The Future of Urine Diversion

an Australian context

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Abstract

With world population expected to reach 9 billion people by 2050, global food production might need to rise by up 70 %. This will require even more extensive use of fertilizers than today. In the wake of an emerging climate crisis the need for biofuels will also increase and further exacerbate the nutrient demand. Most conventional fertilizers are today produced in an unsustainable way and minerals such as phosphorus and potassium that are essential to crop growth are non renewable. This calls for a need to find alternative nutrient sources. From the wastewater stream nutrients can be recycled in various ways. One way is to separate the urine at source in the toilet before it gets in contact with faeces. This way the urine can be used as a sterile and versatile fertilizer containing all of the essential nutrients. Urine diversion has been compared to spreading, precipitation and incineration of sewage sludge in terms of environmental and economic benefits. Urine diversion performs well compared to these other methods when it comes to environmental benefits, but it is still hard to make it economically viable. This thesis examines the drivers and barriers that could promote or hamper the development of urine diversion and compare Sweden to Australia in terms of energy, agriculture and environment. A urine diversion trial at Kinglake, Victoria, Australia has been studied in order to explore the future of urine diversion in Australia.

Australia is an agriculture country with high export of agriculture goods, but it lacks policies that promote recovery of nutrients. At present it is more likely to find support for urine diversion in Australian environmental policies. Even if urine diversion has been around globally for a long time, the industry has still not developed adequate products to make it gain foothold because of a poorly defined market. These are among the key issues to address when implementing urine diversion in Australia.

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Abbreviations

EAWAG: Swiss Federal Institute of Aquatic Science and Technology

WWTP: Wastewater Treatment Plant

CSIRO: The Commonwealth Scientific and Industrial Research Organisation

IFA: International Fertilizer Industry Association

UD: Urine diversion

UDT: Urine diverting toilets

GHG: Green house gases

AUS: Australian dollars

ECOS: ECOS reports on sustainability issues from a scientific perspective for Australia’s national scientific research agency, CSIRO

LRF: Swedish farmer´s association

DE: Departments of the Environment

IIIEE: International Institute for Industrial Environmental Economics at Lund University
VEIL: Victorian Eco-innovation lab at Melbourne University

NFF: National Farmers Federation

1. Introduction

With a growing global population and shift to a more energy intensive diet (FAO, 2009) in many developing countries, more food needs to be produced in the future. That requires more intensive use of fertilizers, but the word´s stock of conventional nutrients are depleting. Phosphorus extraction might peak around 2030 (Rosemarine *et al*, 2009) and rising energy prices makes production of nitrogen fertilizers more expensive (ibid.). Food will become more expensive due to this and harder for some parts of the world to afford. To fight global warming there has to be a shift away from fossil fuels to renewable sources and one of them will inevitably be bioenergy, which also will require fertilizers to be fully utilised.

On one hand the reserves of nutrients that we use today are becoming scarce, but on the other hand the environment has excess of nutrients that causes eutrophication and harm the nature, ecosystem services and industries such as fishery. The spreading of nutrients in the environment has been going on for decades because of human activities such as agriculture, inadequate wastewater treatment and degradation of land. (Rockström *et al*, 2009)

We have become used to recycling our waste to economize the resources of metal, plastics, paper and glass, and now it appears as if the time has come to do it with nutrients too in larger scale. It´s nothing new to recycle nutrients from organic materials and animal excreta (ECOS, 2010), but this have partly been forgotten in the modern society. Sewers have made sanitation easy and hygienic and solved many problems in our cities. But this lead to the problem of eutrophication and we had to build wastewater treatment plants (WWTPs) (ECOS, 2010). The next logical step would be to fully recover the nutrients in wastewater instead of just removing them from discharge water. Up to date this has mainly been done by spreading sewage sludge (by-product of wastewater treatment) on farmlands (EPA Victoria, 2004), but this is not without problems due to the contents of the sludge that could be high in heavy metals, pathogens and other undesirable substances (ibid.). Another way to recover the nutrients is to separate the urine at source in the toilet. Human urine contains most of the nutrients in wastewater but is basically sterile and without heavy metals (Johansson, M. *et al*, 2000). This offers an alternative option to recover nutrients from the wastewater stream that can prove important in the future. Despite the advantages of separating urine at source, the success of recovering the nutrients depends on many factors. Most importantly it has to be economically viable in order to compete with conventional fertilizers. The viability could depend upon many parameters such as commodity price on nutrients, social acceptance, technology sufficiency, policies and legislation.

1.1Purpose and research questions

The purpose of this thesis is to investigate the future of urine diversion in Australia as a way to recover valuable nutrients and to prevent them from polluting the environment. The findings of this study will be base for recommendations on how to approach UD in the future, especially in Australia.

2. Methodology

2.1 Research design

When briefly looking into the subject I quickly realised that phosphorus wasn´t the only nutrient of interest, nitrogen was equally important due to the fact of its energy intensive production and fossil fuel dependence to transform atmospheric nitrogen into a plant available form. Also potassium and other essential nutrients for crop growth were found to face potentially constrains in the future.

This study is based on literature reviews of scientific papers, articles and official documents. On top of that qualitative interviews with people involved in the Kinglake trial, the wastewater industry, the fertilizer industry and academia were conducted. Some of the interviews were conducted in person and some by email or phone. A site visit to Kinglake West was also conducted, as well as anticipation at the third sustainable phosphorus summit in Sydney, Australia. The study has mainly compared the conditions in Australia to Sweden, which has a long experience of UD. Drivers, policies and barriers that could promote or prevent the expansion of UD in Australia have been investigated and UD has been compared to other methods for nutrient recovery. The focus have been on UD in Australia, however regional differences made it important to study a specific case (Kinglake West).

Much points to the conclusion that alternative sources of nutrients needs to be utilised in the near future to meet growing food and bioenergy demands. In the modern world urine is a greatly unexploited resource that could prove valuable. It is however a complex task to recover nutrients in a both sustainable and cost effective way. This calls for an interdisciplinary approach and an extensive case study like Kinglake west is ideal to look into, since it tests the UD technology under real conditions in Australia. The case study of Kinglake was based on the following criteria:

- Sustainability
- Cost effectiveness
- Social acceptance

Three areas have primarily been investigated to find drivers and policies that can promote UD development. The areas were:

- Energy
- Agriculture
- Environment

2.1.1 Structure of the Thesis

- The first step in the research was to conduct a background literature review on nutrient scarcity and food security and finally urine diversion.

- Alternative ways to recover nutrients from the wastewater stream are analysed and compared to UD.

- Examples of UD from around the world (mainly Sweden) were studied in order to compare with the Kinglake Trial.

- Instruments, legislation and other drivers/barriers were then reviewed to find trends that could add to the viability of urine diversion.

- Finally the future of UD in Australia is discussed considering the findings of the Kinglake trial and the leanings from other countries. It is also discussed which policies that need to be in place to promote UD development.

2.2 Limitations

The thesis has been written with the standing point that UD should be as simple and cost effective as possible. This angel of approach also makes UD easier to apply in both developing and developed countries. Due to this condition no further treatment methods of urine have been discussed apart from storage. Urine can still contain hormones and pharmaceuticals whose environmental impact cannot be completely neglected. Even if they are quickly degraded in soils (Jönsson, 2012) and in many countries not considered environmentally harmful in these concentrations, there are grounds for further investigation, especially since some countries have statutory against usage of untreated urine.

3. Background

3.1 Food security

Food security was defined as "when all people at all times has access to sufficient, safe, nutritious food to maintain a healthy and active life", at The World Food Summit of 1996. It includes both physical and economic access to food that is healthy and meets people´s preferences. (WHO, 2012)

Food security is based on three pillars:

- Food availability: Sufficient quantities consistently available.
- Food access: Sufficient resources to obtain a nutritious diet.
- Food use: Appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

(WHO, 2012)

The issue of food security is complex and just as well connected to economic development, environment and trade. Some topics around food security is greatly debated:

- There is enough food in the world to feed everyone adequately; the problem is distribution.
- Future food needs can - or cannot - be met by current levels of production.
- National food security is paramount - or no longer necessary because of global trade.
- Globalization may - or may not - lead to the persistence of food insecurity and poverty in rural communities.

(WHO, 2012)

Agriculture is the largest occupational sector in most parts of the developing world, but very low in many developed countries. This imbalance makes international agriculture agreements crucial to many countries food security. (WHO, 2012)

Fertilizers are crucial to the world's food production. With the world population expected to reach 9 billion by 2050 and economic development changing the diet composition and consumption levels, the food production needs to increase by 60-70 % and for this to be possible the use of fertilizers must also intense. (FAO, 2009) At the same time this has to be done in a way that will decrease our environmental footprint in times of imminent climate change and degradation of ecosystem services.

The world´s population grew by 117 % between 1961-2008 and during the same period of time the crop production rose by 179 %. The same productivity increase needs to be achieved again in the coming decades if to support the expected growth in world population. (FAO, 2011)

One of the most important components in fertilizers is phosphorus. Three countries, China, The US and Morocco/West Sahara share the largest commercially recoverable reserves of phosphate rock in the world (Rosemarine *et al*, 2009). There are disagreements on how long the world´s reserves will last. Some say it will only last another 75-100 years and that the extraction of phosphorus will peak around 2030 (ibid.). On the other hand the industry is much more optimistic and expect the commercially viable reserves to last another 400-500 years (Drew, 2012). What is very likely is that food prices will continue to rise. Fertilizers are dominated by commodity products that are freely trades, so supply and demand determines prices (ibid.). In general if the price of agricultural products rise, then it becomes profitable to apply more inputs and produce more. Rising demand is driven by growth in per capita (GDP) in the developing world, which increases total food demand and the share of higher intensity foods (ibid.). This means that the fertilizer prices will also be reflected in the availability of phosphate, and not all parts of the world will be able to afford them (Rosemarine *et al*, 2009).

In 2007 and 2008 the price of phosphate fertilizer fivefold, partly due to growing demand for biofuels to replace oil, that at the time made it profitable to also grow crops for energy, that increased the demand for fertilizers further (Cordell, 2010). This made food prices increase to all time highs because of competition between food and energy crops (ibid.). This development also linked the pricing structure of fertilized crops for biofuels directly to the price of oil. If the global economic crises wouldn´t have lowered the demand for biofuels, the prices of fertilizers might have remained high to date (Rosemarine *et al*, 2009). Because of the rapidly proceeding events in 2008, no changes in policies with regard to fertilizers and agriculture happened. However what became apparent was that the fertilizer industry is very vulnerable because of the link to biofuels, and the developing world cannot afford conventional chemical fertilizers if the price is too high (ibid.). The above mechanisms of the phosphate market also affected the prices of nitrogen and potassium, as well as the price of food in general. The price of nitrogen is also connected to the price of fossil fuels. Since natural gas today is the cheapest component and energy source for nitrogen fertilizer production, it makes nitrogen fertilizers sensitive to high-energy prices and carbon taxes (ibid.). Especially local carbon taxes can affect the industry, because prices on products such as grains and dairy products are directly linked to international prices so the costs will not be able to be passed on to consumers (ibid.).

With higher fertilizer prices, the inequality of access between rich and poor countries could contribute to major geopolitical conflicts (Rosemarine *et al*, 2009). This puts supplies of phosphate on the agenda as the most important global resource issues, maybe even more important than peak oil. History shows that scarcity of resources often lead to conflicts. Together only five countries control 90 % of the world´s reserves of rock phosphate (ibid.). The largest producer in the world, China, already started to secure its supplies in 2008, by imposing export tariffs on phosphate by 135 % (ibid.). The US´s reserves are quickly depleting, and extraction has already peaked, making them dependent on imports. The second largest supplier of phosphate is Morocco. The country´s reserves are located in West Sahara, which is internationally recognized as a sovereign country, but has been occupied by Morocco since 1975. The US signed a bilateral free trade agreement with Morocco in 2004 that grants the US long-term phosphate accessibility. As a permanent member of the UN Security Council, the US has consistently vetoed any resolution requiring Morocco to leave West Sahara as a favour. Australia on the contrary has halted imports of Moroccan phosphate as a protest against the occupation. (Rosemarine *et al*, 2009)

There have been very few proactive actions to sustainably mange or conserve the reserves of phosphate by the world´s major producers. China´s export tariff might drive the prices up, which could result in more efficient use of fertilizers within the agriculture sector, and high prices give the mining industry an incentive for more efficient extraction of phosphate rock. It is however desirable to keep the price as low as possible to prevent soaring food prices. (Rosemarine *et al*, 2009)

Countries, which are entirely dependent on imported phosphate, will be the first to suffer from increasing global prices (e.g. India) (Rosemarine *et al*, 2009). It´s not only the price of phosphate that affects the price of phosphate fertilizers, one of the main ingredients is sulphuric acid (ibid.). It requires nearly 3 tonnes of sulphuric acid and 3,5 tonnes of phosphate rock to produce 1 tonne of phosphoric acid, which is the basic component of phosphate fertilizers (ibid). Sulphuric acid is mainly produced in the developed world, except for China, who is self-sufficient (ibid). The supply and demand of sulphuric acid directly determines the price of phosphate, exacerbating the geopolitical implications (ibid.). This way the developed countries can control the price of the phosphate they import, by controlling the supply and price of sulphuric acid. Smaller phosphate-producing countries that have no access to cheap sulphuric acid are powerless, and face the same problems as small oil-producers once did. Back then it lead to the creation of Organisation of Petroleum Exporting Countries (OPEC). A similar organisation might be created for the phosphate producing countries to stabilize the market and phosphate supplies. (Rosemarine *et al*, 2009)

There will be more geopolitical impacts on food security in the future, and the fertilizer and phosphate-producing countries will have a big influence. The fertilizer and phosphate-producing countries are not necessarily the same. Many countries produce nitrogen fertilizers from natural gas, so both nitrogen and potassium (the third main ingredient in fertilizers), can directly affect the prices of the others (Rosemarine *et al*, 2009). Only a few countries control the supplies of potassium (led by Canada), as in the case with phosphate, but on the other hand about 60 countries produce natural gas (ibid). The interaction of these factors will affect the fertilizer market in different ways in various parts of the world, making it difficult to predict as the depletion of phosphate reserves, natural gas and new carbon taxes becomes more apparent. (Rosemarine *et al*, 2009)

There is an urgent need for strategies to uphold a better stability in the fertilizer and phosphate markets. Phosphate has to be more efficiently extracted to minimize wastage at source. Higher prices will encourage more efficient use of phosphate and increase recycling, but price increases should be carefully managed to prevent rampant food prices. (Rosemarine *et al*, 2009)

Ranges of agricultural policy reforms are needed to decrease the demand for fertilizers. Farmers should be encouraged to use fertilizers more efficient, and replace conventional ones with organic alternatives and composting technologies. Every year the EU Common Agricultural Policy hand out farm subsidies amounting €50 billion, which has distorted the market to promote wasteful use of fertilizers, since the farmers and consumers don´t pay the full market price. By reducing or eventually eliminating these subsidies, the market competition would become more open, and the farmers less wasteful as a consequence. Consumers can also play an active role in controlling food prices by deciding what and how much they eat. (Rosemarine *et al*, 2009)

But the most effective way avoid phosphate (and nutrient) scarcity might be to promote recovery and reuse of nutrients from organic waste and wastewater streams. According to calculations, the EU could become more or less self-sufficient in phosphorus if policy reforms to promote recycling technologies were introduced. (Rosemarine *et al*, 2009)

Although emerging nutrient scarcity has gotten more attention in recent years, the private sector has showed very little interest. The major phosphate mining companies keep very low public profile and do not have a reputation for sustainable resource management. In common, the fertilizer companies are more interested in potential profits, than conserving its finite resources. Public awareness is also low since most people assume that more minerals can always be found somehow. To a certain extent this might be true in the case of phosphate and other nutrients, but unless actions are taken to preserve the remaining stocks, reduce the demand for fertilizers and recycle nutrients, the costs to society will be enormous in terms of increasing food prices, environmental depletion and widening inequalities between rich and poor countries. (Rosemarine *et al*, 2009)

3.2 Fertilizer

All plants or crops need nutrients to grow. 16 nutrients are essential for most plants growth and the most important nutrients are nitrogen (N), phosphorus (P), potassium (K), and sulphur (S), although calcium (Ca) and magnesium (Mg) are also vital. (IFA, 2012a)

When food or energy crops are produced, nutrients are removed from the farmlands to supermarkets and eventually to the consumer or to facilities for biogas or heat production. To continue producing food and energy crops the farmlands need to be provided with new nutrients, and that is today principally done with artificial fertilizers.

A fertilizer is defined as: “Any natural or manufactured material that contains at least 5% of one or more of the three primary nutrients, N, P or K”. Industrially manufactured fertilizers are commonly known as mineral fertilizers. The two most important sources of nutrients for agricultural use are organic manure and mineral fertilizers. When manure or crop residues are used, they are often combined with mineral fertilizers to achieve optimal nutrient balance for maximum yields. Substantial amounts of mineral fertilizers are added in most parts of the world to get the right nutrient balance for the crops or plants grown. When fertilizers are produced, raw material from nature is gathered and purified to increase nutrient concentration and turn them into plant-available forms. Usually they are also combined into products containing more than one nutrient. (IFA, 2012b)

3.3 Production of fertilizers

3.3.1 Nitrogen

The earth´s atmosphere consists to 78% of nitrogen, but in a chemically inert form that can not be used by plants (except legumes). How to produce ammonia (which is the form of nitrogen used in fertilizers) from atmospheric nitrogen was only discovered in the first part of the 20^{th} century and it´s known as the Harber-Bosch process after two Nobel prize winners; Fritz Harber 1918 and Carl Bosch 1931. (IFA, 2012b)

It requires large amounts of energy to convert the atmospheric nitrogen into a plant available form. Urea and ammonia are the most important nitrogen-based fertilizers. Worldwide ammonia is mainly produced with natural gas as energy and hydrocarbon source. 97 % of the worlds N fertilizers are produced by natural gas (cheapest alternative today) (ECOS, 2010), which is about 5 % of the world’s gas consumption and around 2 % of the world´s energy production (IFA, 2012c). The cost of natural gas counts for about 90 % of the production cost of ammonia, which makes it sensitive to price fluctuations. (IPM, 2005)

3.3.2 Phosphorus

Phosphorus is mined from natural mineral deposits in the form of phosphate. These deposits were once bottoms of seas and have taken very long time to form. This makes phosphorus a non-renewable resource. Rock phosphate is the most common raw material in commercial phosphate fertilizers and is acidified to produce phosphoric acid. Usually phosphate rock also contains heavy metals that can damage the environment and be accumulated by crops. Earlier rock phosphate was directly applied to acid soils, but because of low availability of phosphorus, low crop responses and high transport costs, the phosphate rock is processed to separate the phosphate from the mix of clay, sand and phosphate that is found in the matrix layer. (IFA, 2012b)

There are growing evidence that the production of high-grade phosphate rock will peak within the next 40 years (CSIRO, 2012a). In food production there are no substitute for phosphorus. The price of phosphate will go up at the same time as the quality of phosphate rock goes down. This means alternative sources of phosphorus need to be explored.

3.3.3 Potash

Potash is a salt form of potassium that is used in Fertilizers. Potash deposits are derived from evaporated seawater and occur at only a few places of the world in beds of sediment. The largest deposit in the world is found in Saskatchewan (Canada), and is 2,7-23,5 m thick at depths 1000-10.000 m. To extract the potash at the greater depths, solution-mining methods are used. At depths down to 1100 m conventional underground dry-shaft methods are used. Electrically operated mining machines extract the ore from the deposits and the ore is later crushed at the surface. Salt and clay particles are removed to obtain pure potash suitable for fertilizers. (IFA, 2012b)

3.3.4 Sulphur

The sulphur used by the fertilizer industry is a by-product from industrial process (IFA, 2012b). The cheapest sulphur for fertilizers available today might only last another 74 years according to some calculations (Jönsson, 2012).

3.4 Urine

Human urine is a liquid by-product of the body, which is typically sterile. It consists of 95% water and the remaining 5% is urea, chloride, sodium, potassium, creatinine, a few other dissolved ions, inorganic and organic compounds (EAWAG, 2007). Of all the nutrients in household water, a majority of them are present in the urine. About 80% of the nitrogen and at least 50% of the phosphorus in wastewater comes from urine (morning urine is greater both in volume and concentration) (Johansson, M. *et al*, 2000). Since urine only makes up for 1% of the total waste stream volume, it is basically a concentrated and plant available fertilizer (ibid.). Even if urine is fairly low in individual nutrients compared mineral fertilizers that commonly only contain one or a few nutrients, it can still be very useful because of its diversity. (ibid.)

Sweden is the only place where urine has been used at any scale in agriculture but the use hasn´t been enough monitored or described in scientific papers (Wrigley *et al*, 2010). However no problems with use of urine in agriculture have been recorded in the few studies carried out. Suitable plants for urine fertilization are spinach, cauliflower, ornamental flowers and maize, but lettuce, barley, wheat, Swiss chard, leeks and cucumbers have also been trialled with increased yields. Nitrogen is the main component in urine fertilizer. Urine is considered to have as much plant available nitrogen as chemical nitrogen fertilizers. Phosphorus, potassium and sulphur are also to large proportions in plant available forms in urine, however they may not be completely available due to formation of precipitates and other substances. (Wrigley *et al*, 2010)

Urine has very low levels of heavy metals (especially compared to faeces, grey water and sewage sludge) and is free from environmentally harmful substances. Urine from a healthy person is basically free from pathogens, but some diseases can change the composition or infect the urine, and many pharmaceuticals are secreted through the urine. Also both natural and artificial hormones are added to the wastewater through the urine. (Wrigley *et al*, 2010)

Urine can also possibly contribute to soil amelioration. Collected and stored urine increase in pH from 6 to 9, which could benefit microbial processes in the soil (Wrigley *et al*, 2010). In climates with insufficient precipitation urine could lead to increased salinity in soils. (Jönsson, 2012)

3.5 Urine diversion

The purpose of separating urine at source is to recover most of the nutrients before it get contaminated by faeces. By separating the nutrients already before they reach the wastewater treatment plant, they are also more effectively eliminated, which also reduces the environmental impact from wastewater. (Johansson, M. *et al*, 2000)

A urine-separating toilet has a divided bowl where urine is collected in the front (with or without flushing), and faeces at the back. A separate pipe system leads the urine to a storage tank that is connected to one or more households. The urine can also be drained to a sewer through pipes, or directly applied to the ground via a hose (in developing countries). A big advantage with UD toilets is the low water use, which can make it viable when water is scarce or expensive, even if the urine isn´t fully utilised. (Johansson, M. *et al*, 2000)

Over the last 20 years a number of UD flush toilet models have been developed, and some of them are no longer available. In new models the urine flush consumes as little as little as 0,1-0,3L per rinse and 1-6L to flush solids in the big bowl. This can be compared to new low water use dual flush toilets installed in Melbourne using 3/4,5L water, and even older toilets using considerably more. Considering this, UD toilets used correctly with a 0,2L flush (5 times/day/person), can save potentially save 14L per person/day. (Wrigley *et al*, 2010)

Public urinals also provide an unutilized opportunity to collect urine since no diverting toilets are needed. Modern urinals are also often waterless, which results in water savings and high concentration of the nutrients. Today the urine from urinals are mixed with traditional wastewater, but could easily be diverted to a storage tank instead.

The easiest and cheapest way of hygienizing urine is to store it for a period of time. According to the literature 1 month of storage is considered sufficient to ensure safe use of the urine (yellow water) on fodder crops, however based on WHO guidelines, 6 months of storage at 20°C is widely accepted for use on all crops. (EAWAG, 2007)

The term **yellow water** is commonly used to describe waste water that consists only of diluted or undiluted urine that hasn´t been in contact with faeces, toilet paper or cleaning agents. Some agent that is used for cleaning the toilet might still be present, but it is not considered to affect the "quality" of the urine. (Wrigley *et al*, 2010)

Black water is the liquid waste that derives from flush toilets, washing machines, dishwashers and household sinks and drains. **Brown water** is the black water excluding the yellow water, and **grey water** is black water that is kept separate from toilet waste and preferably also kitchen waste and laundry waste. (Wrigley *et al*, 2010)

Because of the climate in Australia, water savings are important. This has already made source separation and treatment of grey water for reuse common in the country, leading to environmental benefits. (Wrigley *et al*, 2010)

Examples from the literature show that the success of UD can be measured by the quality and quantity of the collected yellow water, the cost of collection and the potential to use it in agriculture. (Wrigley *et al*, 2010)

Important attributes of UD success are:

1. Effectiveness in separating urine and faeces
2. Low water use
3. Cost savings due to reduced wastewater treatment
4. User acceptance
5. Compatibility with Australian plumbing, availability of parts, lack of specialized moving parts and longevity of components

(Wrigley *et al*, 2010)

Even if the basic idea of separating the urine from wastewater streams is simple, there are several issues that needs to be dealt with:

1. Acceptance
2. Sanitary Technology
3. Storage and Transport
4. Process Engineering
5. Micro-pollutants
6. Market Barriers

(EAWAG, 2007)

3.5.1 Acceptance

To successfully introduce urine separation in private households, there has to be a public acceptance and approval. Some behavioural changes are needed to get maximum benefit out of urine-diverting toilets. For example men needs to sit down to urinate. There have been no studies on Australian men's willingness to sit down and urinate, but it can be assumed to be very low (Wrigley *et al*, 2010). Toilet paper must be placed either in a bin (unlikely to be accepted), or in the rear faeces bowl. In the later case it is most important that the large flush isn´t used every time to dispose it. That would spoil much of the water savings. Odour might occur (due high levels of ammonia/ammonium) in the beginning before the system is properly installed and optimized and additional cleaning efforts might be needed to achieve maximum hygiene and comfort. After diversion and collection of urine, farmers need to be willing to use urine based fertilizers on their fields and the consumers need to accept that their food might be grown with human urine. The installation of toilets and collection tanks can´t be too expensive. This would limit installation to people with special interest in sustainable living. Even if there aren´t any special interest in sustainability, there has to be an understanding about the environmental benefits with UD systems in order to be accepted. (EAWAG, 2007)

3.5.2 Sanitary Technology

Handling urine entails certain challenges. To separate and divert urine to storage tanks is basically simple, but the characteristics of urine causes some problems. Fresh urine is an unstable solution, which causes the urea component to break down in siphons and the pipes. When broken down, phosphate, magnesium and calcium precipitates and block the urine drains. Flushing with water can reduce the risk of blockage, but on the other hand you want as small storage tanks as possible and highly diluted urine is inefficient to transport. Several measures can be used to prevent or delay the blockage of pipes:

- Regular use of acid to dissolve precipitates in the system
- Controlled precipitation in large siphons (same as water-free urinals)
- Rainwater rather than tap water for flushing
- Use pipes of large dimensions
- Rapid urine passage through narrow sections

Another issue with urine separation is to obtain as high nutrient concentration as possible in the collection tank. Soluble phosphate might be reduced when flushing with water, due to precipitation.

Also nitrogen can be released as ammonia and lost, if tanks and pipes are ventilated to eliminate odour.

(EAWAG, 2007)

3.5.3 Storage and transport

The urine that is collected needs to be stored for a certain amount of time to kill of all the bacteria that might exist. After that process it has to be transported to the location where it´s going to be used as fertilizer. Since urine consists to 95% of water it is not efficient to transport it long distances. It requires the urine to be used within reasonable distance to source of separation. It is also hard to estimate the amount of flush water entering the tank since most calculations are based on assumptions instead of real on site experiences. The dilution of the urine is important to know in order to use it as a fertilizer in the most effective way in order to compete with mineral fertilizers. (EAWAG, 2007)

3.5.4 Process engineering

There can be different reasons for treating separated urine. You can either treat it so that you recover the nutrients and concentrate them into an applicable fertilizer, or remove the nutrients for better wastewater pollution control. Ideally the urine shouldn´t have to undergo more treatment than the storage to kill off bacteria, but because of arising concerns that hormones and pharmaceuticals might have a negative impact on both human health and the environment, there might be reason to treat it further. Legislation differs from country to country and it is for example illegal to use urine based fertilizers in Germany unless it has been properly treated. For urine separation to be resilient, treatment methods need to be cheap and energy efficient. (EAWAG, 2007)

3.5.5 Micro-pollutants

Urine doesn´t only contain nutrients but also dissolved organic compounds from the metabolism that are excreted through the kidneys. Hormones and pharmaceuticals are two of those and both are becoming more frequently present in water bodies. There is evidence that suggest that these are harmful to aquatic organisms and because of that it is desirable to remove them directly from the urine. It is however unlikely that hormones and pharmaceuticals can cause problems when used in agriculture, mainly due to very low levels and the ability of soils to denature organic compounds more effectively than water (Jönsson, 2012). Chemical studies show that n average of 64% of micro-pollutants are excreted in the urine and some can be toxic in varying degrees. UD can possibly prevent large proportions of micro-pollutants from polluting wastewater, and at the same time unburden WWTPs. (EAWAG, 2007)

3.5.6 Market barriers

Only a handful of suppliers of urine diverting toilets exist and they only produce in small quantities. This makes the improvement and development of the product very slow. Without a large defined market, producers have very little interest in further improving the toilets, and without good products on the market very few toilets are installed. (EAWAG, 2007)

4. Alternative ways to recover nutrients from the sewage waste stream

The CSIRO has in recent analysis explored the theoretical value of carbon, nitrogen and phosphorus in domestic wastewater under the assumption that all of the organic carbon could be converted into methane, and all the nitrogen into ammonia. The finding was that for a city the size of four million people (similar to Melbourne), the total value of recovering carbon, ammonia and phosphorus could be $300 million annually. The total value of energy and nutrients would be $30 million annually. These figures show there is theoretical economic and environmental viability in improved and maximised wastewater management and resource recovery. A likely significant increase in energy and fertilizer costs would further act as a driver for development in recovery technologies. (CSIRO, 2012a)

There are different ways to recover nutrients to the agricultural system. Three of them will be discussed below. These methods all have their advantages and limitations and can be used under different conditions when for example legislation exclude one or another.

4.1 Precipitation

Phosphorus can be precipitated in the form of stuvite (MgNH4PO4·6H2O), and it can be done in all kinds of wastewater treatment if the conditions are right. The process is uncontrolled, and causes problems when struvite is precipitated in pipes and pumps. The only option to have this process under controlled forms is by using biological phosphorus removal in the WWTP, where the dissolved phosphate content is high enough. Currently two WWTP plants in Sweden trial struvite precipitation as a compliment to the conventional treatment, but there are a few commercial plants developed by Ostara Nutrient Recovery Technologies running in the USA and Canada in connection to WWTPs. The one in Edmonton serves about one million people and the struvite precipitation covers 20% of the total phosphorus load. The struvite precipitation process is integrated into the sludge thickening and dewatering reject water systems at the WWTPs. After dewatering of the sludge, the liquid phase goes to an up-flow fluidised bed reactor that has multiple reactive zones of increasing diameter. A combination of magnesium dose and pH control keeps the struvite crystallisation controlled. Magnesium chloride ($MgCl_2$) and sodium hydroxide (NaOH) are added to the process. The extracted struvite fertilizer product is called Crystal Green. The end product also contains some Nitrogen (N) and magnesium (Ma) that are essential to plants. Some cadmium (Cd) is also believed to be present in Chrystal Green based on calculations from limited data in the literature, but the levels are equivalent to the ones in mineral fertilizers. (Linderholm, K. *et al*, 2012)

Recent data on wastewater from the Swedish EPA, shows that a minor part (20-25%) of the incoming phosphorus to a WWTP can be bound in struvite. (Linderholm, K. *et al*, 2012) Edmonton WWTP produces 500 kg struvite every day. Calculations show that only 61 kg of the 420 kg daily incoming phosphorus is present in the struvite. In addition to struvite, sludge is also produced, which needs to be taken care of. The sludge in Edmonton is composted and then either used on agricultural land or in mine reclamation. This sludge is rather poor in nutrients and likely to contain more cadmium than sludge from conventional chemical WWTPs in Sweden. Swedish legislation is very strict about phosphorus losses to water, which means that under Swedish conditions struvite precipitation would need complimentary treatment to the sludge with chemicals. The precipitation chemical can though give other benefits to the wastewater treatment such as improved biogas production and energy savings. (Linderholm, K. *et al*, 2012)

Melbourne Water has had a close look at recovering magnesium ammonium phosphate (struvite). At present this business case runs at a positive cost (i.e. financial loss). This result is largely driven by the high cost of supplying Mg and the current low prices for fertilizers, which limits the potential value of the struvite. To improve the business case there would have to be some combination of increasing struvite production while reducing MgCl2 supply costs and increasing the sale price of struvite. (Mieog, 2012)

4.2 The Ash Dec process

The Ash Deck process is the result of a EU sponsored project with the aim of developing methods for sustainable recovery of nutrients from municipal sewage sludge. The former company Ash Dec developed the method in their pilot facility in Austria, and Outotec Oyj, Finland acquired the patent in 2011. (Linderholm, K. *et al*, 2012)

To recycle phosphorus without spreading harmful substances the sewage sludge can be incinerate and the phosphorus recovered from the ash. The sludge is preheated already in the WWTP to about 45°C, and then dewatered with centrifuges to achieve 34% DM. After that the sludge can be incinerated. When incinerating, heavy oil or other substances with high heating value needs to be added. If the sludge is incinerated together with household waste, the phosphorus content in the ash becomes too low to recover. When monoincinerated, chlorine donors ($MgCl_2$ or $CaCl_2$) are added to the sludge and compacted in a pellet press. The pellets are then fed to a thermal reactor that exposes them to 1000°C for 20 min. During this process most of the metals (Cd, Pb, Zn and Cu etc.) reacts with the additives ($MgCl_2$ or $CaCl_2$) and evaporate. Unfortunately some metals (Cr and Ni) are hard to evaporate. (Linderholm, K. *et al*, 2012)

The full-scale plants that were originally planned by Ash Dec would have had the capacity to incinerate sludge from 1,5-5 million people, producing 15.000-55.000 tonnes of ashes yearly. (Linderholm, K. *et al*, 2012)

4.3 Sewage sludge to farmland

Sewage sludge derives from treated wastewater in WWTPs. To apply sewage sludge to farmland is an established technique to recycle phosphorus from the food chain. Sweden produces about 220.000 tonnes DM of sludge yearly, which contains 6000 tonnes of phosphorus. This would be enough to cover 18% of the country´s phosphorus need to farmlands, provided it doesn´t contain too much harmful substances. About 36% of the added phosphorus to farmlands comes from mineral fertilizers, and sewage sludge could potentially halve this need. Today on average only 26% of the sewage sludge is used on farmlands in Sweden. (SCB, 2010)

Phosphorus is often considered to be the most important element to recover to farmlands, but sewage sludge also contains most other macronutrients (N, P, K, Ca, Mg, S) and only N and K are below the concentration plants need. This means additional sources of these nutrients are needed. All micronutrients (Cl, Fe, Mn, B, Zn, Cu, Ni, Mo) are sufficiently present in sewage sludge, but Cu, Fe and Ni in excess. In addition to the nutrients, sewage sludge contains organic material that increases the soils carbon content and builds up the humus layer. (Naturvårdsverket, 2002)

Even if sewage sludge can be a useful fertilizer, there are certain aspects that need to be taken into consideration before it is applied to productive soils. Everything that is flushed down the toilet or in drains ends up at the WWTP and ultimately in the sludge. This means the sludge can contain varying levels of pathogens, metals and organic pollutants. The fact that the sludge can contain harmful substances raises a public concern that restricts its potential as a source to recover nutrients. The sludge needs monitoring and treatment before being applied to farmlands. (Naturvårdsverket, 2002)

Most of the sewage water from metropolitan Melbourne ends up in the Western Treatment (50 %) and the Eastern Treatment plant (42 %), owned and operated by Melbourne Water. At both sites sludge is treated using anaerobic digestion followed by drying of the liquid digested sludge in sludge drying pans. The drying uses sun and wind to evaporate the moist from the liquid sludge and produce a 'spreadable' dried product that can be lifted and conveyed by earthmoving tractors, diggers and trucks and stored as heaped stockpiles. The majority of the dried sludge is currently stockpiled at the respective sites, as there are no feasible sludge/biosolids disposal or beneficial reuse outlet for the sludge at the moment. Developing a long-term feasible and sustainable biosolids reuse strategy is a key area of research and work for Melbourne Water at the moment, as they cannot continue to stockpile the biosolids onsite forever. (Mieog, 2012)

Melbourne Water's biosolids which are <3 years old are classified as T3-T2 C2 according to the EPA Biosolids Land Application classification system. The biosolids >3 years old are generally T1 C2. The improvement in the treatment classification from T2 and T1 is associated with recognition of the reduction in pathogens, which occurs due to stockpiling. Some of the older sludge is more contaminated with heavy metals and receives a C3 classification. This is due to past trade waste controls not being to the same standard as they are now. T1C1, the highest grade of biosolids and is referred to as "unrestricted" quality which can be used for the broadest range of end uses. All other biosolids classifications are referred to as "restricted" quality with associated restrictions on their end uses. (Mieog, 2012)

Most of the sewage sludge in Australia is either stockpiled or used in agriculture, horticulture and landscaping. Some sludge is combined with other wastes and composted (e.g. Central Highlands Water). This has the advantage of effectively diluting the concentration of heavy metals in the sludge to improve the contaminant grading from C2 to C1. T1C1 "unrestricted" biosolids can be used most readily and T1 biosolids can be used with human food crops according to the EPA guidelines. There still remain some challenges in convincing food producers and particularly supermarkets that are concerned about public perception and the general business risk. At present the management of sewage sludge comes at a cost. The cost of producing T1C1 'unrestricted' biosolids is high and generally not financially viable if one has alternatives such as stockpiling. (Mieog, 2012)

SA Water has provided sludge to farmers for a long time but there are restrictions on its use. Barwon Water has recently completed a biosolids-drying project, which produces a pelletized product that can be applied to land as fertilizer. While this produces a neat product it comes at a significant cost. There is a growing interest in recovering energy and producing fuels from sludge and biosolids however these opportunities are not well developed at present and the current energy balances are not favourable and attract very high cost. (Mieog, 2012)

Generally the industry is looking for financially feasible ways to manage sludge and biosolids and preferably as part of a long term beneficial reuse strategy. For Melbourne Water's biosolids the current biosolids classification places restrictions on its end uses and there isn't enough agricultural land in the vicinity of the two sites to take all the sludge. Melbourne Water's long term solution is likely to come from somewhere other than land application. In this context some regional treatment plants have some advantages. (Mieog, 2012)

There is broad recognition of the value of nutrients in biosolids. There is also lot of encouragement for the beneficial reuse of biosolids. This is outlined in the EPA guidelines. However, the restrictions imposed by the same guidelines to address environmental and public health risks make this challenging. (Mieog, 2012)

Melbourne Water has also investigated nutrient recovery from sludge. However, the cost of recovering the nutrients is not cost effective relative to the commercial value of the nutrients based on current processes and market prices. They will continue to stay abreast of developments in this field in the event that either the cost of recovering the nutrients decreases due to new approaches/processes, or the market value of the recovered nutrients increase. (Mieog, 2012)

4.4 LCA evaluation

A recent Swedish study has evaluated the above options to recover phosphorus to conventional mineral fertilizers from a LCA perspective under Swedish conditions. The published study assed the environmental aspect of each method in terms of global warming potential, eutrophication, energy demand and cadmium flows to farmland. (Linderholm, K. et al, 2012)

The study concludes that fertilization with sewage sludge has the lowest energy demand and CO2 emission. The value is even negative since the sludge contains some nitrogen that can be deducted in the LCA. The second best is fertilization with mineral fertilizer followed by struvite precipitation. It was though discovered during the study that struvite precipitation was not a viable option under Swedish conditions, since only 20-25 % of the phosphorus is precipitated in struvite. That would mean that the process would have to be complemented with chemical precipitation, which leaves two fractions to work with, sludge and struvite. The sludge was considered likely to be more contaminated with Cd and lower in phosphorus. Precipitation of phosphorus requires high concentrations of phosphorus and only really works in WWTPs that uses biological phosphorus treatment. Only about 20 of this kind are up and running in Sweden and even if possible it would be hard to apply struvite precipitation to these with adequate required treatment level of discharge water. Rob Baur, Senior Operations Analyst at the Durham Advanced Wastewater Treatment Facility in Oregon claims that 40 % struvite precipitation can be achieved, but this was neglected in the study as it was still considered too low. (Linderholm, K. et al, 2012)

The Ash Dec process was the most energy consuming and had the highest CO_2 emissions. The difference is considerable compared to the other methods. This is even though all CO_2 from sludge incineration is not counted for in the LCA due to carbon binding in farmlands. The main reason for the high-energy consumption is the oil that needs to be added in the incineration process. Also the added chemicals count for energy and CO_2 in the LCA. Only about half of the energy is recovered in the process in the form of electricity.

The LCA was based on Swedish conditions with a relatively ”clean” energy mix (nuclear and hydropower). Under Australian conditions with high percentage of coal power, the Ash Dec process might perform better in a LCA since incinerated heat is “more worth” if the electricity is made from coal. (Linderholm, K. *et al*, 2012)

One important finding in the study was that there are no tests on imported food in terms of Cd contents. Sweden imports 50 % of it´s food and the number is increasing. This makes the up stream work hard in controlling the Cd levels that eventually end up in the sewage sludge and other organic fertilizers. A recent study has however concluded that imported food doesn´t generally contain more cadmium than domestically produced food. (Linderholm, K. *et al*, 2012)

Urine diversion was not evaluated in the LCA but it can be assumed that it would be viable option considering the above studied environmental aspects. The energy consumption should be the same as for sewage sludge, depending on the dilution of the urine. Transporting too much water would lower the environmental performance. Laboratory tests have however showed that 96-98 % of the P in urine can be precipitated in struvite (EAWAG, 2007). Since heavy metals are not excreted through the urine, UD would be very beneficial considering Cd to farmlands. Cd accumulation is one of the main concerns in Sweden when discussing different fertilization methods. Urine also contains several nutrients, not just phosphorus which would be counted for in the LCA.

5. International examples of urine diversion

5.1 Sweden

Sweden was pioneers in urine diversion and the main driver was the eco-village movement in the early 90s. During that time thousands of UD toilets were installed, primarily in eco-villages, summerhouses and county houses. It was also tested in urban settings and multi-storey buildings with mixed results. Very few porcelain UD toilets were installed during the 90s and only a fraction of these had water-flushed diversion of faeces. (Wrigley *et al*, 2010)

A big research and development programme were run by the Stockholm Water Company between 1995 and 2000. It resulted in a report titled “urine separation – closing the nutrient cycle”. A large-scale urine collection system was set up following this report involving 130 households and conference centre. Three different models of UD toilets were used and large glass-fibre collection tanks were installed in each of the four housing areas. For storage, three PVC balloon tanks of 150 m^3 were used to store the 150-170 m^3 of urine that were produced yearly. It is likely that this was not undiluted urine but yellow water. The Stockholm Water Company was responsible for storage and the urine was then used on land owned by the company and which was leased to farmers. There is an experience in Sweden and Europe to use animal manures as fertilizers, often in the form of slurries. Existing machinery could therefore be used for spreading the urine. (Wrigley *et al*, 2010)

Another municipality directed UD scheme was introduced already in the early 90s at Tanum. It is located in an environmentally sensitive area on the west coast of Sweden, and the UD scheme was driven by the ban of flushing toilets in new summerhouses that were not connected to a high standard WWTP. Since 10 years back **Tanum** require UD in all new construction and at substantial changes to existing buildings. About 750 households up to date have UD or dry toilets, most of them are in summerhouses. Tanum used a similar system design as was later installed at Kinglake, and 3 m^3 tanks for each household were used to store the yellow water with the aim to empty them once a year. Conventional tertiary wastewater treatment was in some areas combined with UD. Subsidies were provided to cover the cost of installing UD toilets. (Länsstyrelserna, 2008)

In 2008 the work on UD was evaluated through interviews with house owners, politicians and officials at the municipality. Since urine is defined as domestic waste, the municipality has the ultimate responsibility for disposing it. This made the municipality conclude an agreement with Farmartjänst, an economic association run by farmers to collect the yellow water. The evaluation concluded that the cooperation between municipality, house owners and farmers were successful. However some house owners lacked trust in how the farmers handled the urine. At the municipality there were some lack of knowledge in how urine and other sewage fractions are used. This made both politicians and officials point out the importance of some form of quality assurance of the system. (Länsstyrelserna, 2008)

The majority of the households were pleased with their UD toilets. The acceptance was generally higher among the holiday residents than the permanent living. There were big differences in how the households experienced the UD toilets. The technology didn´t seem mature enough. Common problems were blockage of pipes and odour. Some also experienced the UD toilets hard to clean and complicated to use for small children. A large majority of the time residents and some of the permanent living disposed the urine and/or the faeces themselves and the urine/mull were used on their lawn or in flowerbeds. However not everybody used the mull as fertilizer. Some just buried it at a "suitable" place. Only a few of the interviewed composted the faeces/mull in a sealed compost which was required by the municipality due to risk of pathogen spreading. (Länsstyrelserna, 2008)

A majority of the interviewed were basically positive to the municipality's requirements of UD, however many had objections of how the requirements were designed. In 2008 the city council decided to build a new WWTP that was a step back from the requirements of UD within municipality activities, but there is still a strong political consensus about UD for private sewers. (Länsstyrelserna, 2008)

There are further examples of UD in Sweden with various successes. UD toilets were installed in a museum complex in **Gothenburg** but problems were experienced with the design of the toilets and the large collection tanks. (Wrigley *et al*, 2010)

At **Gebers eco-collective** 15 km outside Stockholm, 80 inhabitants had UD toilets installed in 1998. A private operator emptied the three collection tanks 2 to 3 times a year. (Wrigley *et al*, 2010)

A school in the **municipality of Mölndal** had a UD system installed in 1999 with 65 Dubletten flush toilets and tanks that could contain 50 m^3. The pipes were cleaned once a year with citric acid, boiling water and pipe cleaners. Once a year municipality contractors emptied the tanks after storage in situ, and the yellow water was delivered to a local farmer for agricultural use. (Wrigley *et al*, 2010)

The only times urine has been used in agriculture is when the municipality have taken responsibility for collection, storage and use of the Urine. For various reasons separated urine has at times even been disposed in the sewage system. In these case the only advantage achieved with UD is water savings due to low or no flushing. Just as in Australia, waterless urinals are becoming increasingly common in public buildings in Sweden and Europe. Since they don´t have the same problems as UD toilets in keeping urine and faeces separated, they might very well act as a driver for urine use in agriculture. The biggest reason for the relative success in countries around the Baltic Sea could though be because of environmental concerns. Application of urine to crops is allowed in Sweden, but in most of Europe the food grown with urine as a fertilizer cannot be labelled organic. Quality certification of concentrated urine has therefore been raised as an important question. (Wrigley *et al*, 2010)

Recommendation from Swedish experience of urine use can be summarized as below:

- The urine should be incorporated into the soil as soon as possible after application and spraying should be avoided to limit nitrogen loss as ammonia.
- Urine should not be applied directly onto plants to avoid burning.
- The urine should be applied at some distance from sensitive plants, even if diluted.
- Drip irrigation is a possibility but measures must be taken to avoid blockages due to precipitates (it has been observed that blockages often increase after dilution as water normally contains some magnesium and calcium).
- Urine can be applied neat or diluted.
- Dilution increases labour, equipment, energy use and the risk of soil compaction.

It has also been recommended not to apply urine to crops within one month of harvesting. The strong smell that comes with stored urine could harm social acceptance, especially in urban or peri-urban areas. Use of urine for fertilization is however well accepted in Sweden and consumers happily accept vegetables grown with urine.

According to Håkan Jönsson, professor at SLU (Sweden´s Agriculture University) who has been involved in most urine trials in Sweden over the last decades, there are three major reasons why UD hasn´t taken off:

1. The range of attractive toilets are non-existent
2. There is a reluctance within the wastewater industry
3. Lack of support in terms of education, knowledge sharing, etc. from central institutions of society.

5.2 Germany

The Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) produced a technology review in December 2009 titled "Urine Diversion Components". It provides very useful information about UD toilets and tanks. (Wrigley *et al*, 2010)

A pilot project on UD ran at the German water authority´s (KompetenzZentrum Wasser Berlin (KWB) headquarters in **Stahnsdorf** in 2010. The trial experienced several technology problems and a urine collection of only 30-40 % could be achieved. They used the Roedinger No-Mix toilet that is designed to collect the urine undiluted and the collecting area of the toilet is then flushed with a spray that is triggered by a switch under the seat. (Wrigley *et al*, 2010)

GTZ has installed a UD system with 56 flush toilets and 25 waterless urinals in its headquarters main building in **Eschborn**. The system is equipped with enamel coated cast iron pipes and four 2,5 m^3 polyethylene storage tanks with sampling and measuring devices. This is up to date the most sophisticated UD installation of flush toilets in the literature. The system has provided much information about the practicalities of urine collection, storage, use of urine in agriculture and the possibility to produce fertilizers or other chemicals from urine. (Wrigley *et al*, 2010)

Germany has put a lot of effort into developing treatment methods for urine to produce concentrated nutrient solutions, derived fertilizers and similar products. Technische Universität Hamburg-Harburg (TUHH) has been especially prominent in this field. They have provided valuable work to understand the behaviour of stored urine. (Wrigley *et al*, 2010)

It is not legal to apply urine to fields other than research plots in Germany. As in Australia, water is very expensive in Germany. This could act as a major driver for further UD development and research. The information is available in the technology review – "Urine Diversion Components" from 2009. (Wrigley *et al*, 2010)

5.3 Switzerland

EAWAG is a world leading aquatic research organisation that has explored the potential of UD in detail over the last decade. They ran a transdisciplinary project between 2000 and 2006 called Novaquantis where UD is referred to as NoMix technology. The main issues identified were problems linked to the transport of the urine from toilet to treatment (in this case a central treatment plant). As in German, urine is not allowed to be applied to fields in Switzerland, and would need further treatment in order to be fully utilised. EAWAG achieved a 60-75 % collection rate of the excreted urine with the UD toilets they used. (Wrigley *et al*, 2010)

From the Novaquantis final report the conclusion was drawn that UD technology is not yet mature enough and the toilets do not meet the standard of conventional models. It was advised that all future installations should consider all aspects carefully and project objectives have to be clearly defined. Several methods for different treatment of urine have been tested by EAWAG and they could be useful in countries where legislation prevents the utilisation of urine in the agriculture sector. However acceptance from consumers to buy urine grown food is much lower than in Sweden (Wrigley *et al*, 2010). This could be a reflection of the authorities position of banning untreated urine based fertilizer products in Switzerland.

5.4 Developing countries

The German GTZ promotes and develops ecosan programmes all around the world and UD is a central strategy in its holistic sanitation approach. Three symposiums on ecosan have been hosted by GTZ and have lead to very useful information. On the first symposium in Bonn 2000 the foreword summed up the reasons to investigate alternative sanitation systems:

(Wrigley *et al*, 2010)

"Conventional forms of centralized and individual sanitation do not offer sustainable solutions to the massive worldwide sanitation problems. Despite the intensive efforts of many institutions at national and international level, many developing countries can not afford to provide adequate water supply and sanitation services to their populations, as the initial cost and operation of conventional systems are often much too expensive. Consequently, about 2.2 million people in developing countries, most of them children, die every year from diseases associated with lack of safe drinking water, inadequate sanitation and poor hygiene. Conventional "flush and discharge" and "drop and store" disposal systems cause worsening pollution, mainly of ground and subsurface water by organics, nutrients, pathogens, hazardous material and other such polluting materials as pharmaceutical residues, hormones etc. Moreover, conventional water borne sewage systems add to the waste of precious drinking water by using it as a transport medium for faeces, urine and waste. But the main reason why conventional sanitation systems are coming under increasing criticism is that they deprive in general agriculture and, hence food production of the valuable nutrients contained in human excrements, especially in urine, thus representing a typical linear end-of-the-pipe technology that contributes to the degradation of soils and to the loss of natural productive capacity due to a lack of nutrients."

(Wrigley *et al*, page 12, 2010)

The Ecosan approach address a wide range of problems related to different sanitation concepts. In developing countries there is often no sanitation or just pit latrines. Conventional sewage systems could be modified to use UD locally for agriculture and/or environmentally friendly wastewater treatment such as wetlands and biogas production. It can also be successfully used in developed countries to collect the urine from outhouse toilets in summerhouses for domestic garden use. (Wrigley *et al*, 2010)

UD trials for agricultural use in Australia can potentially also contribute to the knowledge of alternative sanitation systems under both urban and preurban conditions. (Wrigley *et al*, 2010)

6. Policies, drivers and legislation

6.1 Sweden

6.1.1 Energy

80 % of all energy systems in the EU are based on fossil fuels, dominated by oil, coal and natural gas (Energimyndigheten, 2012). Sweden´s energy mix is considerably less based on fossil fuels and nuclear and hydropower makes up for the larges parts of electricity production (ibid.), however bioenergy is the single largest energy source (Svebio, 2013). The main driver for bioenergy development in Sweden has been the carbon tax that was introduced in 1991, as well as a consistent political support for renewable energy and a strong forestry sector (ibid).

In 2009 the EU decided that 20% of the energy should come from renewable sources by 2020 and the emissions of CO_2 decline by 20% during the same period of time (Energimyndigheten, 2012). Sweden has however set more ambitious energy targets than is required by the EU. They are summarized in the table below:

Table 3. Energy targets in Sweden and the EU

Target 2016	**Sweden**	**EU**
Energy efficiency	9 %	9 %
Target 2020		
Share renewable energy	50 %	20 %
Share renewable fuels	10 %	10 %
Energy efficiency	20 %	20 %
Reduction of GHG	40 %	20 %

Compared to 2008 values.

(Energimyndigheten, 2012)

Sweden reached the 50 % renewable energy goal already in 2012, 8 years before expected. The largest share of renewable energy comes from bioenergy (32,4 %), followed by hydropower (17,6 %). (Energi, 2013)

6.1.2 Agriculture

Common Agricultural Policy (CAP) is the agricultural policy of the European Union. CAP aims to provide farmers with a reasonable living standard, consumers with fair priced quality food and to preserve the rural heritage.

The CAP´s budget is spent in three ways:

1. Income support to farmers in order to comply with food safety, environmental protection and animal welfare and health (70 % of CAP´s budget).

2. Rural development (20 % of CAP´s budget)

3. Market support (less than 10 % of CAP´s budget)

It was commonly regarded that CAP promoted large-scale agricultural production and at the same time permitted farmers to increase production in a unecological way by not restricting the use of fertilizers and pesticides. This however changed in 2004 when EU re-focused the payment scheme to a more environmentally oriented farming policy. Strict environmental standards were introduced and by failing to comply with these standards farmers face substantial subsidy cuts.

In 2010 the EU allocated 31 % of the 5 billion euro earmarked for environmental challenges in the agriculture for protection and promotion of biodiversity in the European countryside. This money supports agri-environmental projects throughout the Member States within the EU rural development policy program.

1993 a jointly **Nitrate directive (91/676/EEG)** was adopted by the EU aiming to reduce the nitrate pollution of water from agriculture. The Member States have various minimum requirements under the directive:

(EU, 2010)

1. Each Member State shall, every four years, identify sensitive land areas that can have a major impact on water according to the criteria laid down in the directive.

2. Within the sensitive land areas, action plans shall be prepared to reduce nitrogen leaching and a monitoring system to check the effect of the measures. Rules are inserted for below:

    - Timing for the use of various fertilizers
    - Storage capacity of animal manure
    - Limitation of fertilizer supply in accordance with good agricultural practice and taking into account the characteristics of the given area.

(EU, 2010)

The only real clarification in the directive is however that the maximum permitted input of nitrate from manure is 170 kg N/ha and year. (EU, 2010)

Since 1995 Sweden used to have a **tax on mineral fertilizers** corresponding 20% of the prize on the fertilizer. The tax was purposed to act as an economic instrument to decrease the emissions of nitrogen and cadmium to the environment from the agricultural sector. The effect of the tax was however low and it was abolished in 2010 in an attempt to make Swedish agriculture more competitive. (Statskontoret, 2011)

6.1.3 Environment

Sweden has 16 **national environmental goals**. One is called "Good Built Environment" and target 5 addresses waste:

- By 2015 at least 60% of the phosphorus compounds in wastewater shall be returned to productive land, of which at least half should be returned to arable land.

(Miljömål, 2007)

To fulfil this objective other environmental goals needs to be addressed as well. For example "non-toxic environment", that would raise the quality of sewage sludge but this goal also prevent return of nutrients if the sewage fraction is too contaminated (Miljömål, 2012a). There are also environmental goals concerning eutrophication that is a driver for nutrient recovery. A "non-toxic environment" is considered to be one of the hardest goals to achieve due to a widespread diffuse dispersion of substances (Miljömål, 2012a).

The Swedish EPA considers it of great importance to return phosphorus from wastewater fractions and other sources to productive land (Naturvårdsverket, 2002). The main reasons are concerns about resource depletion and the environmental aspects associated with mining of minerals and fertilizer production as well as eutrophication (ibid.). The return of nutrients are further supported by the **waste hierarchy** and the **resource management and cyclical principles** in Swedish environmental law:

- Firstly, choose a management that provides recycling of nutrients.
- Secondly, choose a management, which at least recover the energy or material.
- Ultimately, let the sewage fraction go to disposal, in which neither the nutrients, energy or material is used.

According to the EPA, the nutrients might not be returned to productive land neither in the short or long term due to local or regional conditions or environmental/economic unfeasibility. (Naturvårdsverket, 2002)

The EPA has developed a plan of action for return of phosphorus from sewer to productive land. The goal is to do so in a way that won´t hurt the health of humans or the environment. This means that:

- The wastewater fractions are of such quality regarding purity that they can be returned without harming the health of humans or the environment.

- The nutrients in sewer can be returned to both farmlands and other land where it´s needed.

- The use of other fertilizers is replaced.

(Naturvårdsverket, 2002)

The EPA acknowledges not only P, but also other nutrients as well as important to return to productive land. The long-term goal is to also recover nitrogen, sulphur and potassium from the wastewater stream. Five working areas have been identified to reach the long-term goals:

- Progressive development of objectives.
- Continuous monitoring, evaluation and revision.
- Successively higher targets for recycling and tighter regulations.
- Development of systems and methods.
- Implementation of additional measures

(Naturvårdsverket, 2002)

At present in Sweden most of the nutrients returned to soil from wastewater fractions are in the form of sewage sludge. Since the quality of the sludge makes it hard to combine with the environmental goal "a non-toxic environment", other methods are explored as well as attempts to work up stream to improve the quality of the sludge in accordance with "a non-toxic environment". The Swedish EPA highlights the importance of dialog between stakeholders, information dissemination as well as promoting sewage planning. (Naturvårdsverket, 2002)

Sweden also has a certification scheme for sewage sludge called **REVAQ**, which makes it possible for WWTP operators to deliver a safe product that farmers can use without risking public concern about the food they produce. (LRF, 2013)

Another of the 16 national environmental goals in Sweden is "**no eutrophication**", defined as:

Nutrient levels in soil and water should not have any adverse effect on human health, the conditions for biological diversity or varied use of land and water.

This goal is not considered possible to achieve by 2020. The emissions of nutrients are still too high and the ecological recovery is slow.

(Miljömål, 2012b)

The Helsinki commission also known as **HELCOM**, was established to protect the Baltic sea from all sources of pollution that threatens the marine environment. It is an intergovernmental collaboration between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The vision of HELCOM is to restore the ecological status of the Baltic Sea in order to maintain sustainable economic and social activities. (HELCOM, 2012)

To achieve its vision the member states works as:

1. an environmental policy maker for the Baltic Sea area by developing common environmental objectives and actions.

2. an environmental focal point providing information about (i) the state of/trends in the marine environment; (ii) the efficiency of measures to protect it and (iii) common initiatives and positions which can form the basis for decision-making in other international for a.

3. a body for developing, according to the specific needs of the Baltic Sea, Recommendations of its own and Recommendations supplementary to measures imposed by other international organisations.

4. a supervisory body dedicated to ensuring that HELCOM environmental standards are fully implemented by all parties throughout the Baltic Sea and its catchment area.

5. a co-ordinating body, ascertaining multilateral response in case of major maritime incidents.

(HELCOM, 2012)

HELCOM prioritises seven key areas that are considered crucial to address in order to raise the ecological status of the Baltic Sea:

1. Eutrophication, especially the contribution of agriculture.

2. Hazardous substances.

3. Land transport sector.

4. Maritime transport sector, including carrying out the Baltic Strategy.

5. Environmental impacts of fishery management and practices.

6. Protection and conservation of marine and coastal biodiversity.

7. Implementation of the Joint Comprehensive Environmental Action Programme and HELCOM Recommendations.

(HELCOM, 2012)

Two of HELCOM´s most important goals are to reduce the nutrient run off to the Baltic Sea and to monitor the elimination of 132 identified "hot spot" pollution sources in the catchment area. HELCOM has been working since the 80s with these issues and some decrease in discharge of organic pollutants and nutrients have been achieved as well as 50 hot spots have been written off the list. (HELCOM, 2012)

The private sewers in Sweden discharge as much P as all the municipal WWTPs that serve 8 million people (85 % of the population). This makes private sewers major contributors to eutrophication and a source of pathogens and other environmentally harmful substances. Of the about 700.000 private sewers in Sweden only about half of them are assumed to be approved. About 130.000 of them only have sludge separation, which is outright illegal. (Havs och vattenmyndigheten, 2013)

6.2 Australia

6.2.1 Energy

Australia is the ninth larges energy producer in world and accounts for 2,5% of the world´s energy production (Ulrik, 2012). For a small population Australia contributes to 1,5% of world´s GHG emissions which is one of the highest per capita in the world. The energy resources in Australia are considerable with coal, uranium and natural gas all produced (McCormick, 2013). There is no nuclear power in Australia but the uranium is vastly exported (ibid.). Fossil fuels dominate the electricity production and coal accounts for 75 % and natural gas 15 % (ibid). Australia's oil recourses are limited and the county is becoming reliant on imported oil (ibid.). At present bioenergy provides 4 % of the primary energy but makes up for 78 % of the total renewable energy (heat, transport fuels and industry co-firing and cogeneration) (ibid.). The growth in the bioenergy sector is however slow compared to wind and solar. Australia has set a **renewable energy target (RET)** of 20% electricity supply from renewable sources by 2020 (ibid.). It is also expected that this percentage will be able to rise to 40% by 2050 (ibid).

By 2020 Australia has committed to cut GHG emissions by at least 5 % compared to 2000, but up to 15 % or even 25 % is desirable to comply with international climate change prevention negotiations. Further more the Australian government has a long-term target of cutting the emissions of CO_2 by 80 % until 2050. (DE, 2013)

To meet these goals, alternative energy sources needs to be fully utilised. About 8,5% of the electricity from renewables comes from biomass, which equals less than one per cent of the total electricity generation. However there is a goal to increase this figure to 3,7% by 2020. Biomass has a huge unutilised potential in Australia but development has been slow because of strong protection of native forests. This has driven the renewable energy development more towards wind and solar power. (Ulrik, 2012)

A **Carbon Pollution Reduction Scheme** (CPRS) was due to be introduced by the Rudd government in 2010, but was officially deferred to 2013 (FIFA, 2010). The scheme is a part of Australia's shift into a less carbon dependant society. There is a concern within the fertilizer industry that such a scheme could harm the competitiveness of the sector globally if comprehensive international agreements are not concluded (ibid). Even without a reduction scheme, fossil fuel dependant industries (directly or indirectly) will be affected as global carbon constrains will raise energy prices (e.g. natural gas). If the proposed CPRS were to be introduced in Australia, the fertilizer manufacturing industry would be hit by a further six percentage points payroll tax (ibid.). The cost could be even higher in terms of lower fertilizer demand from the agricultural sector if nitrous oxide leakage from nitrogen fertilizers were also to fall under the CPRS (ibid).

A highly debated **tax on carbon** was introduced in Australia on 1 July 2012. At the first stage it will only target the largest emitters and so far the wastewater industry isn´t too concerned. Only the three largest water companies will be affected (Pamminger, 2012). Since there is a national target to cut the emissions by 80% 2050, also smaller actors could be hit with higher treatments costs in the future (DE, 2013). For the fertilizer industry there will be some effects on production and transport costs for fertilizers and other farm inputs. As Australia is an open trading economy some prices such as grains and dairy products are directly linked to international prices so the costs will not be able to be passed on to consumers (Drew, 2012). For products not directly exposed to international trade the costs may be passed on to consumers. (ibid.)

To supply a growing population with water and adequate wastewater services more energy is needed. At the same time the water industry feel the pressure to reduce its carbon footprint (CSIRO, 1012a). The cost on both water and energy is also increasing and will influence food supplies that could threaten the food security (ibid). Wastewater can though be a solution to this as nutrients can be recovery from both the domestic and agricultural wastewater stream (ibid.). Energy consumption is expected to double over the next 20 years in the urban water industry mainly because of harvesting of more energy intensive supplies (ibid.). Today´s gravity fed surface water supplies will be replaced by supplies form desalination, potable or non-potable recycling, new storage or water trading, that generally requires more energy intensive treatment processes greater pumping distances etc. (ibid.). This in conjunction with an expected doubling of energy prices due to transition away from fossil fuels could at least four-fold the energy costs for water supplies in Australia (ibid.).

Water utilities are major individual energy users, which put them under public pressure to reduce greenhouse gas emissions (CSIRO, 1012a). Pressure will further increase if more aggressive global and national reduction targets of greenhouse gases are introduced (ibid.). The water industry will need to both reduce its energy costs and GHG emissions as energy economics of water and wastewater management is shifting (ibid.). Energy cost and energy scarcity will therefore be a driver for resource recovery processes.

Both Australia and the rest of the world will face the future challenge of securing availability of water, energy and food. Fertilizers are absolutely vital to food production (especially in Australia with nutrient poor soils) but the production of fertilizers is very energy intensive, especially for nitrogen (CSIRO, 1012a). The growth in global demand of fertilizers is very rapid, and Australia produces only about half of the six million tones that are yearly used (ibid.). Half of the produced fertilizers in Australia are manufactured from imported phosphate rock (ibid.). Australia imports about 63 % of its nitrogenous fertilizers (ibid.). Around 2008 the price on fertilizers tripled, and if it were not for the global financial crisis the climb would have continued (ibid.). The prices are though expected to rise again as soon as the global economy has recovered (ibid.).

6.2.2 Agriculture

The agricultural sector is huge in Australia and contributes to 12% of the GDP (if including value-adding processes for food and fibre, along with the value of all the economic activities supporting farm production through farm inputs) to a value of $155 billion (2010-2011) (NFF, 2012). The country is self-sufficient and 60% of the produced food is exported, feeding 60 million people (ibid.). This also means that Australia exports a lot of nutrients, at the same time as it is dependant on import of both raw material for fertilizers and already manufactured fertilizers (CSIRO, 2012a).

Australia has very old and nutrient poor soils, which make the agriculture very energy, fertilizer and pesticide intense (AG, 2013). To maintain high productivity large quantities of fertilizers are needed, and since energy prices are on the rise, it can become a burden to farmers in the future. Because the soils are naturally nutrient poor, the wild life has adapted to these conditions and the environment is for this reason particularly sensitive to nutrient input, and that requires proper wastewater treatment (AG, 2013).

Even though the agricultural sector in Australia is an important contributor to the society and economy, farmers receive the second-lowest government agricultural support in the OECD (OECD, 2011). There has been a substantial and continuing removal of policies since the late 80s to prevent distortion of agricultural production and trade (ibid.). Farmers can receive time-limited support if in difficulty, professional advice to maintain best practise farming or grants to re-establish outside agriculture (ibid.).

In 1997 the **Agriculture Advancing Australia** (AAA) was launched. It´s an integrated package of programs to increase the competitiveness, sustainability and profitability of producers. The befits include:

1. Funding for business and natural resource management training and education;
2. Support for industries undergoing change;
3. Financial management tools;
4. Financial information and referral;
5. Funding for professional advice, skills development and training;
6. Assistance for farm families in serious financial difficulty; and
7. Improved access to markets.

The AAA can help farmers adapt to climate change and to adopt new technologies that will increase productivity or improve the sustainability and environmental performance of farming.

The improvement of the agriculture sector is further supported by the **Productivity Commission**. It is the Governments independent research and advisory body that addresses economic, social and environmental issues that concern the welfare of Australians. The Commission help the government to make better long-term policies. The main goal of the Commission is establish a more productive economy to raise living standards. Three fundamental operation principles are followed by the Commission:

(PC, 2012)

- The provision of independent analysis and advice.
- The use of processes that are open and public.
- To have overarching concern for the well being of the community as a whole, rather than just the interests of any particular industry or group.

(PC, 2012)

The Commission is required to:

- Improve the productivity and economic performance of the economy.
- Reduce unnecessary regulation.
- Encourage the development of efficient and internationally competitive Australian industries.
- Facilitate adjustment to structural change.
- Recognise the interests of the community generally and all those likely to be affected by its proposals.
- Promote regional employment and development.
- Have regard to Australia's international commitments and the trade policies of other countries.
- Ensure Australian industry develops in ecologically sustainable ways.

(PC, 2012)

In 2004 the Minister for Agriculture, Fisheries and Forestry gathered a "Reference Group" consisting of high-level stakeholders, with the aim to make recommendations concerning future directions for the food and agriculture sector. Two years later the recommendations were submitted in four areas: market and supply chain responsiveness; competitiveness; adopting to change; and natural resource governance, also called **the Forward Agenda**. The government´s role was considered by the reference group to be enabling, with the aim to secure the best environment for markets to operate. The on-going market-oriented reforms in Australia will if successful make the country even more competitive in the future. Multi-stakeholder collaboration will be the key to developing the agriculture sector and to keep it cutting edge in the world.

53% of the land in Australia is used for agricultural purposes and the sector accounts for 55% of the water consumption (including forestry and fishing) but on the other hand the sector has been the most successful in decreasing its water consumption (-57% 2001-2011) (SAR, 2013). The significant land exploitation by agriculture in Australia makes farmer's role in environmental and resource management important. The trend is however positive that more farmers adopt practices to improve productivity and conserving ecosystem services (SAR, 2013).

As the global food demand is expected to increase by 70% until 2050 Australia has the opportunity to contribute to global food security at the same time as increased food export will stimulate the economy. The highest increase in demand is expected in Asia and Australia´s geographical proximity might give them a competitive advantage that will boost the development of the agricultural sector (SAR, 2013). An increase in productivity will however need to be managed in a sustainable way to prevent depletion of natural resources. Most parts of Australia have water and nutrient scarcity which makes agriculture demanding (ibid.). **The National Sustainability Council** highlights soil erosion, acidification and carbon dynamics of soil as key challenges for agricultural productivity (ibid). Dryland salinity is also a major concern and how these issues will be managed will have direct impact on long-term sustainability of food production in Australia (ibid).

Another growing segment of the agricultural sector is aquaculture. Since 85% of the world´s wild marine stocks of seafood is fully exploited or over overfished the need for aquaculture is growing rapidly to meet increasing food demands (SAR, 2013). It is now the fastest growing food production system in the world. Aquaculture accounted for 43% of Australia's seafood production 2010-11 ($948 million) (SAR, 2013). This sector relies on adequate water conditions and pollution control.

Australian agriculture has been able to maintain remarkable productivity despite harsh climate and very poor soils (SAR, 2013). Know-how has always been the key to success in Australian agriculture and it will be vital to make sure that they stay at the forefront to secure future productivity, especially since climate change and resource scarcity might change the conditions in the future. The National Sustainability Council have acknowledged agricultural science as "the most valuable asset to support food security" in Australia (SAR, 2013). It is already well regarded internationally and public investment in agricultural research and development was about $778 million 2006-07 (SAR, 2013). Even though investments have stagnated in recent years, the Sustainability Council highlights increased investments to lift the food output even more (SAR, 2013).

Australia's first ever **National Food Plan** has recently been developed by the Australian government. It was released by the Minister for Agriculture, Fisheries and Forestry, Senator the Hon. Joe Ludwig, on 25th May 2013 and will help to ensure the government´s food policy settings are right over the short, medium and long term (AG, 2013). It is a roadmap for the direction of government policy on future food. The National Food Plan aim to strengthen Australian agriculture to make it a globally recognized food brand synonymous with high quality (ibid.). The developments and growing demand for food in Asia ("the Asian century") is one of the main drivers, and Australia's role in global food security is recognized as an opportunity to boost the export sector even further (ibid). Australia´s world-leading agriculture research and technology is considered key to the 16 goals set to 2025 for the nations food system:

1. The value of Australia's agriculture and food-related exports will have increased by 45 per cent (in real terms), contributing to an increase in our gross domestic product.

2. Australia will have stronger food trade and investment relationships with countries across the region and the capabilities to promote Australian interests.

3. Australia will have a globally recognized food brand that is synonymous with high-quality, innovative, safe and sustainable food, services and technology.

4. Australia's agricultural productivity will have increased by 30 per cent, helping farmers grow more food using fewer inputs.

5. Innovation in Australia's food manufacturing industry will have increased, building scale and capability through collaborations to make the most of emerging opportunities in the Asian region.

6. Australia's agriculture and fisheries workforce will have built its skills base, increasing the proportion with post-school qualifications.

7. Australia's infrastructure and biosecurity systems will support a growing food industry, moving food cost-effectively and efficiently to markets and supporting new export opportunities.

8. Participation by Australian food businesses in the digital economy will have increased, driving productivity gains and innovation and creating connections with global markets.

9. Australia will be among the top five most efficiently regulated countries in the world, reducing business costs.

10. Australia will have built on its high level of food security by continuing to improve access to safe and nutritious food for those living in remote communities or struggling with disadvantage.

11. Australia will be considered to be in the top three countries in the world for food safety, increasing the reputation of Australia's exports.

12. Australians will have the information they need to help them make decisions about food.

13. Australian children will have a better understanding of how food is produced.

14. Australia will have contributed to global food security by helping farmers in developing countries gain access to new agricultural technologies.

15. Australia will produce food sustainably and will have adopted innovative practices to improve productive and environmental outcomes.

16. Australia will have reduced per capita food waste.

(AG, 2013)

To support sustainable agriculture and natural resource management Australia will:

- Investing over $600 million under Caring for our Country Sustainable Agriculture Stream over the next five years to ensure their natural resources remain sustainable, productive and resilient.
- Appointing a Soil Health Advocate to raise awareness of the importance of soil health.
- Implementing the Murray–Darling Basin Plan to restore our rivers to health, support strong regional communities and sustainable food production.
- Investing more than $15 billion in the Water for the Future initiative, including investment in infrastructure to improve water use efficiency (on and off the farm) and supporting irrigators and food processors position themselves for a future with less water.
- Introducing a carbon price through the Clean Energy Future Plan to help reduce greenhouse gas emissions, drive investment in energy efficiency and promote innovation.
- Investing $429 million through the Carbon Farming Futures program to identify ways to reduce greenhouse gas emissions, store carbon in our vegetation and soils, and enhance sustainable agricultural practices.
- Investing $44 million through the Carbon Energy Future Plan to support regional natural resource management organisations across Australia to plan for the impacts of climate change.
- Invest $1.5 million to support community food initiatives by providing grants to community groups to support the establishment and development of initiatives like food aid and food rescue organisations.

(AG, 2013)

6.2.3 Environment

Australia has a long history of environmental management and has been very successful in protecting its nature. The following acts and legislation addresses the possibilities to return nutrients from the wastewater stream:

Environment Protection Act 1970; According to the Environment Protection Act 1970, all discharges to the environment must be handled to avoid negative impact on the recipient (land, surface water or groundwater). Under the Act approval and licencing is required from the EPA Victoria to ensure sufficient control of the discharge. Further the Act explains the key principles of environmental management as well as the waste hierarchy that promotes waste avoidance and recycling instead disposal. (EPA Victoria, 2004)

The Health Act 1958; Makes provision for the prevention and abatement of conditions and activities, which are, or may be offensive or dangerous to public health. (EPA Victoria, 2004)

Livestock Disease Control Act 1994; Set requirements for livestock grazing land irrigated sewage water. It aims to protect the health of animals grazing that land and humans consuming the ultimate animal products. Taeniasis (also known as “Beef Measles”) is specifically addressed by this Act. (EPA Victoria, 2004)

Agricultural and Veterinary Chemicals (Control of Use) Act 1992; Defines a fertilizer and the agricultural use of biosolids for fertilization. (EPA Victoria, 2004)

Food Act 1984; Legislates quality standards on food. Victoria complies with the standards by enforcing the Australian New Zeeland Food Authority Act 1991. The acts have specified maximum residue limits and maximum permitted levels present in food of pesticides, metals, polychlorinated biphenyls (PCBs), and other organic chemical contaminants. (EPA Victoria, 2004)

National Waste Policy: Australia has a National Waste Policy that covers hazardous wastes and substances, gaseous, liquid and solid wastes in the municipal, commercial and industrial, construction and demolition waste streams. The policy aims to:

- Avoid the generation of waste, reduce the amount of waste (including hazardous waste) for disposal
- Manage waste as a resource
- Ensure that waste treatment, disposal, recovery and re-use is undertaken in a safe, scientific and environmentally sound manner, and
- Contribute to the reduction in greenhouse gas emissions, energy conservation and production, water efficiency and the productivity of the land.

(AGDE, 2012)

The policy has set out six key areas and identified 16 priority strategies that will put focus across jurisdictions, enhance current directions and compliment existing activities. Both business and community will be provided with clarity. The six key areas are:

1. Taking responsibility-Shared responsibility for reducing the environmental, health and safety footprint of products and materials across the manufacture-supply-consumption chain and at end-of-life.
2. Improving the market-Efficient and effective Australian markets operate for waste and recovered resources, with local technology and innovation being sought after internationally.
3. Pursuing sustainability-Less waste and improved use of waste to achieve broader environmental, social and economic benefits.
4. Reducing hazard and risk-Reduction of potentially hazardous content of wastes with consistent, safe and accountable waste recovery, handling and disposal.
5. Tailoring solutions-Increased capacity in regional, remote and Indigenous communities to manage waste and recover and re-use resources.
6. Providing the evidence-Access by decision makers to meaningful, accurate and current national waste and resource recovery data and information to measure progress and educate and inform the behaviour and the choices of the community.

(AGDE, 2012)

The state of Victoria has an **Environmental Protection Policy (SEPP)** that protects the waters of the state. The policy sets the framework for agencies, businesses and the community in order to achieve a sustainable management of Victoria´s surface water.

The policy has three main features:

1. Beneficial uses
2. Environmental quality objectives
3. Attainment program

(EPA Victoria, 2012)

The health of surface water directly impact the usability and value of the water for drinking, industrial use and the ability to support aquatic ecosystems. The state of Victoria intends to achieve protection of the **beneficial uses** by maintaining the level of environmental quality or through realistically achievable improvements. (EPA Victoria, 2012)

EPA Victoria have identified the following beneficial uses of water environments:

- Aquatic plants and animals
- Water suitable for aquaculture and edible seafood
- Water-based recreation
- Water suitable for human consumption
- Cultural and spiritual values
- Water suitable for industry and shipping
- Water suitable for agriculture.

(EPA Victoria, 2012)

Beneficial uses of water environments are those uses identified to be of importance to communities to protect both now and in the future. At present not all beneficial uses in all water environments are protected and that´s the challenge that lays ahead. (EPA Victoria, 2012)

The State environment protection policies uses set **environmental quality objectives and indicators** to be able to measure the grade of protection of the beneficial uses including:

- Water quality indicators
- Biological indicators
- Flow
- Sediment quality
- Habitat indicators.

(EPA Victoria, 2012)

These policies include long term objectives and targets that will assure attainment of the objectives and drive continuous improvement. (EPA Victoria, 2012)

The SEPP defines the actions needed to meet its purpose. The policies would be very ineffectual if they didn´t provide this information. The **Attainment program**:

- Identifies clear roles and responsibilities for environment protection and rehabilitation
- Identifies strategic actions and tools to address activities that pose a risk to Victoria's water environments.

Strategic measures in the attainment program should support, integrate and build upon existing environmental management arrangements that are in place for the state of Victoria. (EPA Victoria, 2012)

Australia began a **National Eutrophication Management Program (NEMP)**, in 1995. It had three objectives:

1. Gaining an improved understanding of the processes leading to the initiation and development of algal blooms.
2. Developing techniques to prevent and manage eutrophication.
3. Effectively communicating the outcomes of the previous two objectives.

The program was reviewed in 2000 and it showed that the projects funded by the NEMP significantly increased the knowledge of the processes behind algal blooms in terms of sources of nutrients, nutrient and light availability and river flow effects. The knowledge on the impacts of episodic alga blooms did however not advance as predicted.

It is estimated that the cost of algal blooms to Australia is $ 180-240 million annually. The NEMP was assumed to be able to reduce this cost by 0.25 % yearly.

6.3 Summary

6.3.1 Energy

Both Sweden and Australia have ambitious targets set for reducing carbon emissions and shift to renewable energy sources. The countries have very different energy mixes where Australia´s is much more fossil fuel based. Sweden has so far been successful in reducing its emissions. An important factor behind the high share of bioenergy is the carbon tax that was introduced in 1991. Australia intends to go in the same direction as Sweden by introducing a Carbon Pollution Reduction Scheme. As a first step a carbon tax was introduced in 2012, but it is highly debated and the political opposition and the industry are critical. It remains unclear if a change of government could scupper the carbon tax.

The Bioenergy potential in Australia is hugely unutilised. The biggest reason for this is the strong protection of native forests and the public opposition against using its residues for energy production.

6.3.2 Agriculture

Agriculture is a very important export sector for the Australian economy, and Australian export feed about 60 million people globally. There is a high ambition that the sector should grow significantly in the future. Key words for Australian agriculture are food safety, sustainability and world-leading research. Australian agriculture receives very low subsidies compared to the rest of the developed world. There are however substantial governmental support to receive in terms of exceptional circumstances or for applying more sustainable practices. The **National food plan** outlines the path to make Australia world leading within agriculture. This will require productivity, sustainability and quality to increase significantly in the coming decades.

Sweden had tried to tax mineral fertilizers in order to limit the environmental pollution from primarily nitrogen and cadmium, but the tax had little effect and was abolished in 2010 to make Swedish agriculture more competitive. Agriculture policies in Sweden are based on directives from the EU. It is compared to Australia highly subsidy intense. The new edition of CAP however promotes more sustainable agriculture practices and don´t encourage as much use of fertilizers and pesticides as the previous edition.

6.3.3 Environment

The main driver for UD in Sweden has been efforts to limit eutrophication and intergovernmental agreements to restore the ecological status of the sensitive Baltic Sea have had some success. Sweden also has national environmental goals to reduce the eutrophication and the EPA has also acknowledged the importance of returning nutrients from the waste stream to productive land. How to best recover nutrients is currently investigated to be the bases of future strategies.

Australia also has a long history of environmental protection. Strong environmental protection of native forests has however limited the development of bioenergy in the country. Eutrophication is a problem that affects many important industries in Australia like fishery and agriculture. It costs society a great deal every year. Legislation limits the possibility to recover nutrients from swage sludge and very little nutrients are recovered from the wastewater stream in Australia.

7. Kinglake case study

7.1 Background

The largest urine diversion trial in Australia to present is the Kinglake project. Kinglake, Victoria is an area not far from Melbourne, which was severely hit by bushfires in 2009 (YVW, 2012). As the destroyed properties were rebuilt, Yarra Valley Water in partnership with residents, Victorian Water Trust and the Shire of Murrindindi started a project that would provide a sustainable and integrated sewage service to the properties in Kinglake West. The area was selected for the trial through theoretical studies and the region was found to struggle with many of the challenges typical to backlog areas, such as failing septic systems, remote from existing infrastructure and in an environmentally sensitive area (ibid.). The service was provided to 93 properties, which formerly used septic tank systems to manage their wastewater (ibid.). The most distinguishing feature of the Kinglake project was the installation of urine diverting toilets and the local recycling of the urine for agriculture purpose. The collected urine was to be used as a sustainable alternative to artificial fertilisers at a local turf farm (YVW, 2012). 23 properties were selected to participate in the UD trial and 30 UDTs were installed in total (ibid).

UD for agricultural purposes was basically non-existing in Australia and no real legislation around it was yet introduced. Due to this Health Regulators, the EPA and the Plumbing Industry Commission were advised by Yarra Valley Water (YVW) before the start of Kinglake project (Pamminger, 2012). The health regulators did first not have any specific requirements as long as the urine wasn´t used in food production (ibid.). Later they changed that and requested a risk assessment of the process (ibid.). The EPA had no specific requirements unique to UD, however the toilets used in the trial did not have WaterMark certifications against Australian Standards approval and a special permit was arranged for the Kinglake research project (ibid.). The fact that products can´t be legally installed into a plumbing system without the WaterMark has blocked previous UD trials in Australia (ibid.). The UDT model for the Kinglake trial was selected based on overseas experience and the choice fell on the Wostman Ecoflush. It was considered to be most similar to existing Australian toilets in terms of user-friendliness, maintenance, appearance, flush volume and cost. (CSIRO, 2012b)

This case study is based on the design and pre-study of the Kinglake trial, the final evaluation report and a site visit. The findings of the Kinglake case study are compared to the other findings in this thesis and are discussed under chapter 8.

7.2 Trial design

The new service contained a sophisticated septic tank system combined with a separate grey water system on each property. Each system is connected to a local sewerage system, which treats and recycles the collected wastewater. (YVW, 2012)

On top of that 23 properties got equipped with UDTs. Every property in the Kinglake trial had a storage tank installed that was designed to provide 60 days of storage for a household of four. In reality the tanks had to be emptied more frequently than that to prevent overflow. (CSIRO, 2012b)

Yellow water was collected into portable 1000 L plastic "cubes" by pumping, and these tanks could easily be transported and batched for storage. (CSIRO, 2012b)

7.3 Objectives

The main objective of the Kinglake project was to achieve the best possible environmental and community benefits to a lower cost, and this way demonstrate the considerable local environmental and health improvements this innovative sewage system could offer, and to find out weather it could be viable in other areas (small communities). Other benefits except recovering nutrients were also identified: (CSIRO, 2012b)

- Decreasing environmental contamination from nutrients, pharmaceuticals and hormones;
- Energy savings at wastewater treatment facilities; and
- Water conservation.

(CSIRO, 2012b)

A pre modelling showed that the following load reductions in wastewater discharge could potentially be achieved by a UD scheme:

- A reduction of 81% in nitrogen loads per year (689 Kg less)
- A reduction of 31% in phosphorous loads per year (69 Kg less)
- A reduction of 17% in BOD loads per year (517 Kg less)

(CSIRO, 2012b)

7.4 Agronomic trial

An agronomical trial was also was also conducted at a local turf farm. Urine is interesting as a fertilizer since it contains about 80% of the nitrogen and 50% of the phosphorus in domestic wastewater but only constitutes 1% of the total volume. Recovering urine also has the following benefits:

(CSIRO, 2012b)

- Reduced environmental contamination from nutrients
- Energy saving at WWTP
- More efficient anaerobic digestion of blackwater
- Water conservation
- Reduces demand for phosphate rock fertilizer, which is depleted non-renewable resource

(CSIRO, 2012b)

The literature is lacking empirical studies that have investigated the above benefits in full-scale case studies. There is also little understanding about the cost effectiveness of UD and nutrient recovery for agricultural production in the whole supply chain of yellow water, compared to other alternative fertilizers. (CSIRO, 2012b)

It was suitable to use a turf farm in the agricultural trial with yellow water since turf requires high and regular amounts of fertilizers, is a resilient crop that tolerates the salinity in yellow water and is not a food crop. A local turf farm (Green acres) was willing to participate in the trial despite the rather unexplored impacts from using yellow water. Following a Quantitative Microbial Risk Assessment (QMRA) supplied to the Victorian Department of Health, all potential routes to humans were identified and measures were taken to reduce risk of pathogen spreading. The main measure was storage of the yellow water for at least 6 months according WHO guidelines. (CSIRO, 2012b)

Agronomic scientist Roger Wrigley at the University of Melbourne designed and supervised the trial. Yellow water from 40 storage cubes were analysed in order to determine the application rate. The analysis showed much lower nutrient contents than expected from literature reviews. This was due to high dilution by flush water. The levels were also significantly variable among the cubes but that could not be correlated to age. Generally storage time doesn´t affect the nitrogen content if collection system and storage is sealed. Also phosphorus and potassium levels varied highly between the cubes. This variability was assumed to be caused by different flushing habits between households and not due to differences in urine composition depending on different diets. The batches need to be somehow homogenous to supply a reliable nutrient source to the turf farm and the need for adjustment of application rates was a major barrier for reuse. (CSIRO, 2012b)

Yellow water was compared with various commercially available fertilizers and growth promotants in terms of nutrient contents (N:P:K ratio). The Kinglake yellow water was found to be lower in nutrients but much higher in salinity. This fact made it impossible for yellow water to replace other fertilizers entirely without salinity causing problems. (CSIRO, 2012b)

Five turf strips of 8m x 315m were used for the agronomic trial. Two different loadings of yellow water were applied to the trialled turf strips. The turf farm ordinarily used a commercial kelp-based growth promotant called Seasol, in addition to fertilizers. Seasol has similar characteristics to yellow water, such as being organic, which makes them quicker to absorb by plants. The turf farm was very interested to see if yellow water could further enhance the turf growth. (CSIRO, 2012b)

The application method for yellow water was identical to the one used for Seasol (tractor towed spray irrigator). The low loading strip was applied with 2500 L of yellow water over 2 months whereas the high loading strip got the double amount. The low nutrient content in yellow water required a high application rate, and due to limitations in irrigation speed with spray nozzles, the tractor had to travel at very slow pace and with multiple passes. It was calculated that two hours were needed to apply the recommended 4000 l of yellow water to the 0,5 ha trial plot. This meant that yellow water fertilization would require more labour hours than ordinary method (only 400 l of seasol was required). A strong unpleased odour was experienced during application by the staff at the turf farm. The odour did however dissipated rapidly and was not detected outside the property. It was also observed by staff that yellow water had a corrosive effect on steelwork, and stripped it from paint over time. Because of this there was a reluctance to use the yellow water in their sprayers. (CSIRO, 2012b)

The soil was analysed both before and after application of yellow water. The samples did not indicate that yellow water had a significant change on soil chemistry. No visible detrimental impact on plant heath was observed either, however the grass became eye-catchingly greener with yellow water, which was considered a success. Replicated trials would though be needed to confirm this. Despite this success could yellow water not replace growth promotants such as Seasoil in a cost effective way. On top of that salinity was a factor that prevented yellow water from being applied at higher rates as a substitute to fertilizers. The time and effort required to apply yellow water spoil the economics of urine diversion if the yellow water is too diluted. Requirements to make yellow water for agricultural use viable was found to be:

(CSIRO, 2012b)

- Improved toilet design and behaviour change amongst UDT users, to reduce the dilution of yellow water.

- Irrigation equipment that allows greater rates of application.

- A method of improving the homogeneity of yellow water collected from different sources. This could take the form of a few large storage tanks rather than small 1kL batches.

(CSIRO, 2012b)

7.5 Social research

Because of lack of UD trials in Australia, the level user acceptance of households beforehand could only be assumed or based on overseas experience before the trial. A European review in 2009 revealed a high degree of acceptance for UDTs both in homes and public spaces. They were found favourable among users compared to conventional toilets in many aspects such as design, hygiene, and smell, but there were also concerns about poor flush performance and more extensive cleaning requirements. Even if the concept of UDT were widely accepted in households, only a few would keep them unless total performance was improved. According to the report it was also vital that people were convinced about the environmental benefits of UD in order to be successful. In a Swedish trial where most of the urine was transported back to the local WWTP the acceptance was found very low, since there was no tolerance for practical inconvenience if the ecological benefit was insignificant. (CSIRO, 2012b)

During the Kinglake trial social research was also conducted and it confirmed the above conclusions in an Australian context, improvements in UDT design is necessary for widespread uptake. In a few households the UDTs were early replaced by conventional toilets at the homeowners request. On the whole however, people were prepared to adopt the new technology despite its deficiencies. One of the main factors to peoples high level of acceptance was the comprehensive support provided by YVW is the form of materials (manuals, signage and cleaning kits) and personal contact and service. When evaluating the Kinglake project the issues caused by UD were considered far minor compared to the faulty greywater systems. (CSIRO, 2012b)

7.6 Outcome

The findings of the Kinglake trial was that the projected environmental improvements were lower than expected and came at a higher cost than anticipated. The additional direct costs exceeded the external environmental benefits that in the early days of the project were instrumental in justifying it. Table 1 below shows the actual achievements in relation to the predicted ones:

(CSIRO, 2012b)

Table 1. Outcome of the Kinglake project

Parameter	**Theoretical prediction**	**Actual results achieved**
Economic savings	Up to 20%	Approximately 40% more expensive
Increase in reliability in of water supply	From 90% to 100%	100%
Reduction in wastewater discharges	Up to 50%	28%
Reduced nitrogen loads to the STP	Up to 80%	56%
Reduction in greenhouse gas emissions	30%	Not yet determined but unlikely to be achieved

(CSIRO, 2012b)

The main findings of the UD and yellow water reuse were the following:

- Using urine-separating toilets does significantly reduce the nutrient load going to the sewage treatment plant.

- Harvested nutrients from domestic sewage can deliver agronomic benefits. The Kinglake West agronomic trial of yellow water demonstrated the potential benefits on the crop health of turfgrass, while arguably delivering a better visual quality.

- Application of yellow water from urine separating toilets was found to be in the order of 100 times more expensive than commercially available fertilizers.

- A major contributor to the high costs was the significant dilution of the urine with toilet flush water. This dilution increased the costs associated with collecting, transporting and storing the yellow water and then increases the need for increased effort to achieve required application concentrations. (See table 2.)

- The viability would be enhanced with a refined toilet design that uses less water, and/or higher density collection sites.

- Multi story buildings using waterless urinals are seen as a potentially feasible urine-harvesting site.

(CSIRO, 2012b)

The evaluation of the Kinglake trial also provided useful pointers for implementation of future trial projects for the wastewater sector in Australia:

- Developing a strong partnership with stakeholders contributes positively to the success of a new servicing project such as this. In this instance, a strong partnership was created among a water utility, local community, a turf farmer, regulatory authorities and research organisations.

- Trialling new products in new environments would benefit from first being testing in a small-scale pilot trial. In this case, the project would have benefited from a pilot trial of the urine diverting toilets and greywater systems. This would have identified that there was a significant difference between the manufacturer's specifications for the performance of the urine separating toilets and greywater systems with the actual performance observed at Kinglake West.

- The trialling of new products often incurs unforeseen costs. The uncertainly in the costs associated with innovative servicing approaches needs to be accounted for. The capital costs of the Kinglake West project are likely to be as much as 60% higher than forecast.

- Finally, innovative approaches benefit greatly from post implementation assessment and monitoring, such as occurred in this project. This ensures that lessons can be used for refining approaches for future YVW projects, while also providing the broader urban water sector with important knowledge that can help facilitate increased adoption of more sustainable approaches.

(CSIRO, 2012b)

Table 3. UDT performance/specification

Performance	Manufacturer's Specification	Actual Performance
Urine flush volume	0,2 l	1,3 l
Full flush volume	2,5 l	5,1 l

(CSIRO, 2012b)

Even if the environmental outcome was worse than expected, valuable insights were obtained when reviewing what was required to construct the wastewater service scheme and in operating it. The system introduced at Kinglake West was very innovative and the actual performance was quite uncertain in reality. Better acceptance and development of the technology was considered likely to solve many practical issues and increase the performance and reliability. (CSIRO, 2012b)

The success of a UD scheme depends on many factors. One is short transport distances for reuse. It was found during the Kinglake trial that after 50 km of transport the greenhouse gas emissions outweighs the benefits of replacing mineral fertilizers and reducing nutrient contents in sewage volumes (for one litre of flush volume). (CSIRO, 2012b)

It was investigated if phosphorus could be chemically precipitated as struvite in large schemes to reduce transport and storage volumes and this way improve the economical viability of UD. This was however found not to be viable since the current price of fertilizers was lower than the cost of magnesium that is needed for the struvite precipitation process. (CSIRO, 2012b)

8. Discussion

It is clear that alternative sources of nutrients need to be utilised in the near future to achieve a sustainable global (and regional) food security with growing population and growing need for bioenergy. There is a lack of consensus regarding the remaining reserves of nutrients in the world and the industry is more optimistic than the academia. Peak phosphorus is a term that has gained acceptance in recent years and the production of high-grade phosphate rock might peak in a few decades. But the debate on peak phosphorus is basically the same as with peak oil. New technologies for extraction are developed continuously and as long as we are dependant on oil it will always be profitable to extract it. Since phosphorus is absolutely vital to food production we are even more dependent on it than oil, and extraction can probably go on another couple of hundred years. This extraction however comes with a price. The environmental aspects of mining are indisputable and the negative effects will be even more severe when low-grade phosphate is exploited or sea sediments are harvested in coastal areas. Mining is also often far from civilization and transports will have further negative environmental impact. Only a few countries in the world have findings of high-grade phosphate rock, and this will lead to inequities globally since food prices will be affected by more expensive fertilizers, hampering the attempts to achieve global food security.

Perhaps phosphorus has gotten too much attention when discussing food security. Nitrogen is just as important as phosphorus to grow plants and crops. Even thought it will never become scarce (78% of the atmosphere consists of it) it is very fossil and energy intense to transform into a plant available form. The cheapest way of producing nitrogen fertilizers is currently with natural gas that also is a finite resource. Emerging climate change also further complicates the fertilizer production in the wake of its fossil fuel dependence. Considering this and that also potassium derive from rock that takes very long time to form, and that the cheapest sulphur that we use today in fertilizers is becoming scarce, the debate on food security and alternative nutrient sources should contemplate not only phosphorus but at least all the four main nutrients (N, P, K, S).

The agriculture sector in Australia is important to the economy and the country depends on import of fertilizers, much due to very poor soils. On the other hand Australia exports 60% of its produced food, which means a lot of nutrients are actually exported also.

At the same time as the soils lack nutrients, streams, lakes, other waterways and ultimately the sea have nutrients in excess (deriving from agriculture and sewage discharge etc.), which causes eutrophication that harms ecosystems and other important businesses such as fishery. This means that there are nutrients in the system that are not properly utilised. Modern sanitation is based on WWTPs that clean our wastewater from nutrients and pathogens before discharging it to a recipient without much recovery of nutrients. It is hard, energy intense and expensive to clean wastewater to such extent that nutrients won´t cause problems in aquatic systems. On top of that the treatment process of ammonia has a significant risk of emitting nitrous oxide, which is a very potent greenhouse gas.

The most common and widespread way of returning nutrients from the wastewater stream to soil is my spreading the sludge that remains after wastewater treatment. Regulations restrict the use of sludge in agriculture due to the quality of the sludge, that sometimes contains too high levels of heavy metals (especially Cd) and organic compounds. There is also a public reluctance to use sewage sludge for agriculture purposes and from consumers to buy the food produced in such matter.

By separating urine at source (in the toilet bowl (or urinals)), it can become easier and safer to utilise the nutrients in the wastewater stream. Since urine contains most of the nutrients in wastewater, only makes up for 1% of the total wastewater stream and does not contain any heavy metals and very low levels of pathogens, the only treatment required to comply with health regulations (not in all countries) is storage for a period of time to kill of bacteria. UD will also reduce the need for wastewater treatment since fewer nutrients reach the WWTPs, as well as saving both water and energy. Sweden has practiced UD since the early 90s with various successes, however it is almost novel in Australia. The ambitious Kinglake trial has for the first time tested UD at any scale in an Australian context. Even though the trial wasn´t completely successful, it has showed how sewage services can be more sustainably provided in areas not connected to the communal sewage system. It is a ground breaking project in Australia and can hopefully pave the way for future UD development.

The environmental benefits with UD have been proven in many trials around the world as well as at Kinglake. However there are other factors that have limited the development of UD. Even if acceptance have been high for UD toilets it is clear that the toilets still aren´t sufficiently developed yet. They still have flaws such as pipes blockage, odour, over water consumption and additional cleaning requirements. Because there is no real demand on the market, development of UD models is rather slow. Most of these problems are however not major and a lot of practical issues can be solved with traditional and sometimes creative plumbing.

The potency of urine as a fertilizer has also been proved in trials around the world and not least at Kinglake. Urine contains all the vital nutrients needed for plant growth and has the potential to be a good fertilizer. Concerns have to be taken into consideration when it comes to salinization in dry climate and spreading of pharmaceuticals through the urine, but so far no major fears have emerged in trials with urine. The precautionary principle should however be applied in this case.

The biggest barrier for UD in trials has not been if urine could be a complimentary nutrient source and replace conventional fertilizers, but to make it a viable business case. So far the value of the nutrients in urine have been unable to compete with conventional fertilizers when collection, storage, transport and application have been taken into consideration. In the Kinglake trial it was even 100 times more expensive to use urine than the ordinary fertilizers. The biggest reason for the low value of the nutrients in yellow water from Kinglake was the high dilution. The UD toilets used had much larger flush volume than the manufacturer claimed. Also other aspects of the UD toilet such as odour and blockage of the drains, made users flush more frequently than anticipated, resulting in low nutrient concentration in the yellow water end product. This shows that the products for urine separation are still not adequately developed even thought they have been on the marked since the early 90s. Since the market still is rather small for UD toilets there is inertia in the development from the sanitation industry. Many scientific UD trials have been carried out around the world, and data from these can be very helpful to the industry in order to refine the products.

Waterless urinals are gaining stronghold around the world and this can prove a real opportunity for UD. It means that large volumes of undiluted urine can easily be diverted to a collection tank instead of the conventional sewage drain. The low dilution can prove to be key to make urine competitive with mineral fertilizers. This will though require proximity to application, which is not always the case in an urban setting.

There are many ways to recover nutrients from the wastewater stream. As mentioned before, spreading hygienized sewage sludge is one of them. The sludge can also be incinerated to remove heavy metals and other unwanted substances and a third method is to precipitate nutrients (primarily phosphorus) from the wastewater. Which method to use depends greatly on local conditions. Legislation, public and political acceptance, quality of the sludge and geography are factors that can determine which method to use. In Sweden spreading of sludge is most widespread and as for Australia some sludge is applied to productive land, but not to a large extent. The sludge is not considered safe enough to spread. Under Swedish conditions these methods have been compared to mineral fertilizers from a sustainability point of view and it was found that only spreading of sludge was considered more sustainable. UD was not evaluated in the Swedish study, however it can be assumed to perform better in a LCA since it contains most of the nutrients found in the sludge, but at are at the same time free from heavy metals that is the major concern in sewage sludge.

Even if it´s not yet considered economically viable to practice above methods for nutrient recovery in Australia, it is changing. There are full-scale precipitation plants up and running in North America, and pilot projects in Europe. Countries in Europe with legislation that prevents spreading of sludge incinerate it and then recover the remaining nutrients in the ashes. Growing demand for nutrients and depleting mineral reserves will make nutrient recovery even more viable in a not too distant future.

There is a real potential for UD in Australia and since it is almost novel in the country there is no real legislation prohibiting it. If more trials can show the benefits of UD and solve the technical and organisational issues around it, guidelines can be drawn for urine use to gain acceptance and make it competitive with convectional fertilizers.

It is difficult to identify the stakeholders that are most likely to drive UD development in Australia. The sanitary industry has yet not seen the commercial potential in refining their UD separating products. Farmers need to be sure that urine can deliver the same yields as conventional fertilizers, or at least be cheap enough to compliment them. It also has to be convenient to handle and apply the urine, but maybe most importantly the consumers need to accept that their food is produced with human urine and be convinced that it is safe. The interest of households to start separating their urine is perhaps not obvious, but keeping in mind that wastewater treatment services are expensive, both the households and the wastewater industry would benefit from lower nutrient loads reaching the WWTPs. The problem can also be looked at from a societal perspective. The value of the nutrients in urine might be more fairly evaluated if other benefits to society from UD such as ecosystem services protection, water savings and energy savings are considered. Swedish examples have shown that UD is successful as long as municipalities cover the cost of urine transport to the fields as well as storage, and this can be an option until other factors have made urine more competitive as a fertilizer.

Since there is lack of direct financial incentives for applying UD, the main driver has been limitation of eutrophication. In Sweden the attempts to save the sensitive Baltic Sea, has acted as a driver for UD trials. The Helsinki Commission (HELCOM) was a very important policy tool in fighting eutrophication. There is however a lot of work to be done and the Baltic Sea are far from a sea in balance, but this kind of intergovernmental/interstate agreement is absolutely necessary to cope with complicated environmental problems. A major contributor to eutrophication is private sewers. 85 % of the population in Sweden is connected to the public sewer system but yet private sewers contribute to 50 % of the P discharge. Assuming Australia has at least the same allocation as Sweden, the need for alternative distributed sewage solutions is obvious.

Another very important driver in Sweden is the environmental goal of returning 60% of the P in the wastewater stream to productive land by 2015. No such policy has been found in Australia during this study.

Australia is an agricultural country with high ambitions of being a world leader in agricultural science. The export of food is high (feeding 60 million people) as well as the global contribution to agricultural technology and innovation. This high ambition is outlined in many national strategies for both food production and resource management, which makes it remarkable that no national targets for nutrient recovery have been set. Australia imports a lot of its nutrients but then export them in the form of food products. This equation makes it very obvious that all available nutrients should be utilised in order to make Australia more self-sustaining. Australia would benefit from adopting similar national goals for nutrient recovery as Sweden has.

Australia is also at a stage where fossil fuel dependence needs to decrease. It is one of the countries where climate change already have become noticeable in terms of extreme weathers in an already extreme climate. At the same time Australia is one of the larges CO_2 emitters in the world. One way out of fossil fuel dependence is bioenergy. Bioenergy is so far quite poorly utilised in Australia due to strong protection of native forests etc. However there is a big potential to increase the domestic production of bioenergy substantially and when this happens the demand for nutrients will increase further. Australia is no longer an exporter, but and importer of oil, and this could potentially spark the interest in biofuels in the wake of energy security concerns.

There have been similar findings in Sweden and Australia when it comes to UD. Wastewater regulations are not adapted to UD. As mentioned before the UDT´s available on the market are still not up to standards. The common knowledge about separating urine at source and using it for fertilization is rather poor. It´s not something that comes to mind when choosing wastewater solutions. It might not be considered modern or even a step back in development. Information needs to be spread in order for UD to become an option and even more accepted. Existing wastewater infrastructure is not adapted to UD and this makes UD most viable in new developments or rural in areas without public sewers.

As with other new technologies (UD is however not new), a "push" of some sort is needed to make it viable. Renewable energy has recently gone through the process of subsidies, changed policies and other governmental incentives and is starting to pay off. Something similar might be needed to drive UD development forward. Nutrients will have to be recycled to a far greater extent than today and a long-term strategy is needed both in Australia and globally. UD could play a significant role in this development if the obstacles presented in this thesis can be overcome.

9. Conclusions and Recommendations

The UD sanitation products that are available on the market today have clear flaws. Even if public acceptance when understanding the benefits of UD diversion is relatively high, additional cleaning, odour and high water consumption hinder extensive development. The sanitation industry needs to be more engaged with all different stakeholders in order to drive the development forward. Without a defined market the industry has little interest in refining its products, but by involving them in the full process of UD development they can perhaps see the potential in a future market. The fact that the models available today do not comply with Australian plumbing regulations is something that needs to be overcome in the future.

There is a lack of legislation and guidelines around agricultural use of urine in Australia. This needs to be more clearly defined, and in this process policy makers and regulators can either facilitate the emergence of UD or curb it. Legislation is currently restricting the use of biosolids in agriculture and this makes use of urine interesting since it contains less pollutants and is still high in nutrients. The environmental impact of pharmaceuticals and hormones spread through urine however needs to be better monitored in the future, in order to conclude if further treatment is necessary before agricultural use.

There is a need for specific policies that promote nutrient recovery. At present Australia seems to be lacking a clear strategy on how to recycle nutrients from the wastewater stream (and other sources). With the high national ambition of a world leading agricultural sector in the wake of the "Asian Century", there should be a major thrust to optimize nutrient management and recycling. Sweden has an environmental goal of returning nutrients from the wastewater stream to productive land. Such goal would be a good driver for Australia to improve their nutrient management and food security, since the fertilizer market is complex and many factors can distort it. There will be funding available for further UD trials and research under the **National Food Plan**.

When considering methods for nutrient recovery, not only the value of the recovered nutrients should be considered. A more holistic sustainability approach needs to be taken into account so that externalities such as wastewater treatment, spreading of heavy metals, greenhouse gas emissions and eutrophication, that bares other big costs to society is not forgotten. In this big picture optimized UD can stand out from other alternatives in terms of number and concentration of nutrients recovered, water consumption, energy consumption and spreading of harmful substances.

It is unlikely that any way of recovering nutrients will gain any ground unless it's economically viable. Policies and legislation can help promote UD development, but ultimately the cost of the recovered nutrients need to be competitive with conventional fertilizers.

The Kinglake project has paved way for UD in Australia and even if many objectives were not met, many important lessons were leaned under local conditions. The next step in Australian UD development would be to trial it in a more urban setting. Waterless urinals will solve one of the key issues with high dilution of yellow water. It will also be easier to collect greater volumes of urine from multi storage buildings and it would be interesting to integrate an urban UD trial with an urban agriculture project. This would be an exciting step towards making cities less dependant on rural areas for such fundamentals as food. There is a need to make future cities more self-sufficient in order to prevent ecosystem depletion. Victorian Eco-innovation Lab (VEIL) are involved in such projects and could be a potential partner in such future projects.

"*Only after the last tree has been cut down,*
only after the last river has been poisoned,
only after the last fish has been caught,
only then will you find that money can not be eaten".

Cree Indian prophecy

References

AG, (2013). Australian Government – National Food Plan. (2013-06-03)

AGDE, (2012). Australian Government Department of the Environment – About the national waste policy. [http://www.environment.gov.au/topics/environment-protection/national-waste-policy/about-policy], (2012-02-10)

Cordell, D, (2010) Sustainability implications of global phosphorus scarcity for food security. [http://liu.diva-portal.org/smash/get/diva2:291760/FULLTEXT01], (2012-04-23)

CSIRO, (2012a). Recovering energy and nutrients from wastewaters. [http://genetech.csiro.au/~/media/CSIROau/Flagships/Water%20for%20a%20Healthy%20Country%20Flagship/ResourceRecovery_WfHC_Factsheet%20Standard.pdf.], (2012-04-22)

CSIRO, (2012b). Kinglake West Sewerage Project – Post-implementation project review. Francis Pamminger by email, (2013-06-03)

DE, (2013). Department of the Environment – National targets. [http://www.climatechange.gov.au/climate-change/greenhouse-gas-measurement-and-reporting/australias-emissions-projections/national], (2013-07-18)

Drew, Nick. Executive Manager, Fertilizer Industry Federation of Australia 2012. Questions by email (2012-04-18)

EAWAG, (2007). Mix or NoMix? – A closer look at urine source separation. [http://www.eawag.ch/medien/publ/eanews/archiv/news_63/en63e.pdf], (2012-02-12)

ECOS, (2010). Peak Fertilizer.

[http://www.ecosmagazine.com/paper/EC156p9.htm], (2012-02-15)

Energimyndigheten, (2012). Mål rörande energianvändning i Sverige och EU. [http://www.energimyndigheten.se/sv/Offentlig-sektor/Tillsynsvagledning/Mal-rorande-energianvandning-i-Sverige-och-EU/], (2012-07-13)

Energi, (2013). Sverige har över 50 procent förnybar energiförsörjning. [http://www.energinyheter.se/2013/03/sverige-har-ver-50-procent-f-rnybar-energif-rs-rjning], (2013-07-01)

EPA Victoria, (2004). Biosolids land application. [http://www.epa.vic.gov.au/~/media/Publications/943.pdf], (2013-05-29)

EPA Victoria, (2012). Water related policies. [http://www.epa.vic.gov.au/about-us/legislation/water-legislation/water-related-policies], (2012-05-14)

EU, (2010). EU:s nitratdirektiv. [http://ec.europa.eu/environment/pubs/pdf/factsheets/nitrates/sv.pdf], (2013-07-09)

FAO, (2009). 2050: A third more mouths to feed. [http://www.fao.org/news/story/en/item/35571/], (2012-02-02)

FAO, (2011). THE STATE OF THE WORLD'S LAND AND WATER RESOURCES FOR FOOD AND AGRICULTURE.

[http://www.fao.org/docrep/017/i1688e/i1688e.pdf], (2012-05-16)

FIFA, (2010). The Australian Fertilizer industry – values and issues. [http://www.fertilizer.org.au/files/pdf/publications/Australian%20Fertilizer%20Industry%20Value%20and%20Issues%20August%202010.pdf], (2013-07-16)

Havs och vattenmyndigheten, (2013). Regeringsuppdrag Enskilda avlopp. [https://www.havochvatten.se/tillstandsprovning-och-tillsyn/tillsyn/tillsynsvagledning-inom-miljobalkens-omrade/enskilda-avlopp/regeringsuppdrag-enskilda-avlopp.html], (2013-06-17)

HELCOM, (2012). About HELCOM. [http://www.helcom.fi/helcom/en_GB/aboutus/], (2012-05-19)

IFA (2012a). What are plant nutrients?. [http://www.fertilizer.org/ifa/HomePage/FERTILIZERS-THE-INDUSTRY/What-are-nutrients], (2012-02-02)

IFA (2012b). What are fertilizers?. [http://www.fertilizer.org/ifa/HomePage/FERTILIZERS-THE-INDUSTRY/What-are-fertilizers], (2012-02-02)

IFA, (2012c). Statistics – Fertilizer Indicators – Details – Raw material reserves (2002-10). [http://www.fertilizer.org/ifa/HomePage/STATISTICS], (2012-06-08)

IPM, (2005). Natural gas prices affect nitrogen fertilizer costs. [http://www.ipm.iastate.edu/ipm/icm/2001/1-29-2001/natgasfert.html], (2012-02-17)

Johansson, M. et al, (2000) Urine separation: Closing the nutrient cycle. Prepared for the Stockholm Water Company, Sweden [http://www.swedenviro.se/gemensamma_se/documents/Urinsep_eng.pdf], (2012-02-03)

Jönsson, Håkan. Swedish University of Agricultural Sciences 2012. Questions by email and phone interview (2012-03-08)

Linderholm, K. et al, (2012). Life cycle assessment of phosphorus alternatives for Swedish agriculture. Resources, Conservation and Recycling. By email, (2012-12-10)

LRF, (2013). Vad innebär REVAQ-systemet - ceritfiering av reningsverk?. [http://www.lrf.se/Miljo/Avloppsslam/REVAQ-certifiering/], (2013-10-06)

Länsstyrelserna, (2008). Utvärdering av urinsortering och torrtoaletter i Tanums kommun. [http://www.lansstyrelsen.se/vastragotaland/SiteCollectionDocuments/sv/publikationer/2008/2008_88.pdf], (2012-06-01)

McCormick, K, (2013). Biofuels for Transport in Australia, Report no. f3 2013:3. [http://www.f3centre.se/sites/default/files/f3_report_2013_3_mapping_australia__130409.pdf], (2013-05-03)

Mieog, John. Team Leader, ETP Planning, Melbourne Water 2013. Questions by email (2013-05-29)

Miljömål,(2007).God bebyggd miljö. [http://www.miljomal.se/Global/24_las_mer/rapporter/miljomalsradet/fu-08/underlagsrapporter-malansvariga/underlagsrapport-fu08-god-bebyggd-miljo.pdf], (2013-05-22)

Miljömål, (2012a). Giftfri miljö - uppföljning. [http://miljömål.se/sv/Miljomalen/4-Giftfri-miljo/Nar-vi-miljokvalitetsmalet/], (2013-09-28)

Miljömål, (2012b). Ingen övergödning. [http://miljömål.se/sv/Miljomalen/7-Ingen-overgodning/], (2013-09-28)

Naturvårdsverket, (2002). Aktionspan för återföring av fosfor ur avlopp. Rapport 5214, Stockholm: Naturvårdsverket

Naturvårdsverket, (2002). Uppdatering av "Aktionsplan för återföring av fosfor ur avlopp". [http://www.naturvardsverket.se/upload/stod-i-miljoarbetet/vagledning/avloppsslam/Uppdatering_av_Aktionsplan_for_aterforing_av_fosfor_ur_avlopp.pdf], (2012-04-11)

NFF, (2012). National Farmers Federation – Farm Facts. [http://www.nff.org.au/farm-facts.html], (2012-04-12)

OECD, (2011). Australia - Agricultural Policy Monitoring and Evaluation 2011. [http://www.oecd.org/australia/australia-agriculturalpolicymonitoringandevaluation2011.htm], (2012-05-06)

Pamminger, Francis. Manager Research & Innovation at Yarra Valley Water 2012. Questions by email and personal interviews (2012-02-05 to 2013-06-17)

PC, (2012). Productivity Commission – A Quick Guide to the Productivity Commission. [http://www.pc.gov.au/about-us/quick-guide], (2012-10-18)

Rockström, J, Steffen, W, Noone, K, et al (2009). A safe operating space for humanity. Nature. Vol 461, 24 September 2009, pp 472-475

Rosemarin, A, de Bruijne, G, Caldwell, I, (2009). Peak Phosphorus – The next inconvenient truth. [http://www.thebrokeronline.eu/Articles/Peak-phosphorus], (2012-01-29)

SAR, (2013). Sustainable Australia Report 2013 – Conversations with the future. [http://www.environment.gov.au/system/files/resources/e55f5f00-b5ed-4a77-b977-da3764da72e3/files/sustainable-report-full.pdf], (2013-02-05)

SCB, (2010). Utsläpp till vatten och slamproduktion 2008. Statistiska Centralbyrån. Rapport MI 22 SM 1001.

Svebio, (2013). Fakta om bioenergi. [http://www.svebio.se/fakta-om-bioenergi], (2013-08-31)

Statskontoret, (2011). Priset på handelsgödsel efter kväveskatten. [http://www.statskontoret.se/upload/Publikationer/2011/201131.pdf], (2013-05-19)

Ulrik, K, (2013). Seeing the Forest for the Trees – Australian Forest Biomass for Energy, IIIEE Thesis 2012:25. (2013-05-17)

WHO, (2012). Food security. [http://www.who.int/trade/glossary/story028/en/], (2012-01-29)

Wrigley, R.J. et al, (2010). KINGLAKE WEST SEWERAGE PROJECT: RESEARCH PROJECT DESIGN FOR AGRICULTURAL TRIAL - YELLOW WATER AS A PLANT NUTRIENT SOURCE. Prepared for Yarra Valley Water, Melbourne, By email (2012-02-23)

YVW, (2012). Yarra Valley Water – An environmentally friendly sewerage service. [http://www.yvw.com.au/Home/Aboutus/Ourprojects/Currentprojects/KinglakeWest/index.htm], (2012-03-26)

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