011) performed a comprehensive study of a human virus surrogate (phage ΦX174) and the eggs of helminth *Ascaris suum* to determine the effect of struvite precipitation on pathogens found in urine. The presence of the virus was reduced by 1000-fold. Inactivation was fastest at high temperatures (20 and 36 °C) and low relative humidity (35%). Struvite precipitation had the opposite effect of concentrating the *Ascaris* eggs to levels 100 times higher than the urine. Over the three day testing period, only drying at temperatures of 35-36 °C had any appreciable impact on egg inactivation. This study shows that a prudent and conservative approach to using struvite in agriculture would require some form of drying treatment after precipitation to limit the potential for pathogens to survive in struvite. Further study is needed to determine what level of pathogen survival can be considered safe and also the survival rates of those pathogens once they reach agricultural soils.

Zeolite adsorption

“Zeolites are natural crystalline aluminosilicates. They are among the most common minerals present in sedimentary rocks. Zeolites occur in rocks of diverse age, lithology and geologic setting…” (Ramesh et al., 2011). Zeolites have many uses for agricultural and environmental engineering purposes. Among the possible applications and benefits of zeolites are: promotion of crop growth due to enhanced nutrient use by plants, acting as carriers of fertilizers, insecticides, fungicides and herbicides, and to inactivate heavy metals in soils (Ramesh et al., 2011).

Research from Lind et al. (2000) indicates that zeolites may also be used as a means to capture ammoniacal nitrogen from urine. The zeolites Clinoptilolite, wollastonite and a mixed zeolite were added at a rate of 0.5 g/25 ml of synthetic urine and NH_4Cl solution. Variables included grain size of adsorbent, type of adsorbent, concentration of NH_4Cl and urine, and contact time of adsorbent to solution. The results indicate that 50-80% of available nitrogen adsorption is possible using these methods. Clinoptilolite, the NH_4 specific zeolite, showed the best results.

In addition to the separate study of zeolite adsorption of nitrogen from urine, Lind et al. (2000) also investigated the combined effect of struvite formation and zeolite adsorption. Zeolite varieties were added to urine samples at the same time as MgO and also to the supernatant resulting from struvite precipitation. The data generally show very positive results with respect to nutrient recovery. The highest rate of nitrogen fixation in struvite and adsorption (80% of available N) occurred when Clinoptilolite was added at the same time as MgO.

Composting

In systems that do collect feces, fecal material must be treated with additional caution, as it is much more likely to contain significant levels of enteric pathogens than is urine. Depending on the region and relative health of the population producing the feces, these can include bacteria such as E. Coli, viruses, protozoa, and helminth eggs. Composted feces should generally be considered safe to use as a fertilizer source once it has maintained a temperature of 55-60°C for several days (Heinonen-Tanski & van Wijk-Sijbesma, 2005). This composting may take place at centralized composting facilities or within toilets that are designed for such a purpose. The World Health Organization suggests pasteurization at 70°C for one hour (Winker et al., 2009). In all cases where human excreta are to be used as a source of fertilizer, the product should be tested in region-specific manners prior to use to ensure that it is free of pathogens that may otherwise be introduced into the food supply.

Ecological sanitation

Ecological sanitation, or EcoSan, is a term that has been used to describe integrated sanitation systems that not only treat human excreta, but also allow for the reuse of nutrients. Harada et al. (2006) detail one example of an ecological sanitation system that is commonly employed in rural and peri-urban regions of Japan, a country with a strong history of collecting and recycling human excreta into agriculture as "night soil". According to the authors, about 30% of the population in rural and peri-urban areas uses systems similar to the one described.

In this situation, urine separating dry toilets are used in households, where the diverted liquid and solid portions are collected and stored. Holding tanks are periodically pumped by vacuum tanker trucks. The collected solids are mixed with other sources of organic waste and (potentially) livestock excreta. This mixture then enters fermentation chambers, often referred to as biodigesters. The fermentation treatment can be split into thermophilic digestion (50-55°C) and mesophilic digestion (35-40°C). These processes break down the organic material in an anaerobic environment and produce methane (natural gas), which can be used to fuel the vacuum trucks and for providing heat for the digestion process. The thermophilic digestion process alone, which typically is 16+ days, may be enough to disinfect pathogens, although the authors assert that performance testing should be carried out for varying systems. Fermented sludge can also be either composted, as referred to previously, to ensure its safe use as an agricultural input, or be incinerated.

The separation of urine has several distinct benefits. From the context of methane production, the separation of urine is vital. Urine contains high amounts of urea, which quickly converts to ammonia once outside the body. Because methane fermentation is inhibited by such high concentrations of ammonia (14,000-35,000 mg/l of urine), the separation of urine is a necessary step in the process.

Agricultural Reuse Technology

Many studies have shown that human urine can be used directly on fields as a quality fertilizer (e.g. Heinonen-Tanski et al., 2007). As urine is a liquid, it is already in a form that existing agricultural equipment is capable of handling. Direct use of urine conveniently can be done using existing agricultural implements. However, as with all fertilizer applications, especially if environmental considerations are to be made, it is important to apply urine in a matter that ensures that the plant nutrients will be delivered to the soil in a way that minimizes nutrient loss and encourages plant uptake.

Consequently, urine should be applied in a manner that reduces the evaporation of ammonia, such as injecting it into a covered furrow 1-4 cm deep, spreading during the evening, and just before rains (Heinonen-Tanski & van Wijk-Sijbesma, 2005). Ideal rates of application depend primarily on the crop being fertilized, the region, and the locale-specific nitrogen content of the urine supply (Heinonen-Tanski & van Wijk-

Sijbesma, 2005). Application of urine also should be timed so that the nutrients are available at the time that crops are most able to absorb them (i.e. only during the growing season). Products such as struvite and zeolite fertilizers will need to be applied in a manner that takes into account their specific nutrient release characteristics. For instance, Ganrot et al. (2007) show that timing of application of struvite and zeolite fertilizers may have an impact on the growth rate of plants due to the slow release nature of these fertilizers.

These dry fertilizer products produced from urine such as struvite and zeolites may benefit from the fact that they are similar in appearance and application procedure to many of the pelletized fertilizer products that are already common within agriculture. On the other hand, spreading raw liquid urine is also a rather simple task that can easily be accomplished using readily-available farming implements. However, while the ease of application and ability to fertilize crops is similar for these two fertilizer products, their rates of adoption may be expected to differ. While the functional ability of the above referenced technologies' abilities to perform their intended purposes are vitally important to their being implemented, the willingness of the public to purchase and use the technologies depend on much more than the products' abilities to perform. The perceptions and cultural mores around reuse technology will be discussed in the following chapter.

Section 4- History of Nutrient Reuse: Shifting Perception

Angyal (1941) notes that when people are asked what they find disgusting, there is near-universal agreement among respondents that excreta is the most disgusting subject they can think of. This author further notes that the progression of disgusting experiences exists. Being in the presence of excreta is a somewhat disgusting experience according to those surveyed. The more intimate experiences of having excreta on ones clothes and getting it on one's skin are progressively more disgusting experiences. Having excreta in one's mouth and then even ingesting them are cited as the most disgusting possible experiences that were cited. This pattern has been replicated in more recent clinical studies (e.g. Simpson et al., 2007). Given the results of these studies it would be expected that some people respond with disgust at the idea of using excreta to produce food.

However, this certainly has not been the case throughout much of human history. In fact, methods of using human excreta as resources have a well-documented precedent. In many parts of Asia, especially China, Korea and Japan, human excreta, known as "night soil," have been applied to agricultural fields for thousands of years and continue to be applied to this day (although as western mentalities encroach on the traditional, the practice is declining somewhat). The practice of using human excreta to grow food crops also has deep historical precedence in Europe. It was common practice until the middle of the twentieth century (Heinonen-Tanski & van Wijk-Sijbesma, 2005). In fact "water toilets were not first accepted in some Nordic towns in about 1900, the main argument against them being that agriculture would lose its resource for fertilization" (Heinonen-Tanski & van Wijk-Sijbesma, 2005).

In addition to agricultural activities, urine has been used for many other purposes. For instance urine was used to launder clothing by the Romans and the Celts, and in medical practices in India (Bracken et al., 2007). The use of urine in agriculture and other sectors of the economy actually led many individuals to the lucrative business of actively seeking out sources of excreta by engaging in such ventures as managing public toilets and contracting with households to collect the valuable resource (Bracken et al., 2007).

Despite the obvious acceptance of human excreta as a resource in humanity's relatively recent past, attitudes shifted over the previous two centuries in many parts of the world. Fewer and fewer societies actively recognize human excreta as a useful resource and modern water-based sanitation systems preclude the recovery and reuse of the material. The currently pervasive belief, especially in western cultures, is that human excreta are disgusting "wastes" that must be disposed of. Drangert (1998) describes this shift in attitudes as "urine blindness." The term is defined as a general consideration of urine (specifically) not as a resource, but rather as a smelly mixture with feces. Jenkins (2005) regards "fecophobia", an "irrational fear" of human excreta perpetuated by sanitation experts as the cause of the trend away from the recovery and use of human excreta.

Bracken et al. (2007) outline four reasons to more fully explain the shift away from systems that allow the capture and reuse of human excreta. The first explanation is that the systems required for collecting and reusing human excreta presented insurmountable logistical and public health challenges in many cities as populations exploded and the volume of material to be dealt with dramatically increased during the last century and a half. Second, the widespread misunderstandings regarding the mechanisms for the spread of disease contributed to the notion that human excreta should be disposed of in the waste stream. The *miasma* was one such notion that falsely proposed that illness was caused by the inhalation of volatile substances. Because bad odors were considered to be the cause of illness, it followed that bad-smelling things were to be gotten rid of. Increasing prevalence of piped domestic water during the nineteenth century is the third reason cited for the shift away from nutrient collection simply because it allowed for a sewer system based on flushing toilets to become possible. Bracken et al. (2007) cite the resulting dilution of the nutrients caused by water-based sanitation systems as the final factor that made the capture and reuse of human excreta-derived nutrients nearly impossible. The arrival on the market of cheap synthetic fertilizers during the twentieth century rendered "efforts to recover and reuse the nutrients and organic material from the large volumes of sewage completely obsolete" (Bracken et al, 2007).

The research referred to above indicates that there are major psychological hurdles that must be overcome if urine separating technology is going to become socially feasible, especially in industrialized countries. The broad trend over the last century has been toward a throughput pipeline in the agricultural and sanitation sectors. Plant nutrients have been seen as one-time-use resources that are to be used just one time and then discarded after they are consumed by humans and enter the wastewater stream. At that point, they in fact become a pollutant that the wastewater sector must clean up and remove before the water can be returned to the environment. This mentality has spread not only to the professionals who make decisions regarding the structure of the system, but it has also become commonly accepted by the general population to the point that it is not even thought about. The ability to just “flush and forget” has allowed societies to do just that.

Several studies have been carried out to consider what factors are important in shaping attitudes regarding the collection and potential reuse of human excreta. The studies provide insights regarding public perception of UD technology. Given the dominance of the existing paradigm, these studies find surprisingly high acceptance of UD technology and also of the idea of recycling nutrients from human excreta to agriculture. However, they also show that many people have reservations about of safety, convenience, and other issues.

Leinert and Larsen (2009) compiled and sorted a literature review of 75 publications regarding 38 pilot projects and studies on the acceptance of urine separating technology in seven European countries. Eighteen of the studies were from private homes, 15 came from “institutions and exhibitions”, and five surveys considered farmers’ opinions of UD technology and the use of human excreta as a source of fertilizer. Survey categories included topics such as general acceptance of the concept of ecological sanitation and UD technology, perception of the technology, and acceptance of fertilizer from human excreta. Some of the data from these studies pertaining to the acceptance among different groups of people of both the technology and the idea of nutrient reuse are outlined below.

Perceptions Regarding Reuse Technology

In contrast to conventional sanitation systems in which individuals are able "to adopt an out of sight, out of mind attitude" (Burkhard et al., 2000), the relatively decentralized technologies that are necessarily involved in urine separating systems require some level of involvement from end-users. Hence, inquiry was made about users' experiences with urine separating technology. Overall acceptance of the *idea* of UD technology was quite high at 84% (±13%). When asked about using UD toilets at their workplace or in public buildings, 79% (±4%) responded favorably. There was an equally high acceptance (79% (±13%)) of using a urine separating toilet at home.

Likewise, the overall perception of the technology was positive. The design was approved of by 79% (±11%). Eighty five percent (±9%) were satisfied with the hygiene of UD toilets. The comfort of the toilets was also rated quite high, with 85% (±11) approving. There are some areas where improvements can be made regarding the design of urine separating toilets. "Cleaning was judged more laborious, with only 52% (±17%) finding it equaled conventional toilets" (Leinert & Larsen, 2009). Respondents in many studies reported blockages (due to precipitate crystals) in urine drains. Many users also found issues with flushing toilet paper. The small amount of water used for the urine bowl is often not enough to flush toilet paper. The studies found that users found that using the large flush on the back bowl was a solution to this problem. However, this completely negates the desired water-saving effect of the technology (Leinert & Larsen, 2009). This concern will either require a redesign of the toilet, or perhaps a change of behavior on the part of the user, such as disposing of toilet paper used after urinating in a trash can or in the feces bowl without flushing. The study found that 49% (±20%) of users would be willing to take such actions. Other issues noted regarding the design and function of the toilets were that both sexes must sit to urinate and the smell associated with the toilets.

Perceptions Regarding Nutrient Reuse

Certainly acceptance of the technology itself is an important aspect if urine separation is to be implemented. If nutrient reuse is also a desired outcome, society will also need to accept food grown from nutrients derived from urine. Research into this subject also yields somewhat promising, and perhaps, surprising results.

When asked about their opinion of using human excreta to grow food, the public opinion was found to be quite high, with 85% (±13%) finding it to be a “very good idea” (Leinert & Larsen, 2009). A study conducted in Switzerland by Pahl-Wostl, Schönborn, Willi, Muncke, and Larsen (2003) echoes this finding, with 80% stating that they would prefer vegetables grown with a urine fertilizer over those grown with artificial fertilizer. However, a strong concern about pharmaceuticals and hormones entering the food supply was also voiced. Pahl-Wostl et al. (2003) found that “citizens requested absolute certainty that potential threats to human health could be excluded for using urine-based fertilizer.”

Farmers were more skeptical of urine-based fertilizers than the general public. Although “50% (of farmers) regard urine fertilizer as a good idea…only 34% would use or purchase it” (Leinert & Larsen, 2009). Lack of a need for a new source of fertilizer, ecological concerns (e.g. heavy metal and micro-pollutant contamination), fears of liability, smells and concerns about consumer acceptance were among the reasons provided for their skepticism.

Obviously, these studies reveal only the acceptance and perceptions of a European sample of the world population. As such, the results are likely not representative of the global population. Some cultures will be more inclined to accept urine separation and nutrient reuse than others. However, this research does indicate that, at least in some cultures, there is considerable tolerance of the idea for nutrient reuse from urine, despite the general aversion to the excreta from which the nutrients are derived.

It is also of interest that the idea of nutrient reuse is gaining traction in the wastewater sector. As Mitchell (2011) notes “this year’s International Water Association Leading Edge Technology conference, held as part of Singapore International Water Week that attracted up to 10,000 delegates from across the globe, opened with a workshop explicitly focused on carbon and nutrient recovery.” Further evidence of a shifting paradigm in wastewater management is seen when wastewater industry groups such as the Water Services Association of Australia makes statements such as “Given the need to maximize the efficient use of recycled water, it is highly likely that the days of extending sewage collection systems over ever- increasing distances to be connected to coastal sewage treatment plants are coming to an end” (Water Services Association of Australia, 2009). Further interest in more fully integrating systems is obvious in the pursuit of urine separating systems already noted in European countries (e.g. Germany, Sweden, Switzerland and Denmark). Hence, it seems that the concept of nutrient reuse from human excreta faces no inherent problem with attitudinal feasibility. However, there are major psychological and technological hurdles that will have to be overcome before the broader society will accept the practice of nutrient capture from excreta.

Section 5- System Comparison and Analysis

There are many ways that a technology can be judged. Ultimately, the technology must effectively perform the task that it is designed to perform. Additionally, though, the technology can be judged based on its ability to perform a beneficial task compared to the negative consequences that stem from its use. Thus far, a description of the pertinent attributes of conventional and UD sanitation systems has been provided so that a comparison can be drawn between the two technologies and a determination made about whether the less common technology (UD systems) can feasibly replace ubiquitous conventional sewer-based systems.

Both systems have been shown to adequately and effectively provide for their primary intended use: to limit human contact with excreta and to handle excreta in a sanitary manner to prevent potential health impacts. However, when directly compared to conventional systems, there are many reasons that make UD technology a very attractive alternative technology. Some of the metrics that have been brought up previously will be considered in this section for the purpose of drawing a direct comparison. Also considered are some of the barriers that remain with regard to the implementation of UD technology.

Urine diverting technology vs. conventional sanitation systems

As noted in section two, there are multiple significant challenges facing the existing modes of handling human excreta. While there are ways that the existing system can be repaired, many of the issues stem from the inherent essential design and logic of the systems. Given the changing world, a growing body of knowledge indicates the possibility that a more sensible investment will be in the employment of new technologies that more directly meet the emerging needs of coming centuries.

Urine diverting systems, and other less-centralized alternative systems, show much promise for being used to mitigate the noted problems of high net energy use, extensive water consumption, high costs of operation and maintenance, and excessive environmental pollution. In addition to the ability to reduce the demand for some resources, these systems also offer a means of recapturing and reusing other valuable resources.

Energy Use

Urine diverting technology offers the potential to reduce energy consumption because a potential for resource conservation exists both from reduced inputs for sanitation and also by providing a nutrient resource. For instance, in a study carried out by Magid et al. (2006), the potential energy savings of several urine separating systems were compared to a reference conventional sewage treatment system in the medium-sized town of Hillerød, Denmark. All energy inputs/outputs in the model were normalized to kWh equivalents. For each of the 12 systems analyzed, the study used a simple equation that concludes that for either a conventional or alternative system:

$$\text{Energy consumption} = (\text{Fertilizer savings} + \text{Water savings}) - (\text{Transport energy})$$

In the case of the reference (existing) system, per capita annual energy consumption for treating household wastewater was figured to be 7.3 kWh. It should be noted that it is entirely clear in the study that the accounting of energy cost for the reference system actually includes the energy required to grow the food that ultimately produced the nutrients being handled by the system. If that energy use was not included, the actual energy use of the system should be somewhat higher. Additionally, the transport cost seems to be assumed at zero. A true lifecycle cost of using drinking water for flush water could arguably also include some cost for initial treatment of the water. However, the authors note that conservative assumptions and estimates were made with regard to the costs of the conventional system so as not to overly inflate the indicated potential savings from the experimental systems.

With the exception of an experimental system that relies only on wet composting of combined excreta and household organic matter (with mechanical aeration systems) all of the experimental systems had at least better energy consumption characteristics than the conventional reference system. In most cases the experimental systems actually produced more energy than they consumed. For instance, in a system that separates urine and feces from greywater, combines the excreta with other household organic material prior to treatment at a biogas plant, and then re-circulates the nutrients into agriculture, a net energy *production* of 118 kWh/person/year was estimated. For a system that consists of only urine collection and reuse, a more modest energy savings of around 20 kWh/person/year was demonstrated, with the savings resulting from not only the reductions in energy used for treatment, but also from energy savings from reduced synthetic fertilizer use. Although this study was necessarily based on some predictions and assumptions, it suggests that such systems warrant investigations for future, larger-scale, cost effective implementation.

This study, though, is also illustrative of the difficulty in developing a generalized comparison of UD systems and conventional systems. For instance, as mentioned above, it matters greatly if methane gas production is included in the overall system energy balance. Also, the distance that recovered nutrients are transported will have a large impact on energy use. If methods of nutrient concentration such as struvite production are employed, the energy cost to transport goes down dramatically due to the smaller volume and lighter weight of the product. However, in cases where direct comparisons have been done (see also e.g. Wilsenach et al., 2006 or Tidåker et al., 2005) it appears hopeful that UD technologies can compete as more energy efficient alternatives to conventional systems. Given the newness of the technology, the systems also have much room for improvements, leaving room for increased efficiency gains.

Water consumption

Fresh water is another resource that is heavily relied upon by sewer-based sanitation systems. While there are ways to reduce the rate at which fresh water is cycled through the system, such as low-flow toilets, and using rainwater as the flushing medium, it is impossible to even come close to eliminating the use of fresh water because of the inherent design of sewered systems. UD toilets, by comparison, represent a technology that could potentially virtually eliminate the use of fresh water in sanitation systems.

It is true that UD systems that capture only the urine portion will only conserve the portion of water that would have been used for flushing urine. Considering the fact that most individuals use the toilet for urinating around three to five times as often for urinating as they do for defecating, there are significant savings to be made by simply conserving this portion of the flush water, even if system design involves flushing solids into a conventional sewer-based system. There are potential technological barriers for UD technologies, though. Some of these barriers relate to the technologies themselves, while others have more to do with the way that human operators use the technology.

With any evolving technology, it can be expected that earlier versions will exhibit more operational problems than later ones. Generally speaking, the technical problems most commonly reported in relation to UD technology concern the ability to flush and odor/appearance issues. Many of these problems are related to floc accumulation in plumbing lines that results from the precipitation of the myriad minerals that are present in urine. As these precipitates form in the plumbing, they can cause the improper flushing and also potentially bad odors. Some models of toilets that use a small amount of water to flush, likely because manufacturers aim to limit water consumption, have also been reported to flush poorly. This may especially be true for women due the fact that they are accustomed to flushing tissue after urinating. A common solution employed by users and noted by researchers has been to flush twice. This practice dramatically reduces the potential water savings of the toilet. Fortunately, as the technology develops, many of these issues are likely to be engineered out of existence. Additionally, many of these problems can be avoided in the first place by encouraging different behaviors on the part of users.

Pollution

As discussed in section two, pollution of ground, surface, and marine waters downstream of conventional treatment plants is a major problem. Significant threats to human health and negative economic impacts are the result of conventional systems' designs and limitations. Urine separation presents a major opportunity to limit the negative consequences to human and environmental health, two factors that, many would argue, are inextricably linked.

Urine separating toilets remove the vast majority of primary plant nutrients from the wastewater stream. Once the nutrients are removed, they may be more easily treated, concentrated and recycled into agriculture, thereby reducing pressure on other natural resources and ecosystems. But, even if the nutrients are not to be reused, simply by separating them from the waste stream, a major pressure is removed from the conventional treatment system. Although there are still costs associated with the handling of separated urine, the dramatically reduced and concentrated volume is easier to handle and could potentially represent a significant economic benefit by reducing the work load of WWTPs (Wilsenach et al., 2006 and Berndtsson, 2006).

The economic benefit of reducing pollution by plant nutrients in aquatic environments and groundwater aquifers could be quite substantial. Improved functioning of fisheries, improved biodiversity, increased recreation opportunities, improved drinking water quality, and reduced human health impacts are but a few of the benefits that could be claimed by reducing the levels of anthropogenic plant nutrients that are introduced to the environment.

In addition to an often incomplete removal of plant nutrients, as mentioned previously, conventional treatment systems have no means by which to deal with the recently recognized issue of micro pollutants. The direct, and possibly synergistic, effects of hormones and pharmaceutical residues found in wastewater are not completely understood. However, as mentioned in previous sections, the data collected thus far indicate that there are substantial negative environmental, human health, and economic impacts that are resulting from water pollution by micro pollutants. By removing urine, and the micro-pollutants it contains, from the conventional wastewater stream, it becomes much easier to remove or deactivate the micro-pollutants (e.g. Maurer et al., 2006 and Escher et al., 2006). In particular, removing micro pollutants from "hot spots" such as hospitals would be beneficial (Larsen et al. 2010).

As mentioned in the previous section, options are available that offer promising means of separating the micro pollutant residue from urine and the nutrients that it contains. Such locations as hospitals and nursing homes represent locations that potentially offer many strategic opportunities to take advantage of the additional benefits of UD technologies. In these locations, where heavy investment in infrastructure is already available and where there is an exceptionally high level of micro pollutant production, even if nutrient reuse is not the desired end result, simply removing the micro pollutants from separated urine prior to their release into the environment would represent a major improvement over the status quo. And this advantage could seemingly be attained at a reasonable price when all potential costs are factored in to the equation.

Cost of Operation and Maintenance

The reasons listed above provide significant reasons why societies might consider a shift toward alternative sanitation systems. Future replacement of existing sanitation systems and the provision of sanitation in areas currently lacking it are other considerations. As discussed in section two, sanitation systems in much of the industrialized world (specifically in the United States) are aging and in need of major repairs, renovations or replacement. Given the significant potential advantages of alternative sanitation systems, investment in the improvement of these technologies could present a more forward-thinking investment than simply rebuilding the conventional systems that are already in existence. Also, considering the substantial costs of operation and maintenance of conventional systems and the potential savings that accrue to society from the reduction in use of natural resources by UD systems, it is likely that UD systems can at least be cost competitive with conventional systems.

In fact, a simple search of the internet indicates that a sewer-connected UD toilet is available for approximately $700 (http://www.ecovita.net/ekologen.html). It is certainly possible to obtain a simple, moderately water efficient toilet for about a third of that price. However, when compared to the myriad options for the more stylish and water conservative commodes, the price is actually very near the conventional competition. In fact, a search of a common "big-box" building supply store's website (http://www.homedepot.com) indicates that the cost of the UD toilet is actually cheaper than many of the fancier conventional toilets. While there are also minor additional costs associated with UD systems (storage tanks, separate urine drain lines), if UD toilets were to become more commonplace, the advantages associated with mass production would be expected to make the toilets/systems even more cost competitive.

In areas of the world that do not rely on already-constructed sewer systems, such as rural regions of Europe and North America, and also many parts of Africa and Asia, UD systems represent a viable method to provide cost effective and ecologically sound sanitation (e.g. Meinzinger et al., 2008 and Vinnerås & Jönsson, 2002). Likewise, in locales where pharmaceutical use is low and there is no existing wastewater infrastructure, separation and direct use may be feasible. The development of sanitation systems to allow for the protection of human health all across the world is certainly a desirable objective. However, on a planet with an ever-growing number of mouths to feed and a finite amount of natural resources, many consider it foolhardy to continue to construct sanitation systems based on an outmoded paradigm. Along those lines, even within societies where centralized sewer-based sanitation systems are available, there are still countless opportunities to for choices to be made to begin moving away from the dominant paradigm and toward alternative systems.

Fertilizer resource reuse

Perhaps the most important aspect of UD technology is the capacity it provides to convert a waste stream into a resource stream. All of the other relative benefits between UD and conventional systems that have been listed stem at some level from this characteristic. Conservative estimates indicate that, for example, fertilizer products from UD toilets could meet at least 10-20% and 20-30% of the demand for mineral fertilizers in Germany and Sweden, respectively. In sub-Saharan Africa, the quantity of nutrients available from human excreta exceeds the local demand for mineral fertilizer, (Winke et al., 2009). As noted previously, urine can be used as fertilizer directly or can be processed into fertilizer products.

Human urine has potential value as a fertilizer. However, there are difficulties in quantifying the exact value of human urine versus conventional fertilizer. An example of this can be seen in Berndtsson (2006). In this study, a urine/water mixture was collected from a UD system in an apartment building on the campus of Lund University in Sweden. The urine was collected and hauled to a local farm for use as fertilizer. The nitrogen content of the collected urine was measured for a year. The researchers estimated that an average of 125 people stayed in the dormitory for about 15 hours per day. The measured nitrogen and phosphorus collected was 150 kg/yr and 11 kg/yr, respectively. It was thus assumed that this is the amount of fertilizer nutrients that could be displaced based on the given parameters.

The basic comparison described above is often as far as many comparisons can be taken. But, this comparison doesn't tell the whole story of the relative value. As pointed out by Berndtsson (2006), factors such as heavy metal pollution are not easily quantified. As noted in section two, in the case of conventional fertilizers, heavy metal pollution is a growing concern as sources of rock phosphate are depleted. Heavy metal contamination certainly has a negative financial impact on agricultural fields. As human urine is effectively free of heavy metals, there is an economic benefit to be gained by changing the source of the nutrients for use as fertilizer. However, internalizing the value of reduced heavy metal contamination is an example of the difficulty of comparing not only the value of the quantity of product available, but also the value of the *quality* differences between conventional fertilizers and urine-based fertilizers.

Relating to the issues of both quantity and quality of urine-based fertilizers are growing concerns over the future provision of phosphorus to agricultural systems. The efficient use of phosphorus will be one of the most pressing challenges of this century (Cordell et al. 2011). Phosphorus, being an essential element to all life, is a key ingredient in conventional fertilizers. The worldwide production and consumption of rock phosphate amounts to approximately 20 million metric tons annually (Cordell et al, 2011). At this rate of consumption, this non-renewable source will become more increasingly scarce and prices will increase as world markets grapple with "peak phosphorus" at some point around the middle of this century (Cordell et al, 2011). Increasing costs of phosphorus will have a direct impact on the ability to provide adequate food for growing world populations and to do so at a reasonable price. As noted previously, urine accounts for approximately 50% of the urine in the wastewater stream (Langergraber & Muellegger, 2005). Therefore, the ability of UD technology to recycle phosphorus through agricultural systems is a very significant advantage over conventional systems.

The recognition that wastewater and excreta contain a set of resources (energy, water, nutrients) that need to be captured and reused, rather than treated as a waste stream, is not limited only to isolated scientists in laboratories. The promising benefits of UD technology are beginning to be acknowledged by entities such as wastewater trade groups. For instance "this year’s International Water Association Leading Edge Technology conference, held as part of Singapore International Water Week that attracted up to 10,000 delegates from across the globe, opened with a workshop explicitly focused on carbon and nutrient recovery" (Mitchell et al., 2011). Hence, it is becoming more widely accepted that urine diverting technology is a viable technology.

The comparisons between UD as an alternative to conventional systems show that there are indeed potential gains to be made should societies choose to employ UD technology. However, the implementation of technologies does not depend exclusively on whether or not they can fulfill their intended roles. The decision has to be made to employ technologies, and that decision often depends on how society and individuals perceive of a given technology.

How to Change Perceptions

The importance of the inter-relatedness of technology and perception cannot be overstated. As has been described, the technology of UD systems is relatively simple, and the engineering challenges that exist can likely be overcome. However, altering societies' perceptions and user behaviors will likely be the most difficult aspect in spreading the use of UD technology.

The four explanations provided by Bracken et al. (2007) and those from Jenkins (2005) and Drangert (1998), indicate that the trend away from the reuse of human excreta has been caused in part by fear or other attitudinal barriers, and also to a large degree by shifts in technology. As has been described previously, there are developing technologies that could likely be implemented on larger scales than they currently are, especially in parts of the world where water-based sanitation systems have not been fully embedded as the dominant technology. However, these technologies cannot and will not be put into practice if societal attitudes do not allow for them.

Harms from existing systems must be known

Part of the reason why alternative sanitation options have not become common is that it is widely accepted that the existing system does an adequate job at providing sanitation services. Pahl-Wostl et al. (2003), in a focus group-based survey, noted high public confidence in the current sanitation system. In many regards the public is correct in placing its trust in conventional systems. However, as has been widely noted in this paper and elsewhere, there are major challenges that face the conventional sanitation system with regards to environmental protection and the protection of human health. Pahl-Wostl et al. (2003) also found that much of the public perception was based on very little specific knowledge and that, furthermore, “the average citizen is not interested in a technology that is invisible and outside the realm of decisions made in daily life”.

In order for the technology to enter the realm of decisions made in daily life, individuals and public policy makers must witness the implications of the decisions that are made each day. For instance, in the case of communities along waterways, large-scale fish kills caused by algal blooms fueled by an over-abundance of plant nutrients from the local WWTP may start local conversations that may encourage the reconsideration of piping wastewater into the waterway. Or, as communities face challenges of meeting their needs for freshwater, the efficacy of conventional sewer systems may come into question when the need to flush excreta away is compared to the need for fresh water to drink.

With regards to the issues of nutrient reuse, the linkage between choice of technology and end result is not as readily apparent, and so may be a more challenging point to be recognized. It is easy for the public to quickly grasp the concept that more toilets flushing leads to more water use and, in turn, if there are fewer toilets flushing (and more UD toilets) that water conservation could be achieved. However, the fact that plant nutrients are added to crops via synthetic fertilizer using substantial quantities of natural resources, food is eaten, excreta produced, toilets are flushed, myriad environmental problems are caused, and that nutrients are piped out of the system has more steps and is more difficult for people to grasp. It seems likely that market forces will most likely be required to encourage adoption of UD technology for the purpose of nutrient recapture. As prices for fertilizer inputs become more and more costly, it will become necessary to adapt to meet the needs of food production. Given the need to provide plant nutrients to grow food, means to obtain nutrients (e.g. UD toilets) will likely become more widely used.

Reuse must be safe

There are many good reasons why human societies have largely established varying levels of taboo around excreta. There are, after all, illnesses that are easily transmitted between individuals via vectors related to sanitation systems (or lack thereof). Laboratory and small-scale tests have indicated much promise for the potential to develop technologies that would allow for the safe treatment of separated urine and also for its reuse. However, in order for these technologies to be accepted, a fear of reusing resources linked so intimately to human excreta must be overcome.

An interesting parallel can be seen in relatively new technology of direct purification and reuse of sewage as drinking water. An example of this technology can be found in Orange County, California, a city in a region that is already experiencing a shortage of freshwater. This water treatment plant directly recycles water from raw sewage through a series of specialized processes. The finished result is purified water that is safe for human consumption directly from the outflow of the plant. However, although the Orange County, CA water treatment plant is technically capable of producing clean drinking water, the public psyche demands that it be pumped to a holding reservoir before being dispersed to the drinking water system (Royte, 2008).

Hence, technology can provide a means of changing perception, if the technology can delink the connection between a concern and an end result. For example, in the case of using human excreta to grow food, it is unlikely in many societies that direct use of urine will be tolerated even though the practice can be made potentially just as safe as many currently allowed practices. This is because the primary fear in this case is of “contaminating” food with excreta. On the other hand, a product like struvite would have a much higher probability of being accepted. The dry, solid nature of struvite may present an advantage over other means of reusing excreta. As Angyal (1941) notes, touching a dry, solid material is much less likely to be offensive than touching a wet, sticky material. The latter material would be more likely to stick to the skin and cause one to be “soiled”. Struvite, because it is a dry pelletized product, would be less offensive than a wet product that is more reminiscent of raw human excreta. In a way similar to the lake water being more acceptable than directly recycled water in Orange County, nutrients in struvite are isolated by a technical process that would likely make the finished product more acceptable to the public.

Technology must be user friendly

As noted previously, even when a technology operates properly when manufacturer's directions are followed, malfunctioning is a possibility when used improperly by an untrained or careless operator. Hence, the improper use of technology can cause as many problems as faulty technology. In many cases the perception of the user of the technology will dictate to what extent the technology is properly used.

Lienert and Larsen (2009) state that "…to be fully accepted, No-Mix (urine diverting) toilets must reach the high standards of conventional bathroom installations…" In order to determine the extent to which UD toilets have been able to meet this challenge, the authors compiled data from 75 publications regarding 38 pilot projects in seven European countries to determine users' perspectives of a range of aspects of UD technology. This literature review reveals many interesting trends. With regard to users' opinions of UD toilets themselves, many of the respondents found the toilets overall satisfactory with, for example, 79% (±11%) responding positively about the design. However, when asked more specific questions, concerns tended to arise. For instance, only 56% (±22%) found that the flushing equaled that of a conventional toilet. Also, only 52% (±17%) found that cleaning UD toilets was as easy as cleaning a conventional toilet. These survey results indicate that, at least in societies where conventional sanitation systems exist, UD technology has much room for improvement to gain a fuller acceptance among users. Acceptance and understanding of UD technology will have a major impact on how well the technology meets its objectives (nutrient reuse, reduced water consumption, etc.).

Many studies (e.g. Lienert and Larsen (2009) and Berndtsson (2006)) have indicated that even when users are generally in favor of the technology (urine separation and reuse in agriculture), they often have incomplete understanding of the details of the system. For instance among the findings form a survey of UD toilet users in a Swedish dormitory carried out by Berndtsson (2006) found that while 74% of respondents felt they knew why the specialized toilets were in use, only 43% felt they knew what happened to the collected urine. The general response to the concept of the system was very favorable with 77% responding that capturing urine for reuse was a good idea. However, nearly half of the female respondents said that they always used the big (feces) flush after urinating. The authors note that a lack of education regarding a novel technology, combined with a disinterest in the general topic of sanitation, led users to improperly use the toilets in a large number of cases. Lack of knowledge and understanding was also a major factor in poor functioning of the system in this case (only about half of the theoretically expected amounts of plant nutrients were collected).

The studies cited above indicate that UD technology must not only “work”, but it must also meet users’ expectations and be simple enough to use that users understand how to appropriately use the technology. In order to move towards these goals, cultural norms must be understood and catered to wherever possible. For example, in many western industrialized countries, it is not customary for men to sit while urinating. However, many early designs of UD technology virtually required men to sit in order to direct the stream of urine into the smaller front bowl. As a result, it is easy to predict that many men would simply urinate into the larger feces bowl from a standing position and thereby use an unnecessary volume of water to flush and flush the urine into the sewer.

This sort of conservation defeating behavior will be even more common if users do not understand how the system operates. This is illustrated in the example of women who acknowledge using the large flush to flush urine. This problem is likely to be reduced as the technology becomes more common and users become more accustomed to using it. It is likely that public ad campaigns, for instance in toilet stalls where UD toilets may be installed in public buildings, would be very helpful to encourage the dissemination of technical knowledge within society. Additionally, ensuring that the proper technology is deployed (e.g. installing UD urinals in men's restrooms in addition to standard toilets) will also help to ensure that the public utilizes the technology in as near to optimum a manner as possible.

Existing Technology is Embedded and Obdurate

Despite very compelling arguments to be made for new technologies, often it is very difficult for new technologies to achieve widespread use. In her work “Unbuilding Cities: Obduracy in Urban Socio-technical Change”, Anique Hommels (2005) provides detailed insight into why it is so often difficult to alter the built environment. She claims that many of the "common sense" explanations for obduracy of human constructions are often not sufficient. Rather, she provides examples in three different cities to illustrate three principal reasons for why it can often for the built environment to adapt to a changing world. The following is a synopsis of these main points from this in-depth study of technological fixity with emphasis on the ways that these concepts help to explain the challenges that are faced by UD technology.

In many ways conventional sanitation systems offer a prime example of the phenomena Hommels refers to. Although, as has been previously described, technology is readily available that could meet the requirements for sanitation, ease pressures on the environment, and provide useful resources to human endeavors. However, the obduracy of conventional systems will likely make it difficult for alternative systems to be adopted.

Hommels provides three concepts that she feels properly explain why it is difficult for aspects of cities to be "unbuilt" and new structures built in their place. These concepts are "dominant frames", "embeddedness", and "persistent traditions". Each concept applies to and helps to further explain the challenges that UD systems face to become a viable alternative to conventional systems.

Dominant Frames

Hommels begins her description of dominant frames as: "conceptions of technology's obduracy that focus on the roles and strategies of actors involved in the design of technological artifacts" and "highlights the struggle for dominance between groups of actors with diverging views and opinions" (p. 22). Dominant frames is a useful concept to describe the paradigms that constrain the thinking surrounding technological decision making within cities, primarily at the local level. The concept applies both to designers and users of technologies.

As has been described previously, users of sanitation systems have become generally accustomed to the idea of "flush and forget". Human excreta is profoundly framed as a "waste" that should be gotten rid of. In this case, the meaning and function of existing sanitation technology are fixed in the public mind as a means by which to simply remove this waste product.

Likewise, Hommels notes, dominant frames can be used to describe the "professional worldviews" that limit the thinking of professionals such as planners, architects, civil engineers, etc. These worldviews impact the decisions that are made. They dictate what technologies and practices are acceptable and comfortable. Berndtsson (2006) explains that “The existing technical and administrative infrastructure is to support conventional wastewater handling. There is neither support nor infrastructure for the collection, transportation, and use of human urine." Additionally, due to the restricted worldviews of those who created and maintain the existing system, there exists an inherent bias which, as Berndtsson notes causes "all extra work, costs and responsibilities associated with the system (to be) incurred by the owner and user.”

The dominant frames model draws attention to the constructions built according to the dominant "meaning and values they attribute to technology" (p.36). To illustrate the resulting obduracy, one could consider a hypothetical situation where a community has a problem with eutrophication in local bays. This community has been in existence for centuries, but is now growing faster as people move there as a nearby large city reaches a capacity and people choose to live farther out of the city and commute in. The community is located on the coast on a peninsula that causes individual neighborhoods to be widely spread apart with moderate infilling in between. The low-lying land upon which the community sits precluded the construction of a sewer-based sanitation system back when the initial infrastructure of roads, lot layout, etc. was designed. However, it is now widely accepted that one major source of the nutrient pollution in the surrounding waterways are the septic systems that are ubiquitous to the entire community.

As the planners and residents of the community grapple with the problem, according to the dominant frames concept, they would be strongly inclined to attempt a massive undertaking of installing a retrofit sewer-based sanitation system. This would be a massive investment, requiring not only new plumbing to be installed under every street, but pump stations and a new treatment plant. It seems that this would be a prime opportunity for the widespread implementation of alternative sanitation systems. However, acceptance among both designers and users of the proposed technology would be very difficult due to the conceptual limitations that the dominant paradigm places on their realities. The conceptions of reality make up a framework that dictates that the conventional technology remains obdurate and also encourages its continued expansion.

Interactions of social groups and institutions with differing dominant frames could be another way in which innovation may be quashed. For instance, government regulations may require certain levels of sanitation from WWTPs based on levels of existing technology. So, even if a forward thinking city or town created incentives and encouraged the installation of UD toilets in its boundaries, it still may not reap all the potential benefits. If this town were regulated by a more rigid and conventionally-inclined state, provincial, national, etc. government, a government body with higher authority may hinder innovation by requiring a conventional technology (e.g. tertiary treatment) where it would not otherwise be required to properly remove the already low levels of plant nutrients from out flowing waters (due to widespread use of UD technology). If the town were thus required to invest in this much more expensive technology, the financial benefits of UD technology would be greatly reduced.

Embeddedness

Embeddedness refers to technological "artifacts" analyzed within social networks. The concept is an explicit recognition of the co-evolution of society and technology and that "the technical is socially constructed, and the social is technically constructed" (p.27). It refers to the *relatedness* between technologies and other social networks. Embeddedness "refers to the difficulty of changing elements of socio-technical ensembles that have become closely intertwined” (p.30).

Conventional sanitation systems are a good example of an embedded technology. In fact, there are several ways in which the technology is embedded. First, sewer-based systems are embedded within *physical* social networks. Plumbing is connected to every single toilet that is connected to the system. This plumbing is connected to pipes that run inside buildings' walls, into their crawlspaces or basements, through their foundations, then under the yard or sidewalk or parking lot adjacent to the building. From there, the plumbing connects to larger pipes that are buried under networks of streets in every neighborhood connected to the WWTP. These pipes may be connected to pump stations and storm water drainage systems. Altering the sewer system at any point represents a disruption to other social and technological systems.

In addition to being physically embedded within the built environment, conventional sanitation systems are heavily linked to value-based social systems. Sanitation systems of any kind represent massive capital investments. Investments in a sanitation system represent a commitment to the technology. The more money that is sunk into the system, the harder it becomes to abandon the investment and thus the more obdurate it becomes. Thus, when a WWTP becomes under-sized to support a growing community, a hypothetical city may consider a decision between investing millions of dollars into a new WWTP, or keeping the original and to begin diverting money into an alternative system to work in parallel with the existing system. However, this decision is hardly ever considered in part due to the amount of capital invested into the existing system.

Persistent Traditions

Choices made in the past and the present continue to influence the future development and implementation of technologies. The obduracy of socio-technical artifacts that stem from these choices represent what Hommels refers to as persistent traditions. It is important to note that persistent traditions is distinct from dominant frames. Where dominant frames refers mostly to decision making at a localized level, persistent traditions represent wider cultural views and decisions. Hommels refers to the concept of "momentum", and notes that as decisions are made in favor of certain technologies trajectories are set (p. 31). It can then become very difficult to alter these trajectories.

Such trajectories are not formed at such a local level as in the case of dominant frames. Rather, they permeate throughout society and become engrained via social institutions and practices. Hommels refers to the case of the poly-phase electrical supply system adopted during the 1890s as an example of how traditions become persistent (p.

31). First, investments were made in this particular supply system, creating a demand for products that was then met by manufacturers who adapted to make products that met the requirements of the new system. As momentum grew for the "winning" technology, educational institutions began to teach students about the new systems and began churning out workers capable of building and maintaining the expanding infrastructure. As the system became larger and more ubiquitous, professional trade groups developed and best practices within the paradigm came to be disseminated in professional journals. Research institutions aimed at solving "critical problems" help to further perpetuate the momentum of the existing system and contribute to its lasting obduracy. It is not difficult to see the parallels between the decisions made on a societal level that led to the adoption of the electrical grid as we have come to commonly accept it and the decisions that led to the adoption of sewer-based sanitation systems.

Section 6- Conclusions

The widespread use of urine diverting toilets would represent a radical departure from the conventional system in that it would require a much less centralized approach to the handling of human urine. The trend for the last century in many realms, especially in the United States and other industrialized countries, has been towards centralized systems rather than away from them. The production of electricity is a prime example: rather than opting for building- or neighborhood-scale production of electricity, choices have been made that ensure that electricity largely comes from city- or regional-scale facilities.

There is nothing inherently "wrong" with centralized facilities. In fact, they often represent a way to increase efficiency of a system. However, just like with the electrical grid, there are also losses of efficiency (and resulting resource use) that come with transport to and from centralized facilities. By definition, conventional sewer-based systems use water as a transport medium. Reduction of water use has to be considered one of the prime objectives for creating more sustainable societies. However, conventional centralized, sewer-based systems face a monumental task when it comes to meaningfully reducing water consumption. Likewise, few options exist that allow for efficient long distance transport of urine to centralized facilities without using water as a transport medium. Therefore, if reduction of water use and improved nutrient retention are to be considered as primary objectives of sustainable sanitation systems, the main infrastructure of the system will likely need to change and become less centralized. There is evidence that such changes are already slowly occurring.

While the trend toward centralization has been the rule for the most recent past, there is evidence that new ways of thinking are creeping into the existing paradigm. For instance, the value of on-site provision of a building's needs are coming to be recognized. The Leadership in Energy and Environmental Design (LEED) rating and certification system is but one example of rating systems that allows for a comparison of the environmental sustainability of new and remodeled existing buildings. These rating systems are becoming increasingly popular and often favor a shift toward decentralization by encouraging onsite production and collection of energy, food, and water, and also of onsite handling of waste and byproducts. Since 2000, 9 billion square feet of buildings have been LEED certified, and an additional 1.6 million are certified each day (www.usgbc.org, 2011). This trend indicates that building methods and practices may be starting to shift in favor of decentralized technologies such as UD systems.

Larsen and Maurer (2011) mention that on-site treatment of industrial wastewater has long been a commonly accepted practice in the wastewater community. Additionally, they note that source separation and UD technology are generally accepted within the field as sensible means by which to provide sanitation to parts of the world that currently lacks infrastructure. However, they also point to a 1997 issue of *Water, Science and Technology*, the publication of the International Water Association, as a specific point in time when the concept of source separation came to be seen as having potential applications in the realm of urban, industrialized, residential wastewater treatment. Since that time they note the abundance of studies that have been produced that address some the potential benefits of source separation mentioned in this paper (efficient use of resources, ability to treat more concentrated streams, micro-pollutant removal). In addition to highlighting the reasons why such systems are being more widely recognized as viable alternatives to conventional systems, the authors go on to note that "decentralized treatment options could become more attractive if treatment technology for source-separated waste streams becomes integrated into household technology instead of the prototype wastewater treatment plants that we know today."

Therefore, if UD systems are to become more common, it is likely that more, smaller storage/treatment facilities would be required to replace the relatively few and larger facilities that are common to sewer-based systems. Storage and/or treatment of urine on-site would also be a possible solution. Many truly “sustainable” visions for future buildings would take this one step further and actually use the nutrients within the building on roof top gardens, etc. In order for positive changes to (continue to) occur, the obduracy of the existing system will be challenged.

In order to get around the obduracy of the existing system, UD systems may need to operate in parallel for some time until investment in the current order can be fully amortized. This will be possible if the new technology can be installed as new buildings and developments are constructed. Within new developments of single family homes, it would be possible to have a semi-centralized storage and/or treatment facility to serve a neighborhood of homes equipped with UD toilets. Such a system could conceivably operate via vacuum lines to transfer urine to a holding facility. Alternately, pump trucks such as those that currently empty septic systems could pass through neighborhoods on a regular schedule in a similar manner that garbage collection trucks do. If collection is to be done by truck, minimizing the distance to the treatment facility would be necessary to limit energy inputs. Once collected at a neighborhood facility, a volume-reducing treatment, e.g. struvite production could take place prior to shipping, or materials could be piped from intermediate storage facilities to larger, regional treatment facilities. From the regional facilities finished products could be carried by rail or trucked to agricultural areas. Ideally, as this system evolves, agriculture would also become less centralized. By infilling urban and suburban land with agricultural land, the distance for fertilizer products to travel would be greatly reduced.

The use of U.D. systems could conceivably have other, more broad-reaching environmental, social and economic impacts. For instance, pharmaceuticals may be produced differently once nutrient recapture becomes a more important goal. The focus that U.D. systems place on the lifecycles of excreta, nutrients, and pollutants in wastewater could be cause for the re-evaluation of how pharmaceuticals are manufactured and the ways that their chemicals move through human bodies and the environment at large. These changes could make it easier to regulate pharmaceuticals and to keep them out of the environment.

Perhaps the most important and radical change that would potentially come about if UD technology were widely adopted would be the re- connection of the human developers and users of the technology to their environment and the systems that sustain their lives. As Drangert (1998) notes, the existing "flush and forget" sanitation system in most industrialized countries falls within the professional realm of water engineers, physicians, and chemists. This professional involvement has undoubtedly had a positive impact on public health as water quality throughout the industrialized world has improved markedly over the last century. However, Drangert (1998) states that these professional groups are also often restrained by their professional training and their interest in maintaining the integrity of their professional paradigms and have difficulty "seeing" the larger issues that surround their fields of expertise and coming up with solutions outside of their limited worldview. So, in addition to the incremental changes that have already been witnessed in the fields of water and waste management it is quite likely that, in a world facing ever-changing challenges, new methods and bold new ways of thinking will need to be brought to bear on the growing problems.

The "sanitize and reuse" option provided by UD systems promote the inclusion of many more professional groups (e.g. ecologists, agriculturists) and also brings user groups at least somewhat more in touch with an important stage in the human food cycle. Encouraging the cooperation of seemingly disparate segments of the economy as wastewater treatment and agricultural inputs could have rippling effects through the rest of society. Where a water chemist may be able to easily suggest a solution for removing nitrogen from wastewater, an agriculturist may be able to assist with considering the requirements of plants if those nutrients were to be reused as a fertilizer. The resulting technology would likely look quite different.

Evidence exists that expanding awareness and including more groups into the discussion can aid in finding ways of reducing environmental harm and other societal problems. For instance, there has already long been a movement afoot to increase the awareness among consumers about where their food comes from. This increased awareness has led to an explosion of the market for local and organic food. The Organic Trade Association in the United States (2011) claims that sales of organic food and beverages rose in the period between 1990 and 2010 from $1 billion to $26.7 billion in

2010. The growth in this market has been largely due to grassroots organizations pressuring producers, distributers, governments, etc. to provide products to meet the demand for food with fewer chemical inputs.

Implementing urine diverting toilet technology provides a means to further that understanding and awareness that has begun with such shifts as the organic food movement. As stated previously, much effort will need to go into convincing consumers that food grown with fertilizer sourced from urine is safe and acceptable. However, in a similar way as the organic movement has grown, as pilot UD systems are installed and become available as options, awareness and acceptance are likely to grow. This pattern could create a feedback loop where additional people come to recognize the benefits and grow to support the technology. It is quite conceivable (and indeed has already begun to occur in some European towns) that as systems are installed, the growing understanding will in turn beget more systems and eventually revolutionize the way that humanity handles its excreta and fertilizes its crops.

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