IWA Resource Recovery Cluster

the international water association

State of the Art Compendium Report on Resource Recovery from Water

Preface

By Cluster Chair Willy Verstraete

Increasing population growth leads to increased resource (water, food, chemicals and energy) demand. Concomitantly, increasing volumes of ‘used resources’, commonly considered waste, are produced. There is a growing awareness that the resources that could be potentially recovered from these used streams or wastes represent economic value and should not be lost. One of the greatest challenges is pursuing sustainable and economically responsible management of all resources, primary as well as used ones.

In this context, the resources present in 'used water' deserve to receive fresh attention. Indeed, some of them (including energy and phosphorous) have already become of interest. Yet overall, the feeling that 'making the things which are present in used water dissipate, or disappear as much as possible' is still the safest and economic line of work. This is particularly so for waters contaminated with faecal matter. The cultural 'disgust' towards unhygienic matter is certainly founded on long-term sanitation practices. Nevertheless, as we are entering an era of cyclic economy that is aware of the need for integrated sustainability, it is important for the International Water Association (IWA) to demonstrate its commitment to resource recovery, in all aspects. The creation of a specific cluster overarching all specialist groups in the IWA is demonstrative of this willingness to act. This compendium aims to provide a preliminary assemblage of what can be on the agenda or could become of critical importance to get things going. The subsequent chapters thus try to raise awareness of the issues involved, and are particularly meant to activate readers from different backgrounds towards the conceptual but also pragmatic approaches of "cleantech" in the water business.

- WILLY VERSTRAETE

By Cluster Co-Chair Peter Cornel

Almost all societies and cultures throughout history have banned excreta. Long before bacteria, viruses and other pathogens were discovered it was common sense and common use to stay away from excrements and wastewater, something documented in ancient writings. These traditions and today's ambition in some regions of the world for living in an "aseptic" environment, affects our thinking and acceptance of resources and products gained from wastewater, as numerous campaigns and reservations against water reuse have shown in the past.

While accepting that resource recovery from wastewater is a must, we still have to overcome these prejudices. "Water should not be judged by its history, but by its quality", stated Louis van Vuuren form the National Institute of Water Research South Africa in 2005**[x]**. We might expand this to other products recovered from wastewater as well.

Lessons learnt from water reuse: resource recovery is far more than just a matter of technology.

- Recovered resources must be transferred in sellable products meeting product specifications
- "Fit for purpose"; the specification depends on the requirements:
  - Water reuse standards differ depending on the intended use;
  - Phosphate can be recovered in various forms (struvite, Biosolids, sewage sludge ashes etc.) but need to fulfil standards either for direct use as fertilizer or as substitutes for raw phosphate to be processed further;
  - Biopolymers, cellulose, metal recovery…pureness, texture, stability…might be quality parameters to-be adopted..

- "Loss of identity": how directly is the product linked to wastewater?
- "Branding"
  - Treated wastewater (or even better used water) should be renamed.
  - What sounds better: Treated wastewater or NEWater® **[xi]**?
  - "All water is reused water" **[xii]**
  - I am driving a used car. Would I have bought a "waste car"?

- We need customers for our products and we need their acceptance. The aim of the cluster is not developing new technologies but to focus on three main objectives:
  1. To promote resource recovery from water and wastewater, for example by identifying existing examples and exploring their potential for extending to other places, outlining possible routes for resource recovery, assessing constraints and ensuring successful marketing strategies,.
  2. To network on innovations of resource recovery through conferences, meetings, working groups, publications, etc.
  3. To promote links with complementary organisations to find proper ways to build value chains where waste is converted to resources in a well-managed and beneficial way.

This compendium aims to interest and involve people in the work of the Resource Recovery Cluster.

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Abbreviations

AD	Anaerobic Digestion
IWA	International Water Association
MAP	Magnesium Ammonium Phosphate
MFC	Microbial Fuel Cells
Mtoe	Million Tons of Oil Equivalent
PE	Population Equivalent or Unit Per Capita Loading
PHA	Polyhydroxyalkanoates
RO	Reverse Osmosis
RR	Resource Recovery
WEF	Water Environment Federation
WERF	Water Environment Research Federation

Glossary of Terms

Resource Recovery Cluster	An IWA Cluster focusing on the science and technology around the recovery of components, energy and materials for effective reuse.
Used water	Used water treatment plant.
Wastewater	Wastewater treatment plant.

Unit Conversion

1 million gallon per day (US) = 3,785 m^3 per day

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1. INTRODUCTION

Driven by environmental, economic and ecological benefits, resource recovery from water draws worldwide attention. Increasingly, resources from waste streams are being recovered. Novel forms of existing resources are now abstracted from water and wastewater based on waste streams, while more conventional forms, such as methane production, are gaining momentum. Simultaneously, major research efforts are focused on valorisation and recovery of, for instance, cellulose, bioplastics, medium-chain carboxylic acids and metals. A range of new initiatives is underway to promote and accelerate the development of science and techniques related to resource recovery. Within the plethora of initiatives there is a need to bring together a broad set of actors: to improve coordination and cooperation between science and practise, so as to accelerate innovation and adoption of appropriate resource recovery practices.

Water utilities and their consultants are becoming increasingly aware of the need to implement resource recovery. Their main motives are to: 1. Reduce costs by recovering materials; 2. Reduce energy usage with the goal of becoming carbon neutral; 3. Mitigate risks from the occurrence of precipitates, for example phosphates; the emission of odours, such as hydrogen sulphide; emission of greenhouse gases, such as methane or nitrous oxide; the discharge of metals into the environment; the increase in salinity; and economic risks from increasing prices, including for energy. Moreover, water utilities can profit from green practices that might be of interest in terms of reputation management. Thus, the industry sector is more and more supportive for the concept of resource recovery.

Recovering resources is in itself nothing new. However, major developments have recently been noticed in the up-scaling of practices and advancements of new techniques with the potential to recover water, energy and a wide array of value-added components. While there is an entire spectrum of resources to recover, this state of the art compendium will focus on resource recovery from water. Seeing as the expression "wastewater" incorrectly gives the impression that water is considered as waste, the term will henceforth be referred to as "used water" and the place to treat this water will be denoted as "used water treatment plants".

To be successful, recovering resources from water-based waste streams must be both beneficial for the environment and economically attractive. A proper reflection on design of products and processes, market prospects, appropriate public policies and regulations, and institutional arrangements are fundamental for accelerating resource recovery. Importantly, there also must be a readiness to accept usage of the recovered materials and to recognize its true value. A set of milestones needs to be defined to develop a comprehensive and holistic approach to resource recovery. To achieve proper resource recovery, value chain sectors that until now hardly collaborated need to start interacting and exchanging information. This requires a strong knowledge sharing and communication platform.

With a vast network of expertise across the water sector, IWA today plays the leading role on water and used water. IWA can supply platforms on: knowledge sharing, awareness-raising, capacity building, over-arching activities and cross-cutting talks among scientists, engineers, regulators and decision makers, and therefore can contribute to the paradigm shift from waste to resource. To involve both the experts within the IWA network and external partners and associations working on resource recovery, an IWA cluster on resource recovery from water is formed. The Resource Recovery Cluster will act as a platform in bringing laboratory scale research to full-scale applications, and in promoting practices from resource recovery-intense regions to locations that have yet to elaborate on such cases.

This state of the art report aims to give water professionals a general overview on available technologies for resource recovery, as well as outline obstacles and opportunities for recovering resources from water in terms of technical, social, economic and political aspects. The document further emphasizes the need to encourage good practices by introducing several cases before providing some general suggestions on future trends. The document will serve as a roadmap for IWA's cluster on resource recovery from water and for its activities.

1.1 REPORT OVERVIEW

The report is divided into five chapters. As per figure 1, the first chapter gives an introduction to the topic of the report while the second chapter Recovery of Resources from Water provides a brief technological overview of recovered resources divided into three sections: water, energy and components. The third chapter explores opportunities and obstacles in the field of resource recovery while focusing on demand, regulations, policies and social aspects. Good practices are explored in the fourth chapter of the report as well as ways in which innovation and technology implementation can be accelerated. Future trends are discussed in the fifth chapter and the document rounds off with a summary of the state of the art report and ways that IWA's newly established cluster on resource recovery can contribute to that process. References are provided at the end of the document. Abbreviations, a glossary, unit conversions, table of contents and lists of figures and tables can be found prior to the introduction.

CHAPTER 1	CHAPTER 2	CHAPTER 3	CHAPTER 4	CHAPTER 5
_PRE-FACE _INTRODUCTION _REPORT OVERVIEW	_RECOVERY OF RESOURCES FROM WATER _WATER _ENERGY _COMPOUNDS	_DEMAND _REGULATIONS AND POLICIES _SOCIAL ASPECTS	_ADOPTION _INNOVATION _GOOD PRACTICES	_CONCLUSION _FUTURE TRENDS _ROLE OF IWA _CLUSTER

Figure 1.1 Schematic Figure of Report Overview.

As will be noticed, many of the examples taken from the literature are from Europe, North America and some from African and Asian countries. The representation does not necessarily reflect the spread of resource recovery in the world but rather on what can be found in published material. In order to get a deeper understanding of the topics at hand and to get an insight of current operations from un-published sources, surveys have been carried out. Stakeholders from two different sectors have been targeted namely: academia and industry. The survey reached approximately 120 researchers and 65 people in the industry sector. In total 21 and 12 replies were respectively gathered. The survey was sent out to a broad network of water professionals, the majority of these being IWA members. In order to broaden the scope of respondents, cluster committee members also had the opportunity to provide names of individuals who they felt were suitable to send the survey to. For the most part, participants from Asia, Europe and North America participated in the study. The sample group and sample size has greatly influenced the provided answers and the data gathered from the survey which are incorporated in the report.

2. RECOVERY OF RESOURCES FROM WATER

There are different ways to categorize recovered resources from water. This report presents three main groups: water, energy and components, in which the latter is, among others, comprised of nutrients, chemicals and metals.

The technological synopsis of the report has been prepared as a means of providing a brief state of the art overview on technological aspects of resource recovery. Ideas on future trends, drawn from the IWA survey among others, conclude each section.

Numerous journal papers and books have been published describing the below mentioned technologies further in detail. Furthermore, several excellent topic-based compendiums have been prepared, such as the Water Environment Research Federation (WERF) nutrient recovery study (Latimer et al, 2012) which includes a technical overview of extraction techniques used for nutrient recovery. A book edited by Jimenez and Asano (2008), *Water Reuse - an International Survey of current practice, issues and needs* provides a good overview of current status of water reuse and the book *Water–energy interactions of water reuse* edited by Lazarova, Choo and Cornel (2012) examines in-depth different linkages between water and energy.

2.1 WATER

One of the recovered resources from used water, traditionally termed 'wastewater', can be water in itself. Recovered water from used water is utilized for different purposes. The majority of water reuse projects worldwide are for agricultural irrigation (Lazarona and Bahri, 2008). Municipal and public uses of water play an important role in total urban water use, and there are multiple successful cases worldwide where local water authorities have implemented water reclamation and reuse projects. In the industrial sector, cooling is the most common reuse application, and power plants worldwide have adopted large-scale water reuse schemes (Jiménez and Asano, 2008). Increasing interest in using recovered water has further been noted for groundwater recharge and potable reuse (Asano et al, 2007; Drewes and Khan, 2011; Gerrity et al, 2013).

2.1.1 TREATMENT OF USED WATER FACILITATING A BROAD RANGE OF REUSE OPTIONS

More than 99.5% by mass of used water consists of water (Meda et al, 2012), representing an enormous pool of recoverable resources. With treatment processes available today, used water can be treated to the extent required for any given reuse purpose. An increased level of treatment of used water can result in higher water quality and therefore reduced risks during human exposure, for both potable and non-potable usage.

Traditionally, used water treatment can be defined as primary, secondary, and advanced. In primary treatment a portion of suspended solids and organic matter is removed (Tchobanoglous and Burton, 1991). Due to its poor quality, no use of water is recommended after this treatment stage. Secondary treatment removes biodegradable organic matter and suspended solids, commonly followed by disinfection. Groundwater recharge, surface irrigation and industrial cooling processes are some examples of uses for this level of water quality (US EPA, 2012). Advanced treatment, which targets removal of nutrients, organic constituents as well as suspended and dissolved solids (NRC, 2012), broadens the pool of alternatives for the usage of reclaimed water. Toilet flushing, food crop irrigation and recreational impoundment are examples of what such water can be used for in terms of non-potable purposes. Water that is treated by advanced processes can also be utilized for potable reuse. Various treatment combinations representing multiple barriers against microbial and chemical contaminants have been established worldwide (Drewes and Khan, 2011). Most commonly these include combinations of advanced oxidation processes, activated carbon and biofiltration or integrated membranes systems such as ultrafiltration followed by reverse osmosis. The first plant for indirect potable reuse was established in the Montebello Forebay, California in 1962 while Windhoek, Namibia inaugurated the first direct potable reuse plant in 1968. In Europe a first major project in this context was the up-cycling of treated sewage in Koksijde, Belgium to obtain drinking water (Dewettinck et al, 2001).

For the domestic sector, it has been proposed that the concept of the current approach of dealing with sewage, which is mainly based on dissipating the non-aqueous molecules present in water, could be reversed entirely by maximizing on reuse (Verstraete et al, 2009). A suggested treatment method is to provide an up-concentration at the front of the treatment plant and subsequently process a minor flow to be dealt with in terms of recovery of materials and a major flow from which clean water can be obtained.

2.1.2 NEW TRENDS

Increasing water scarcity and growing populations have triggered a growing use of unconventional water resources such as reclaimed water. One researcher in IWA's survey predicts that recycled and purified water is a future trend for resource recovery. Another respondent further anticipates that the portion of reused water in freshwater resources will increase in years to come. Due to the impacts of severe droughts, recent developments in USA and southern Africa have led to an increase in favouring direct potable reuse uses (Leverenz et al, 2011). In such applications, highly treated water is either fed directly into a drinking water distribution system or into a raw water supply of a conventional drinking water plant. This procedure is carried out without the water passing through an environmental buffer such as a surface water reservoir or groundwater aquifer. In addition, there is a growing recognition for de facto potable reuse in many regions of the world where used water discharge impacts downstream drinking water abstractions. These trends, combined with decades of experiences with indirect potable reuse schemes and improved treatment and monitoring strategies, are likely to support a growing interest in establishing direct potable reuse schemes.

There is also an increasing recognition for water-energy interactions in water reuse, resulting in more energy-efficient treatment schemes, such as decentralized reclamation approaches which reduces the need to pump reclaimed water over a long distance and tailoring water qualities to local needs that are fit for purpose (Lazarova et al, 2012; Vuono et al, 2013).

2.2 ENERGY

2.2.1 TYPES OF ENERGY

Energy plays a big role in the resource recovery sector, both since electricity is needed for the treatment process and since energy in different forms can be recovered in the treatment process. The majority of recovered energy from treatment plants is used on-site, producing both electricity and heat needed for the ongoing processes. Energy contained in used water sometimes even exceeds the energy that is necessary for treatment. The onus in energy recovery is currently moving from energy efficiency to energy neutrality and to having a production that exceeds consumption.

Used water contains energy in different major forms: potential energy, chemically bound energy and thermal energy (Meda et al, 2012). Energy from used water is to a large extent stored as thermal energy. The kinetic energy content of used water is negligibly small and depends mainly on flow rates. There are two major routes to recover energy from used water. One is to on-site turn sludge into biogas through anaerobic digestion (AD), thus recovering electricity and using the heat to heat up the reactor. The other major route is to concentrate the sludge and transport the digested sludge product to central incineration. A positive correlation has been seen between the size of treatment works and the energy recovery potential.

2.2.2 BIOSOLIDS AND BIOGAS

The chemical energy embedded in biosolids is theoretically enough to cover the energy necessary for treatment (Lazarova et al, 2012). AD is the most typical method in which biosolids can be converted into energy. The process involves the readily biodegradable portion of the volatile solids in sludge which is transformed into biogas by microorganisms in the absence of oxygen. Apart from used water, sources for biogas include landfills, livestock operations and food wastes. The end product of biogas consists predominantly of methane (60-65%) and carbon dioxide (30- 40%) as well as small concentrations of nitrogen, hydrogen sulphide and other constituents. Biogas is mainly used to produce electricity and heat.

The methane portion of biogas is a valuable fuel and can with conditioning be used in place of natural gas. Currently around 1% of the biogas beneficially used is upgraded to the same quality as natural gas for transmission to the natural gas system (Moss et al, 2013) and can be used to provide heat and power. Pipeline injection is one method of use, which is also known as biomethane or 'green gas' (Hardi and Latta, 2009). In order to resemble the qualities of natural gas, biogas needs to be enriched in methane and carbon dioxide needs to be removed. The biogas should be further cleaned from sediment, water and foam before it is compressed for injection. This approach is being currently used in many countries and companies. Biogas can further be upgraded to compressed natural gas (CNG) or liquid natural gas (LNG) to be used in vehicles capable of using such fuels.

Biogas production through AD typically only converts the readily biodegradable portion of the solids. Ways to enhance the degraded fraction include processes such as pre-treatment and co-digestion. Pre-treatment breaks open the bacterial cells in the activated sludge, thus releasing the cell contents and making them available to the anaerobic bacteria for conversion to biogas. Technologies for pre-treatment include thermal hydrolysis, sonication, mechanical disintegration and electrical pulse treatment. For co-digestion, readily biodegradable feedstock is added to the digester and thus these are co-digested with the biosolids, thereby increasing the biogas production. Fats, oils and grease (FOG) can for example be co-digested. Another way to recover energy is through incineration of biosolids in fluidized bed or multiple-hearth furnaces.

2.2.3 MICROBIAL FUEL CELLS

Microbial fuel cells (MFC) are an alternative for AD, which directly delivers electricity. This is a system which generates bioelectricity from biomass using bacteria (Rabaey and Verstraete, 2005; Logan, 2008). Through oxidation of organic matter by microorganisms, electrons are produced which are used to create power. Common MFC systems consist of an anode and a cathode chamber separated by a membrane (see Figure 2.1). The bacteria grow in the anode chamber while electrons react with the catholyte in the cathode chamber (Logan, 2008). In the system, used water is treated at the same time as energy is produced through conversion of chemical energy into electrical energy. Ammonia can further be recovered through this process.

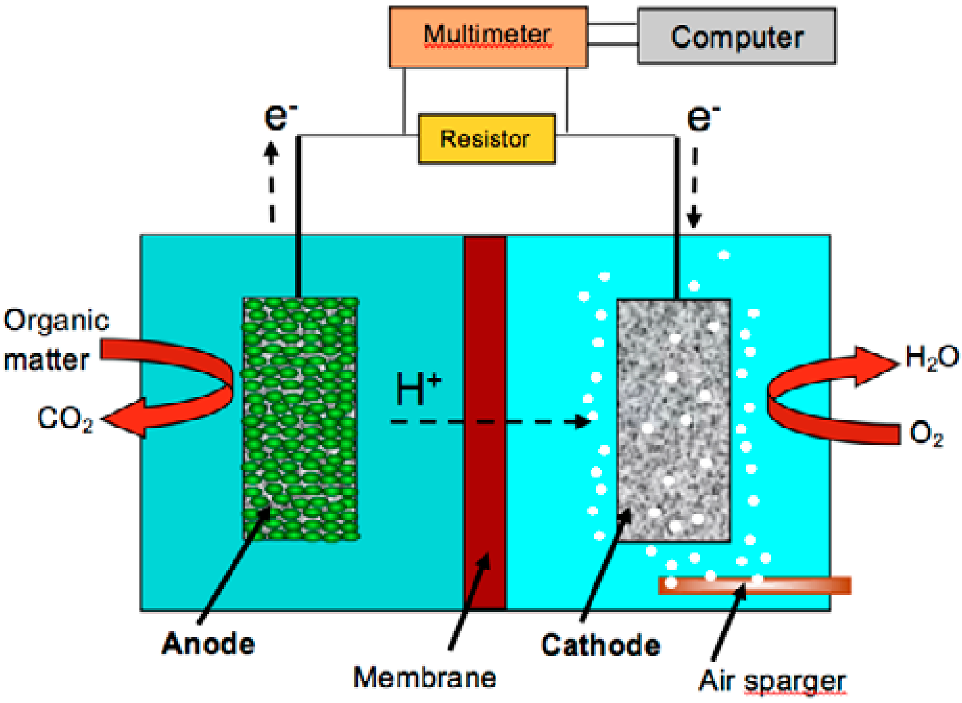

Figure 2.1 Microbial Fuel Cell (Logan, 2008).

2.2.4 HEAT RECOVERY

Heat recovered from used water treatment plants can either be used for district heating, sludge drying or thermophilic heating in a sludge digestion process (Hawley and Fenner, 2012). The financial feasibility of the different heating options typically depends on the current shadow price of carbon. One study comparing different plants recovering energy in the UK showed that district heating applications have the greatest carbon reduction potential and thus the greatest energy savings (Hawley and Fenner, 2012). Thermal energy from used water can be concentrated by heat pumps, to be used on-site in the process or off-site for district heating. It has been reported that over 500 used water heat pumps are in operation worldwide, with thermal capacities ranging from 10 kW to 20 MW (Schmid, 2008). The heat pump systems can be used when used water treatment plants are located near a residential area and these typically use existing underground sewage piping as their heat source. Thermal energy recovery from used water has successfully been tested and implemented in countries such as Canada, China, Finland, Switzerland and the United States of America (Hawley and Fenner, 2012; Jeuch-Trommsdorff et al, 2011).

2.2.5 NEW TRENDS

Combining energy recovery from organic constituents and use of waste heat provides opportunities for highly integrated resource recovery strategies that represent a role model for the future. In IWA's survey one researcher noted that recovery of carbon dioxide to valuable products such as methane and carboxylic acids are new trends along with recovery of carbon wastes with gastification. Co-digestion and mainstream deammonification are other areas which are anticipated to increase in scope in the upcoming years.

One researcher in the survey predicted that nitrous oxide is an upcoming trend within the field of resource recovery. This process has been documented in some areas already. For example, the Stanford Nitrogen Group has developed a process called the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) in which ammonia is converted to nitrous oxide before combusting fuel with nitrous oxide to recover energy (Scherson et al, 2013).

Another noticed trend is to rethink how large surface areas on used water treatment plants have traditionally been used through installing onsite wind and solar power. This is currently being carried out in several locations in the US (Mo and Zhang, 2013). A used water treatment plant in California, for example, uses solar integration to provide 80% of the facility needs. Although renewable energy can be integrated in treatment plants in many different ways, few such studies investigating this have been carried out.

An area that further needs investigation is looking at the effects of discharging cooled effluent into aquatic ecosystems as these are currently relatively unknown (Hawley and Fenner, 2012).

2.3 COMPONENTS

Many components can be recovered during the treatment process of used water and from residuals from water treatment, such as nutrients, metals and biodegradable plastic. Some examples of recovered components are provided below.

2.3.1 NUTRIENTS – PHOSPHORUS AND NITROGEN

The two most prominent nutrients that are discussed in terms of resource recovery are phosphorus and nitrogen. These are both critical components to the agricultural system worldwide. While removal of the components from the liquid stream is standard and a widely implemented practice (WEF, 2009); recovery of the components vary in terms of scope and stage of development. Nutrient recovery can be divided into three sections, namely accumulation, release and extraction in which nutrient products are recovered in the last step (Latimer et al, 2012). The main focus on nutrient recovery has been on chemical phosphorus products.

2.3.1.1 Phosphorus

Since the 1950s, several techniques have been investigated for phosphorus recovery from used water and other aqueous solutions. 22 different P-recovery technologies have been distinguished by Sartorius et al (2011), ranging from lab-scale to full-scale applications. Sources from which phosphorus can be recovered include used water, urine, ash and sewage sludge.

There are two main possibilities of recovering phosphorus from municipal used water, namely recovery from used water treatment and recovery from produced sludge. Recovery from sewage sludge results in, for example, magnesium ammonium phosphate (MAP), calcium phosphate and iron phosphate. MAP is more commonly referred to as struvite and can easily be separated from used water due to its specific gravity (Latimer et al, 2012). A method in which phosphorus can be recovered from sludge is through supercritical water oxidation (SCWO), a technique which is growing in terms of practice and commercialization. The process destructs organics in the sewage sludge and leaves a slurry of inorganic ash in a water phase free from organic contaminants. Components, such as phosphorus and coagulants, can then easily be recovered from the residual ash. As such, phosphorus removal therefore depends on the production of biomass and precipitated sludge (Latimer et al, 2012).

The majority of the processes involved in recovering a phosphorus product need chemical consumption (Stark, 2004). Crystallization has been proven to be the established technology with the highest percentage of recovered resource for phosphorus, with a recovery rate exceeding 90% (WERF, 2012).

2.3.1.2 Nitrogen

While many multiple technologies remove nitrogen, not as many can recover the resource. Nitrogen removal can be done either biologically or physico-chemically. The selection of the method is based on the concentration of nitrogen in used water. In order to efficiently recover nitrogen from used water, techniques typically require concentrations above 1,000 mg NH4/L (Morales et al, 2013).

Nitrogenous materials present in the sewage or paper mill effluents can be removed from sewage effluent and converted into biomass through activated secondary treatment processes (Lau, 1981). A technology of protein-based wood adhesives sourced from secondary sludge is further currently being investigated (Pervaiz, 2012).

Fertilizer grade ammonium sulphate can be produced from the high ammonia-nitrogen concentration sidestreams from sludge digestion processes by stripping and adsorption. This stream can also be treated biologically by nitration and anammox, the latter being autotrophic denitrification. While not resulting in nutrient recovery, this approach significantly reduces energy requirements compared to the conventional nitrification/denitrification process and eliminates the carbon requirement for heterotrophic denitrification. Stripped ammonia can be recovered via condensation, absorption or oxidation, resulting in a concentrated fertilizer product (Latimer et al, 2012). Nitrate/nitrite species can further be recovered through using liquid-liquid extraction technologies. This method is based upon the technique of separating components based on relative solubility in two immiscible liquids. The end result is a concentrated nutrient solution which can be stripped from the organic phase.

Another way in which ammonium can be removed from the stream of used water is through electrodialysis (see Figure 2.2). The approach is to first concentrate nutrients into appropriate dialytic leaves in an overall electrodialysis cell and subsequently recover through a range of technologies, including precipitation, adsorption, desorption and air stripping (GRDC, 2014). The technology is founded on the method of using an electrical current in which anions and cations are separated across ion exchange membranes. Multiple nutrients can be recovered through this process but it is most suitable for nitrogen and potassium.

As with phosphorus, WERF states that among the established techniques, crystallization is a technique with a high percentage of recovery efficiency (Latimer et al, 2012). The process of obtaining struvite is such an example, in which nitrogen is recovered in addition to phosphorus.

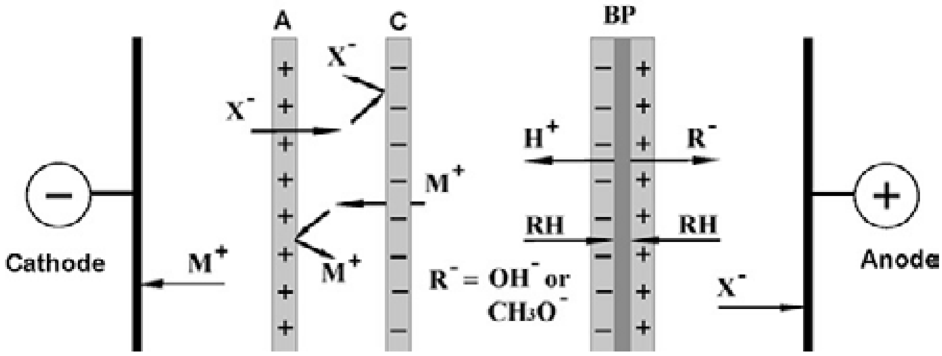

Figure 2.2 Electrodialysis (Huang et al, 2007).
BP: biopolar membrane; A: anion-selective membrane, C: cation-selective membrane;
M+: cation; X-: anion; H+: hydrogen ion; OH-: hydroxide ion; CH3O-: methoxide ion.

2.3.2 METALS

There are certain factors that need to be considered when recovering metals. Such features include initial concentrations of all metals, origin of used water, identification of metals to be recovered and the choice between recovering one specific metal opposed to a group of metals. Furthermore, different removal technologies have different benefits. Some have short processing time while others have cheap and easy monitoring systems. Several techniques have a complete removal of metals from water while others have partial removal of some particular metals.

Used water content from industries such as mining, electrical and electroplating can contain traces of heavy metals such as cadmium, copper, zinc, gold, magnesium, silver and calcium (Saniedanesh et al 2013). There are many elaborated techniques for how metals, with a focus on heavy metals, can be removed. Common methods of removing metals involve physiochemical techniques such as filtration, chemical filtration and solvent extraction. Removal can also be performed through adsorption, electrodialysis and through biological and membrane processes; the latter which are becoming more widely accepted (Saniedanesh et al 2013). Chemical precipitation is most extensively used for metal removal from inorganic effluents (Wang et al, 2004). Drawbacks to the method include a slow metal precipitation and excessive sludge production that requires further treatment. Depending on size of particle that is to be retained, various types of membrane filtration, for example ultrafiltration, nanofiltration and reverse osmosis, can be employed for metal recovery from used water (Barakat, 2010). Membrane bioreactors (MBR), which combines a membrane with a bioreactor, has received increased attention both academically and commercially.

In comparison to the number of removal techniques, there is less emphasis on how metals can be recovered. However, there are a couple of different heavy metals recovery technologies (HMRT), for instance ion exchange, leaching, adsorption, magnetic nanoparticles and foam fractionation which recover different types of metals. Electrolytic recovery is, for example, a method that uses electricity to leave a metal deposit behind which then can be recovered (Kurniawan et al, 2006).

Certain techniques can be chosen for specific metals and for recovering metals from specific materials. Cation-exchange capability using synthetic zeolites is, for example, currently being looked into and investigated for their effectiveness of recovering metals through modified natural material (Kurniawan and Babel, 2003). While metal sulphides can be recovered using sulphate reducing bacteria (SRB), electrodialysis can recover metals such as Cr and Cu. Photocatalysis, which is a technique using low-energy ultraviolet light with semiconductor particles, can recover noble metals from industrial waste effluents. Deposited metals can be extracted from slurry by mechanical and/or chemical means. Mercury(II), chromium(VI), silver(I) and iron(III) ions can be recovered using this relatively new technique. Even a by-product such as ash can be chemically modified in order to recover metals from used water (Aklil et al, 2004).

2.3.3 OTHERS COMPONENTS

2.3.3.1 Biodegradable Polymer

One non-traditional technology under development is the production of a biodegradable plastic. Polyhydroxyalkanoates (PHA) are a type of biodegradable polymer, plastic resins, which many types of bacteria synthesize to store energy. PHA are formed when bacteria are introduced to harsh growth conditions due to limited resources of phosphorous and nitrogen for example, and when there is an excess of a carbon sources such as glucose and proteins.

There are currently some small-scale projects that are researching the possibility of producing PHA using biosolids from used water treatment plants. These biosolids represent an ample carbon source that is available at no cost. An advantage of the produced plastic is its lifespan of months which can be compared to the centuries needed to break down petroleum-based plastics. A suitable environment is necessary for the bacteria's growth and there are multiple mature examples of technologies that perform this on scale already. Figure 2.3 illustrates a prototype used by a start-up company for manufacturing such biodegradable plastics using biosolids (Meyers, 2011).

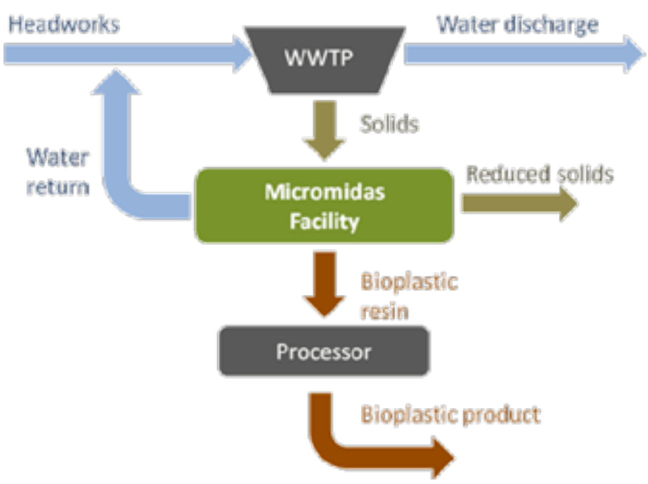

Figure 2.3 Start-up company Micromidas' concept for manufacturing biodegradable plastics (Meyers, 2011).

2.3.3.2 Methane, Carboxylic Acids and Hydrogen

The organic materials in used water can be converted in anaerobic fermentation processes with a mixed community. The mature technology of anaerobic digestion is best known to produce methane, but since the conversion is channelled through carboxylic acids, including volatile fatty acids and hydrogen gas, these products can also be produced when methane production is inhibited. The separation of carboxylic acids is difficult. One method that is currently under investigation is chain elongation within mixed cultures, which produces longer-chain carboxylic acids such as caproic acid with six carbons, which can be easier extracted (Agler et al, 2011). As such, products typically requiring methane for its production can be produced even when methane is not accessible.

2.3.3.3 Industrial Chemicals

Other products from recovered resources include industrial chemicals such as hydrogen, hydrogen peroxide and caustic solutions. Such products can be produced using microbial electrochemical technologies (MET), for example microbial electrodialysis cells (MEC). These technologies have yet to be scaled-up to full-scale applications. There are further alternate anaerobic processes that result in industrial chemicals.

Sulphate, which is a common chemical in industry, can further be recovered from water and used water. One way of recovering sulphate is through a two-staged process in which sulphate is converted into elemental sulphur (S). In the first step the sulphate is converted into dissolved sulphide in high-rate bioreactors. The sulphide is then oxidized to elemental sulphur by mixing with air and separating it from the liquid. The process further recovers metals such as copper, nickel and zinc as marketable metal sulphides.

2.3.4 NEW TRENDS

Many of the above described technologies can be classified as new trends in the field of resource recovery. Some of the replies from IWA survey respondents regarding novel developments include recovery of nitrous oxide and ammonium as well as Zero Liquid Discharge. Co-digestion from mainstream deammonification is another prediction of a future trend. Another new innovation that was mentioned in IWA's survey is nitrogen recovery via ion exchange membranes.

To recover cellulose from used water is another phenomenon that is currently being investigated. Cellulose fibres have recently been highlighted as a potential resource that can be recovered from used water (Ruiken et al, 2013). Although toilet paper is, and has been, a major constituent of used water, there are hitherto few studies that have investigated the behaviour of cellulose fibres in the activated sludge process. Before cellulose is metabolised, it needs to be hydrolysed and this process, to a large extent, depends on temperature and sludge retention time. In the survey, one IWA researcher respondent noted that realization of cellulose production has been one of the biggest developments within his/her research field of resource recovery.

2.4 SUMMARY

Numerous techniques have been developed that can be used to recover water, energy and different value-added components. Some techniques have been applied since centuries back while others are new or involve new ideas applied to old applications. Concentrations of different types of substrates, quality of resource and internal and external cost are some crucial factors that need to be taken into account when making decisions on what technologies to use and which end product will evolve. As such, there is a need for a systematic approach when considering technologies for recovering different resources. A trade-off will always be seen. For example, techniques recovering nutrients can be efficient but may require a huge quantity of water and energy. Further, some effective technologies can have negative environmental impacts, such as biosolids incineration which releases persistent environmental pollutants.

Factors can also been seen to be influencing each other. Power generation from biogas is for example particularly attractive in areas with high electricity rates. In the United Kingdom when energy prices doubled during 2003-2006, onsite generation of energy from sludge was increased (Kaye, 2007). WERF (2008) endorses this by stating that maximum energy available in sewage and sludge is taken advantage of as energy prices rise.

It should be acknowledged that there is no single technology that is perfectly suited for complete nutrient recovery for all scenarios. The same can be said for water and energy. In all these sectors new trends and technological innovations are continuously emerging. In order for such technologies to be implemented and used on full-scale several factors such as demand, policies and social acceptance need to be taken into consideration.

3. Demand, Regulation and Policy and Social Aspects

In order to enable, produce and implement the aforementioned technologies, there are certain aspects that need to be taken into account. This chapter looks at demand, regulations and policies and social aspects and how these can act both as accelerators and barriers in the field of resource recovery from water.

3.1 DEMAND

Demand for resources can be investigated in the separate sectors of water, energy and components.

3.1.1 WATER

Demand for water is steadily increasing due to an increase in population and change of lifestyle. In order to meet the constant need for water, global withdrawals have tripled over the last 50 years (WWAP, 2009). Under an average economic growth scenario, the 2030 Water Resource Group predicts that global water requirements will grow from 4,500 billion m^3 to 6,900 billion m^3 by year 2030 (Addams et al, 2009). The withdrawal numbers are based on analyses from the International Food Policy Research Institute (IFPRI) from 2010. Research shows that the predicted figure for 2030 exceeds current accessible and reliable supplies by 40 percent (Addams et al, 2009). One third of the world's population will by this time reside in basins where the water scarcity is larger than 50 percent (Addams et al, 2009). A gap between supply and demand is thus evident.

Moreover, it is anticipated that in the year 2050, 1.4 billion people will be without access to basic sanitation and that half of the world's population will by then live with less than 1,000 m^3 of water per capita per year (Jiménez and Asano, 2008). The issue at hand further does not solely relate to water quantity but to water quality as well. Currently, more than 700 million people do not obtain their drinking water from improved sources (WHO/UNICEF, 2014). Ground- and surface waters are continuously being polluted, resulting in eutrophication, microbial contamination and spread of persistent toxic chemicals (UNEP, 2012).

About 70 percent of the total worldwide withdrawals from 2011 was for agriculture while 18 percent was for industry and 12 percent for domestic use. The 2030 World Resource Group (2009) predicts that by 2030 industrial withdrawals will account for 22 percent of the global water demand (Addams et al, 2009). The sectors where the biggest increase will be seen are manufacturing (+400 percent), electricity (+140 percent) and domestic use (+130 percent) (Leflaive, 2012).

Drivers for demand in water can in large be attributed to development and economic growth (Addams et al, 2009; UNEP, 2012). An increase in population, alteration in dietary patterns and consumption growth are examples of phenomena creating pressure on local water supply. A worldwide rural to urban migration is also noted as main themes of the global water challenge. The rapid ongoing urbanization in which 60 percent of the world population is predicted to live in urban settings by 2030, further fuels the challenge of meeting growing water demands (WWAP, 2009).

Water demand varies across the globe and needs and demand criteria differ according to local conditions (Davis, 2008). Along with the notion that water is central to all ecosystems, demand for water is shaped by the perception of its quality and the fact that it contributes in many different production processes (Hatton McDonald and Proctor, 2008). It is difficult to predict water demand as it to a great extent depends on socio-economic scenarios (Shen et al, 2008). Although the importance of such studies has been recognized, few integrated assessments based on consistent climate and socio-economic scenarios have been carried out. It is difficult to generalize water scarcity as countries and regions face very different problems (Addams et al, 2009).

Growing worldwide water demands are forcing non-traditional water sources to be considered (US EPA, 2012). Water reuse is such an example, for both potable and non-potable uses. The demand for water and thus the market for water reuse vary across the globe. One of the factors influencing water need is weather conditions. The greatest water recycling occurs in regions suffering from water scarcity such as Australia, the Middle East and south-western USA (Radcliffe, 2008). Saudi Arabia has for example a goal that 10 percent of its water demand will be met by water reuse (Redwood and Huibers, 2008).

US EPA (2012) breaks down drivers for water reuse into three different components. One is the need to address urbanization and water supply scarcity while another is for environmental and public health protection. The third driver is achieving efficient resource use. Since agriculture is the biggest sector that consumes water globally, an increase in irrigation with recovered water would have a great impact. Currently only about 10 percent of the world's crops are produced with used water (Jiménez and Asano, 2008). The market and use of used water varies regionally and in Vietnam for example, the equivalent amount is a staggering 80 percent.

3.1.2 ENERGY

The world's consumption of energy has constantly been increasing since the 1990s **[1]**. The average annual growth rate for the past decade has been 2.4 percent while the increase in 2012 alone was 1.4 percent. According to the Global Energy Statistical Yearbook 2013, the total primary energy consumption was approximately 13,200 million tons of oil equivalent (Mtoe) while the global primary production the same year was estimated to 13,600 Mtoe. Predictions for future energy consumption can be seen in table 3.1. The numbers signify that our energy consumption is projected to increase by more than 8,000 Mtoe in less than 30 years. It is expected that the more than 85 percent of the increase in global energy demand in the upcoming 20 years will be in countries that are not part of the Organisation for Economic Co-operation and Development (non-OECD).

YEAR	ENERGY CONSUMPTION (IN MTOE)
2013	13,200
2020	16,400
2040	21,300

Table 3.1 Current and Future Energy Consumption [1].

Energy consumption can be linked to weather conditions as well as economic growth. China and India serve as examples in which a high economic growth results in a high demand for energy. When projecting changes in worldwide energy consumption, economic growth is one of the important factors that need to be considered **[2]**.

The primary energy demand growth comes from China, a trend that is predicted to continue until the year 2020 after which India will take over the role (OECD/IEA, 2013). In 2010 China and India accounted for nearly 24 percent of the total world energy consumption and the two countries lead the economic growth **[2]**. China, India and the Middle East are further the biggest drivers of the global oil demand. On the other hand, an increase in energy production in the past couple of years has been in Africa, Asia and Latin America while Europe has experienced a decrease in energy production **[3]**.

In terms of energy sources, a sharp increase in wind and solar power production has been noted and the share of renewable energy will continue to increase with hydropower as the main supplier (OECD/IEA, 2013). Renewable energy is predicted to account for an estimated 25 percent of the global energy mix in 2035. Out of this share of renewably-produced energy, hydropower will be likely to account for 50 percent.

3.1.3 COMPONENTS

Demand and supply for components vary depending on which material is being investigated. A heavily debated resource is phosphorus. The primary use of phosphorus is in fertilizer for agricultural production. There is a market for the nutrient as phosphorus is vital for plants and crops and that there is currently no substitute for it. While the world's consumption levels are increasing, phosphorus production is anticipated to enter a long, slow decline once the peak has been reached, which is estimated to occur by year 2033 (WERF, 2012). This is attributed to the reduction of economically recoverable phosphorus reserves, which are calculated using current mining technology to be exhausted in less than 80 years at the current production level (Jasinski, 2012). Phosphorus is concentrated in certain areas in the world which further complicates the limited supply of the resource. Almost 90 percent of the world's reserves of phosphorus can be found in just five countries (WERF, 2011). Phosphorus is mined from non-renewable elemental deposits. In 2012, the global phosphorus reserve was approximated to be 71,000 million of tons (Jasinski, 2012). Phosphorus-fuelled conflicts are predicted to become analogous to oil conflicts **[4]**.

Another important component for agriculture is nitrogen. Reactive nitrogen, ammonia nitrogen, is produced by the Haber-Bosch process (Latimer et al, 2012). While nitrogen is renewable, the process of producing ammonia is energy intensive, produces significant greenhouse gas and is dependent on natural gas. As is the case for phosphorus, nitrogen is accumulating in the environment at unwanted levels. In 2000, the nitrogen effluent from used water was just above 6 million tonnes of nitrogen per year while the projection for year 2050 is that the annual nitrogen effluent will be approximately 18 million tonnes (Leflaive, 2012). Component usage will, therefore, have tripled. Consequences of too much nitrogen can for example be seen in excessive algae blooming. While the true market value of recovered nutrient products is unknown, it is recognized that 85 percent of all nutrient products are linked to the agricultural sector (Latimer et al, 2012). Historical data show that nutrient prices have remained relatively steady over the past 50 years (WERF, 2012). Data from the US indicate an increase in demand for nutrient products over the past decade (Latimer et al, 2012). As for metals, some experts have predicted that exploitable metal reserves such as nickel and zinc will be exhausted within 50 years (Veolia, 2013).

Resource scarcity in metals and in nutrients will lead to increasing prices for such commodities in the global market. This fact could be an indirect economic incentive to start recovering such resources. Use of recovered nutrients and metals can therefore become beneficial since they represent an environmentally desirable product with relatively good market values while still preserving the declining pool of resources.

The four main products that can be or that are being produced from used water are: biomass, biosolids, char/ash and chemical nutrient products (Latimer et al, 2012). Many chemical nutrient products contain numerous nutrients allowing the industry and market to adhere to a framework encapsulating multiple recovery benefits. Used water treatment facilities are the main platform for research and for development of commercially viable technologies recovering nutrients.

3.1.4 SURVEY REPLIES

The demand aspect of resource recovery was not frequently mentioned in the IWA survey. However, one researcher points out that one/a new development within this person's field of research was the quality of struvite and the fact that on-demand size of the material struvite is now being produced. While there is a great demand for the covered resources, such as water, energy and nutrients, another researcher makes note that there is a lack of market of recovered products.

3.2 REGULATION AND POLICY

Regulation and policies play a vital role in the field of resource recovery. Guidelines and laws can both act as a promoter and as a barrier and it has been noted that the rate of development is typically dependent upon legislation, which highlights its importance (Stark, 2004).

3.2.1 REGULATIONS AND POLICIES ON INTERNATIONAL LEVEL

Overall there is a lack of policies and regulations on the topic of resource recovery from water on an international level. There is, for example, much work that remains to be done by professionals to produce standards for water reuse (Jimenez and Asano, 2008). The same is true for recovered energy and components. One of the few documents addressing reused water is the Guidelines for the Safe Use of Wastewater, Excreta and Greywater provided by the World Health Organization (WHO, 2006).

3.2.2 REGULATIONS AND POLICIES ON REGIONAL AND NATIONAL LEVEL

Drafting of regulations and policies can further be explored on a regional basis. The Urban Waste Water Treatment Directive in the European Union, for example, is predicted to have nearly 100 percent compliance in 2015/2016 (Shröder, 2014). The European Union further has the Water Framework Directive (WFD) which was put into practice in the year 2000, with the goal of having all water bodies at good ecological standard by 2015. Although the WFD is in place, there are no EU-wide technology-based regulations or guidelines for tertiary treatment of water (Radcliffe, 2008). The European Union also lacks EU-wide standards in terms of water reuse (Schröder, 2014). Moreover, there is no legislative development on the water and energy connection.

Policies and regulations can also be seen on a country-wide basis. In the US for example, the majority of the used water discharge rules and regulations are imposed at state level rather than at federal level (US EPA, 2012). Due to this, policies and regulations differ widely between states. Some states have, for example, yet to define rainwater harvesting as a practice distinct from water recycling. There is currently no federal regulation on water reuse. On the federal level there is, however, a Resource Recovery Act which stems all the way back from 1970 (OTA, 1979). The past decade has seen an increase in the number of states that have implemented either rules or regulations affecting resource recovery.

In some parts of the world access to water is a recognized property right and, therefore, water is tradeable (Radcliffe, 2008). In Australia, for example, environmental protection agencies have imposed discharge standards on disposal of treated effluent into rivers, lakes and estuaries. The act has resulted in used water being treated to an appropriate standard and the treatment is typically paid for by the consumer on the basis of 'polluter pays'. By doing it this way, treated effluent may be provided at minimal or no charge to irrigation users. The situation exemplifies that regulations and economics can be closely intertwined.

Another example highlighting linkages between the financial and regulatory sector is in regards to water reuse. Investing in water supply and sanitation is cost-effective compared to the expense of treating water-related diseases, the latter being a common consequence of having polluted waters (Lazarona and Bahri, 2008). Regulations can also be seen as necessary to increase financial investment in a sector. For example, local groundwater and treated local surface water are less expensive compared to reclaimed water. Therefore economic incentives to enhance the technology and market for reclaimed water is needed which could be brought about through regulations.

3.2.3 DEVELOPING REGULATIONS AND POLICIES

Who should set the standards and draft regulating documents and what should these consist of? One suggestion is to have global targets which should consist of local targets as the latter are easier to formulate and achieve as well as to monitor and evaluate (UN, 2014). Furthermore, accurate baseline information should first be established at the national level before monitoring the progress on the global level. In developing countries it is typically the government or public bodies that manage water resources and water services (Radcliffe, 2008). In Europe and Australia a recent trend has been that service functions of water supply and sewage treatment are now implemented by water companies rather than governments as was common before (Radcliffe, 2008). The private sector, with its own needs and rules, has been noted to be more highly involved in the industrial reuse and recycling sector compared to municipal and agricultural reuse (Jiménez and Asano, 2008). The rules set up by the private sector are typically driven by economic motives, and the phenomenon occurs mainly in developed countries where the amount of water used by industry is substantial. In terms of water recycling, many argue that there must be a role for governments (Radcliffe, 2008). The risk of having diseases spread through recycled water is usually borne by local governments (Hatton McDonald and Proctor, 2008). Local governments therefore typically do not want to take risks in introducing recycled water schemes as suggested by state governments. In Australia there is only one privately owned and operated used water recycling project that does not involve a subsidy. The example calls for governmental involvement, albeit indirect, in issues tackled by the private sector.

Some question whether regulations should be compulsory or only guidelines that actors can abide by at their own will. Government strategies, rather than compulsory regulations, have in some cases proven to better promote and encourage industrial reuse (Jiménez and Asano, 2008). While defining own standards can lead to an internal competition of who can have the best standards, there is also a risk that it limits innovation and that the economic sector overshadows environmental and social aspects.

Not only do policies and regulations need to be drafted, they need to implemented and enforced as well. In some countries and regions attempts have been made to have standards for agricultural purposes, but these were not effectively used or referenced by others. Regulations and guidelines need to be targeted toward local conditions, and it is not advisable to set regulations that are excessively strict as there is a risk that these will not be enforced. Examples can be seen from Ghana and Senegal where it is officially banned to use used water for irrigation purposes, a policy which is currently being ignored (Redwood and Huiters, 2008). Revelation of this has led to the acknowledgement that used water used for irrigation cannot be outlawed or ignored as it is a common reality in many settings.

Standards and guidelines need to be continuously updated to address new applications and advances in technology and also to be brought up to date with state regulatory information. Harsher regulations can come about due to different circumstances, such as increases in cost and changes in weather conditions. In Brisbane, Australia the authorities were forced to enforce a decreasing consumption of water after a severe drought in Queensland (Olsson, 2012). In two years, between the years of 2005-2007, the daily cap consumption decreased from 300 to 130 litres. The example indicates the effect and positive change that can come about through regulations.

3.2.4 ACCELERATOR

3.2.4.1 Encourages Innovation and Adoption

Regulations can act as a promoter and as a barrier to resource recovery, both directly and indirectly. One positive aspect of regulations is that it can be an incentive for new technologies. In Sweden for example, regulations have been used to initiate the development of technologies for phosphorus recovery from sewage sludge (Hultman et al, 2001). The country has established regulations requiring used water treatment plants to recover nutrients which have greatly increased such practices. An additional example is from Denmark where more strict legislation and introduction of taxes related to sludge incineration and sludge landfilling has resulted in conversions to thermal treatment and drying of sludge (Stark, 2004).

Regulations can be a stimulating factor also when there is no direct economic driving force. In regards to nutrient recovery, the countries in Europe with the strictest regulations are typically countries that early on invested in phosphorus recovery, such as Sweden and the Netherlands. The Netherlands further holds one of the most stringent regulations in Europe regarding maximum heavy metal content of the sludge from used water treatment plants going to agricultural use. The country was a pioneer in the field of phosphorus recovery from sludge. The ban on land application of sludge has further resulted in wider use of the sludge as a fuel in cement kilns and a high rate of incineration.

Policies in other parts of Europe have proven fruitful as well. In the United Kingdom there was a consensus amongst industry experts and businesses that European and national policies, along with legislation and directives, have been the primary drivers of change within the waste management sector (Ekogen, 2011). The same industry experts furthermore agreed that the need to divert waste from landfill has stimulated the use of new technology.

Along with counterparts in Europe, the US has also seen an increased investment and technology applications in the field of nutrient recovery due to increasing nutrient discharge regulations from used water treatment facilities (WERF, 2011; US EPA, 2012). The Stanford University-developed process entitled CANDO, which came about due to more stringent regulations in combination with rising energy costs, is an example of such (Scherson et al, 2013). Other examples from the US are their air regulations governing ground level concentrations of ozone and NOx that favour the adoption of energy recovery equipment such as microturbines and fuel cells which produce low emissions of the air pollutants. An additional US incentive is its renewable energy credits (REC) that are being distributed for the electricity that treatment plants generate from renewable energy (Willis et al, 2012). This motivational concept could lead to an increase in the use of renewable energy sources in as organisations strive to gain more REC.

3.2.4.2 Encourages Good Practices and Discourages Unsuitable Practices

Another reason for having regulations is that it can encourage good practices that are already implemented. Along with promoting best practices, laws and policies can further act as discouragement for unsuitable practices. An example is to phase out subsidies that encourage unsustainable water use. One way of doing this is by removing incentives which encourage people to settle or invest in risk prone areas (Leflaive, 2012). Early action is instead promoted as to avoid being locked in costly and detrimental trajectories.

3.2.4.3 Prevents Confusion

Having functioning and reliable regulations and guidelines can also limit confusion. It can act as an indicator for decision makers and companies to help determine what is adequate and achievable. For example, the absence of standard protocols for conducting life cycle analysis for biosolids management has made it difficult to come up with consistent plans and recommendations for future use (Mo and Zhang, 2013).

3.2.4.4 Increases Public Participation

Positive outcomes of regulations and policies can be noted on different levels. The River Basin Management Plan on a European level has, for example, led to an increase in public participation and stakeholder involvement as well as an enhancement of international cooperation and improvement of knowledge bases (Schröder, 2014). The EU has further proposed stringent regulations concerning biosolids spreading in order to develop public confidence (Stark, 2004). Others argue that an opposite approach should be taken, meaning that worldwide accepted standards need to first be in place in order to increase public acceptance of water reuse (Jiménez and Asano, 2008).

3.2.5 BARRIER

3.2.5.1 Discourages Innovation and Adoption

Regulations can also be counterproductive as it can discourage different types of recovery. An example of this is through the classification of resources. In the US biosolids are defined as solid waste rather than as a renewable fuel (WERF, 2013). This makes it difficult or impossible for biosolids-to-energy projects to benefit from renewable energy incentives. Some utilities in the US have applied to the US EPA for approval of classifying their solids as renewable fuels via a 'non-waste petition process', an action requiring multiple resources. Another policy that hinders practices in the US is that domestic used water is regulated and managed as a waste stream (Meeker, 2014).

Regulations and policies can also hinder project ideas and new technologies within the field of resource recovery, as well as slow down implementation. A resource recovery facility can, for example, take time to be set up when having lots of policies and regulations that are necessary to comply with.

Lots of technologies recovering materials have a high start-up cost. Regulations and policies not encouraging large capital investments can also act as a barrier. Absence of provision of subsidies or financial assistance into the research and development sector, arising from regulations and policies or lack thereof, also hinders recovery practices.

3.2.5.2 Creates Confusion

A difficulty in the regulatory and political sector of resource recovery is that the arena is typically fragmented. Responsibility for action can easily fall in-between segments and stakeholders, as in the case of solid waste where both local government and the private sector are involved (OTA, 1979). Regionalized resource recovery can also be hindered if states and countries prohibit transport of material into or across jurisdictions.

If too many stakeholders are involved in the process of legislation and policy making, it can become confusing and daunting for the producer, promoter and end user. Overlapping agency standards can lead to conflict as well as raise concern that resource recovery is not represented by a single institution or voice (OTA, 1979). Some of the regulatory and institutional challenges lie in the fact that regulations lack uniformity and that they are sometimes conflicting.

Lack of clarity and insufficient definitions of resource recovery can also be obstacles. In some cases, health and environmental performance standards for resource recovery facilities have yet to be established (OTA, 1979). One of the primary barriers to material reuse and resource recovery is the complex set of rules and definitions. An example is the discussion on regulation over whether a material is to be regarded as a hazardous waste (Allen, 1993). Investment in the sector will most likely be slowed as a consequence until relevant standards are defined and stakeholder involvement is mapped out.

3.2.6 NEED FOR COLLABORATION

In many regions of the world, improved water efficiency remains a policy imperative (Leflaive, 2012). In order to tackle arising challenges, sectors need to work together (UN, 2014). Used water collection needs, for example, to be systematically coupled with treatment of used water (Leflaive, 2012). Water policies further require an equal emphasize on both quantity and quality issues. Initiatives work best when integrated with policies that have an impact on water availability and on adjacent fields such as agriculture, energy and land.

There is also a need to share information which can both inspire and teach others. Companies can further encourage each other by formulating targets and goals that set the stage for competition.

3.2.7 SURVEY REPLIES

In agreement with the views described above, responses from IWA's survey signal that regulators and regulations are vital in the context of resource recovery. Many participants in the category 'researchers' replied that the regulatory aspect was one of the biggest barriers for resource recovery within their field of research. One researcher replied that consistent and well-targeted incentives in terms of regulatory drivers would be a great asset in increasing the rate of technology transfer and uptake; another respondent pointed out that a regulatory framework covering ammonia and phosphate specifically needs development. Overall a large number of people noted that collaboration between different stakeholders such as policy makers, researchers and industry needed to increase. Also in the utility sector, multiple respondents replied that departments need to work closer together and that regulatory incentives are necessary in order to increase resource recovery. Some call for general legislative frameworks and regulations while emphasizing that legislation for promoting and supporting financial costs is also needed.

3.3 SOCIAL ASPECTS

As with regulations and policies, social aspects can function both as a promoter and as a barrier for resource recovery. One major feature is acceptance, which can be reached in different ways. While acceptance to produce and use recovered products is vital, it is also important to recognize the involvement of a diverse group of stakeholders in this process, extending beyond the public.

Different factors come into play when discussing social acceptance (Anderson et al, 2008). Knowledge, trust, attitude toward the environment, costs and source of recovered resources are all examples of factors that need to be taken into account. It is also important to acknowledge that social aspects can also include religious, cultural and aesthetic values. Water is the substance in the world that is endowed with the most cultural and religious significance (Davis, 2008). It is important to view water beyond it being a product and to recognize that it can have intrinsic value to people and societies.

Reusing water is, thus, an excellent example of combining the use of advanced technology with cultural and spiritual values. It is furthermore essential not to rule out impressions and emotions from public policy-making. As these change in-between countries, regions and settings, it is important to acknowledge that what might be socially accepted in one place may not be suitable or tolerated in another.

Many of the examples provided below touch upon acceptance of using reused water for potable and non-potable uses. Social aspects regarding recovered resources can also include approval of using fertilizers consisting of recovered phosphorus and nitrogen.

3.3.1 REACHING SOCIAL ACCEPTANCE THROUGH DIFFERENT METHODS

3.3.1.1 Campaigning

Acceptance of recovered products is a vital component when discussing social aspects. One way to bring this about is through providing people with information. Campaigning has been proven to be a successful tool, as public awareness campaigns can greatly enhance both the acceptance and the usage of recovered resources. In Singapore for example, a massive awareness campaign was launched when the NEWater project was introduced, including media, briefings at community centres and schools, panel debates and study visits to the water treatment location site. Wording can be important as well when promoting recovered resources. The term ‘NEWater’ has proven to be effective. It has further been suggested to use the phrase ‘recycled water’ as opposed to ‘repurified’ water. Re-branding can also be done through changing the phrase ‘wastewater reuse’ to ‘water reuse’, the latter being considered as more appealing (UN, 2014). Another example is referring to treatment plants where used water is treated as water resource recovery facilities, as done by the Water Environment Federation (WEF) since 2012 (Fulcher, 2014). Other projects have noted similar success reaching out to people with information. The longest and most successful multi-use recycling projects in California, the Irvine Ranch Water Recycling Program, credits its commitment of social awareness about efficient water use and reuse as their success factor (Po et al, 2003). Acceptance of recovered resources can also extend to different sectors, such as drinking reused water to accepting crops that have been irrigated with recycled water (Radcliffe, 2008).

In order to be successful, the campaign must be targeted to and suitable to the local context. Prior to preparing for a campaign, people involved should actively listen to and engage in discussions, concerns and deliberations from the public. By doing this, questions and topics that concern people can be addressed in an appropriate manner.

3.3.1.2 Best Practices

Successful case studies and good practices can be another way to gain popularity among people on the phenomenon of recovering resources. Such cases must therefore be promoted and frequently showcased. In the IWA survey, several researchers noted that successful cases can help bridge the gap between science and technology and to move from lab-scale to full-scale applications. In the utility category, apart from mentioning that demonstration projects are needed in order to convince people of the importance of resource recovery, one respondent also pointed out that financial incentive for achieving this is needed as well.

3.3.1.3 Enabling Tools

Another method to reach out with information is through different tools. In the United Kingdom a mechanism has been launched in which regulatory agencies can provide information to the public (UKWIR, 2014). The tools, the Pollution Inventory and the Scottish Pollution Release Inventory, offer information on different substances being discharged to water, air and land. The tool further enables water companies to report their annual returns via an auditable method, allowing the public to easily access current procedures and targets. Not only does the method allow for people to get an understanding of the amount of resource that is being wasted, it also puts pressure on companies to provide the best service. Another example of a tool comes from the US. The United States Department of Energy has provided maps on their websites illustrating the potential for wind and solar power which can be used to assess the economic feasibility of onsite wind and solar technology (Mo and Zhang, 2013). Such provision of data is highly valuable in order to enlarge the pool of adopters. A treatment plant in Belgium used obtained acceptability of the end-user by implementing Hazard Analysis and Critical Control Points (HACCP) as is common practice in the food industry (Dewettinck et al, 2001). HACCP is a management system which addresses safety through analysis and control of biological, chemical and physical hazards from raw material production to consumption of the finished product. An example of putting the program to positive use comes from Belgium where water is typically not scarce. By strongly accentuating the safety aspects through HACCP, short-cycling of used water in coastal areas was sufficient enough in the summer of 2001 to cope with high touristic demands (W. Verstraete, personal communication, July 2014). Furthermore, this was possible by providing a green natural infiltration area.

These tools provide the users with information so that they themselves can make their own choices. Data has revealed that implementing a tool can also lead to a change in behaviour. An example from Sweden shows that instalment of individual water meters decreased the total water consumption by 20 percent (Olsson, 2012). Acceptance extends beyond the mind set of people to use recovered products, to further enhance and adopt various practices.

3.3.1.4 Involvement in Decision-Making

A way to gain credibility and acceptance among the public is to involve them in the process and to value their contributions. It is common that people are left out in decision-making processes and that they do not have an opportunity to influence plans until they have already been made. Providing the public with both data and a voice can be crucial in the process of social acceptance of new technologies. This can further enable the public to call for more sustainable practices among companies and to lobby for legislative change in their governments. Societal pressure can be a carrot for investment in technologies and the market of resource recovery.

3.3.2 CONSEQUENCES OF LACK OF SOCIAL ACCEPTANCE

In the same way in which social acceptance can promote projects, a non-acceptance of practices can hinder processes. Absence of acceptance can lead to people loosing trust in a technology, a product or in the people promoting them. Projects can be left unfinished as a result. An example of non-compliance from the public which hindered a project is the San Diego water re-purification project during the 1990s. The project was put on indefinite hold due lack of acceptance from the local residents of using recycled water mixed with imported freshwater in reservoirs (29, 30). Konheim (1984) investigated thirty-five resource recovery projects in the US and she writes that public opposition to a facility site is the most prominent cause of delay or termination of such a project.

3.3.3 ACCEPTANCE FROM MULTIPLE STAKEHOLDERS

As public perception highly influences the sustainability and environmental concern agenda, it is necessary to factor social acceptance into the resource recovery equation. However, it is not only the public who needs to see the value of recovered resources but also other stakeholders. Stakeholders vary due to the circumstance and can be investors, researchers, government officials and company employees. As has already been noted, recovered resources need to be valued at an appropriate market price. Due to reasons discussed above, recovered products are, and will be, valued differently in different places. Owners and operators of used water treatment facilities producing reclaimed water should be urged to adopt the attitude that they are performing resource recovery and that their operations have public health significance. Worldwide a positive trend has been noticed as the traditional used water treatment industry is shifting from ‘removal and treat’ to ‘recovery and beneficiation’ (Chandran, 2014).

One survey respondent stated that today’s conservative nature of the industry focuses more on risk minimization rather than growth opportunities and, thus, creates barriers for recovered resources. As noted in another survey response, the necessity for open-mindedness extends to regulators and decision-makers as well. This participant writes that a current limitation is the lack of understanding among policy makers about the needs and potential of technologies in the field of resource recovery. It has been suggested that most decision-makers are unmotivated and unconcerned when it comes to used water and water re-use (UN, 2014). This can be linked to the fact that many remain uninformed, which calls for the need of a spread of information on all levels. As an example, Konheim (1984) points out that local officials are essential and that they must have close connection to project managers and be continually kept up to date on project ideas.

3.3.4 TRUST

One vital component when examining stakeholder interactions is trust. In order to innovate and accelerate resource recovery, trust is needed in the technology, in the product as well as in the regulatory body managing topical regulations and policies. One survey respondent pointed to a lack of trust in recovered products to be a common barrier in the field of resource recovery. Furthermore, receiving communities need to have sufficient confidence and trust in their service providers and regulatory body to ensure the acceptance of the schemes (Radcliffe, 2008). Fear that a practice will not be socially accepted can also diminish innovations and the speed of technology implementation.

3.3.5 LOCALLY SUITABLE

Issues of trust and valuing of recovered resources can differ regionally and must therefore be targeted to the local context and appropriate group. The same approach applies when mapping out drivers of resource recovery. It has been seen that, in places where water is scarce and the numbers of options of water sources are few, people are more accepting of water reuse compared to in regions where multiple sources are available (Anderson et al, 2008). A project in Windhoek, Namibia is such an example where all other options had already been exploited and water reclamation was seen as the only way out (Law, 2003). One of the main drivers behind the advanced technologies used in Singapore is their urge to decrease their dependency on water supply from Malaysia (Tortajada, 2006).

Depending on the setting, different social aspects need to be either tackled or encouraged. In some countries, such as China and Japan, the use of human excreta as fertilizer is acceptable while in other parts it is viewed with disaffection or indifference, as in the Americas and in African countries (Redwood and Huibers, 2008). Willingness for people to pay for treated used water for irrigation also shifts between contexts.

3.3.6 LACK OF RESEARCH

Although the importance of the linkages between social aspects and recovered resources has been recognized, there is a significant lack of data investigating the field, and the research that has been carried out contains gaps. The majority of the studies that have taken place typically focus on water reuse. Even so, there is little social research that has been performed on the topic, specifically on indirect water reuse and public acceptance in developing countries (Anderson et al, 2008). Understanding public perception and the determinants of acceptance is one of the main ingredients of success for any reuse project which is why minimizing the research gap is important (Po et al, 2003). The absence of data can lead to undermining social aspects in the discussions about resource recovery as well as lack of best practice in how to tackle challenges that arise in the field. WaterReuse Research Foundation, based in the US and an Australian project, the National Demonstration, Education and Engagement Program, are currently trying to tackle the observed research gaps of public acceptance dealing with recovered resources (Dugan, 2014).

3.3.7 SURVEY REPLIES

Numerous survey participants mentioned social aspects when outlining barriers for resource recovery, such as limitations by psychological and cultural perception. One survey respondent felt that social acceptance was one of the most important subjects to tackle in order to progress from laboratory research to large-scale application.

One survey respondent said that the most noteworthy development within resource recovery in the past 15 years has been the change of viewing sludge as a resource. This statement implies that there is not only a demand for the resource itself, but also how the resource is viewed and valued. Valuing recovered resources appropriately is, therefore, an important feature. A change can be noted although much work remains to be done, as can be seen in another reply that urged the need for a change in mind-set and suggests that 'wastewater treatment' should be viewed as 'resource production' instead.

A pattern that became apparent from the survey was that social aspects were more frequently mentioned in the researchers' answers compared to the replies gathered from the utility sector. Reasons for this can include that there were more researchers compared to utility people that filled out the survey and that the questions were formulated in different ways. Another speculation is that researchers might fear social unacceptance to a higher degree compared to utilities that perhaps have established a successful value chain, and therefore do not meet social unacceptance to the same extent.

3.4 SUMMARY

An overall trend is that, while the demand of resources is increasing, the quantity of resources is decreasing. A gap between current consumption and worldwide supply is evident in many cases, and the situation is predicted to become even more severe. The dire need of recovering material instead of using virgin, finite resources is realized. One method of enhancing resource recovery is through regulations and policies. However, agreement does not exist on a global level and the extent of guidelines and conventions, as well as their degree of implementation, differs between countries.

Multiple social aspects on different levels should be considered when discussing resource recovery. Social acceptance can be the key to success or failure of a project and must not only come from the consumers but also from regulators and producers; this in turn needs to be built on the foundation that recovered resources are valuable. More research on this topic is needed as well as an integration of social aspects at all stages in resource recovery projects.

As fundamental points for success of resource recovery can differ geographically, methods and ways of implementation need to be targeted to and suitable for the local context. Communication among stakeholders is vital in the process of successful resource recovery, and cooperation between researchers, utilities, municipalities and end users can be key in moving resource recovery forward.

The correlation between demand, regulations and policies and social aspects can be discussed as well as what component acts as the main driver. The EU has, for example, proposed stringent regulations concerning biosolids in order to develop public confidence (Stark, 2004). Jiménez and Asano (2008) on the other hand argue that worldwide accepted standards need to be in place first in order to increase public acceptance, in the example provided regarding water reuse. A conclusion that can be drawn is that they are all interlinked, they must all be taken into consideration when discussing resource recovery and they can all act as both promoters and barriers for recovered resources.

4. INNOVATION, ADOPTION AND GOOD EXAMPLES

When discussing how to further develop the field of resource recovery, it can be worthwhile to reflect upon themes such as innovation and adoption. In order to exemplify these themes, several good examples have been highlighted. All the examples provided below, apart from providing useful guidelines and information on technological advancements, can also act as inspiration and provide a roadmap for people inside and outside of the water sector.

4.1 INNOVATION

Today's technologies present an opportunity in the field of resource recovery. The quantity and quality of technologies that result in recovered resources have gradually increased over the years. Benefits of recovering resources such as: an increase in public health; boost in natural resilience and economic growth; more sustainable practices; business certainty as well as an improvement in lifestyles and wellbeing (UN, 2014), are becoming evident. In exploring different resource recovery options and related technologies, it can be worthwhile to acknowledge the evolutionary path for emerging technologies. Innovation and ways to move from an idea to a full-scale application are therefore important to investigate, which can be done in different ways. One approach is dividing the path that new technologies must go through into different phases. A visual representation of such a hypothetical model can be seen in Figure 4.1. The figure illustrates an innovation beginning with an idea and evolving into a large-scale application.

At the premier stage an idea of an innovation or technology has been thought of, yet no further research has been conducted upon the topic. Lab-scale application and early-stage testing encompass the second innovation step. Demonstration pilot is when the idea has been formalized and tested while an applied pilot is one that is functioning at a larger scale in the setting it is sought to be applied in. Small- and large-scale applications are reserved for technologies that are commercialized and being used in smaller and larger quantities respectively. Best practices can be derived from both of these latter categories.

In the figure, the x-axis symbolises time while the y-axis represents maturity level. Maturity can be defined as different aspects: development, recognition, usage and acceptance. It can also symbolize the pool of adopters. The width of each category on the x-axis can be modified depending on the innovation and circumstances. For example, sometimes ideas take years to develop while other times an idea can occur in the course of a couple of minutes. The research stage can also be varied and range from days and weeks to decades. Another variable that can fluctuate is the slope of the S-curve. In some cases acceptance of an innovation can take much shorter or longer time than depicted in the figure, depending on the invention and the context.

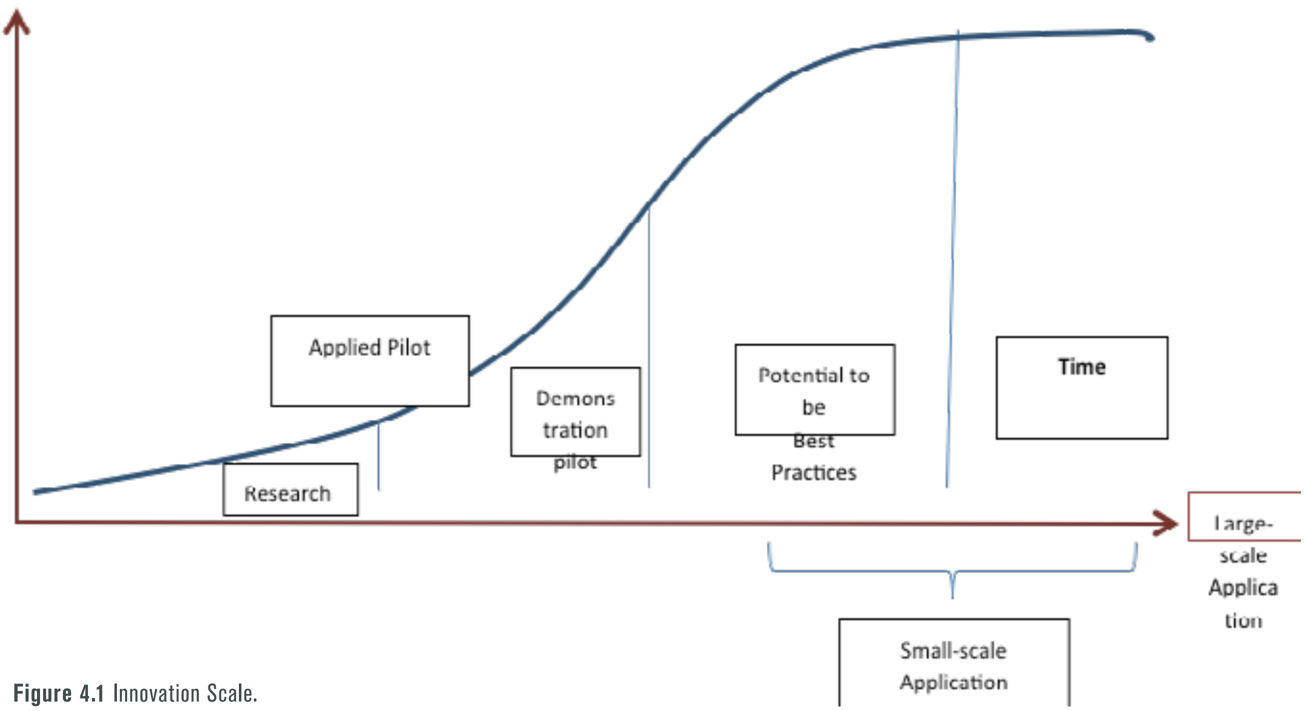

Figure 4.1 Innovation Scale.

The development depicts an iterative process as an innovation or idea can also need to be revised as it evolves. More research may be needed depending on the results from the demonstration pilot. An innovation can lead to new innovations, thereby beginning the innovation scale all over. The figure is a proposed schematic view of what an innovation scale can come to look like and will be modified according to the innovation and the context it is placed within.

Due to an evolving up-scaling of technologies, there is a constant push forward to move to the next step on the innovation scale. However, while it is important to scale up in scope, it is also necessary to scale down technologies in size so that there are a variety of dimensions in order to accommodate different needs. For example, resource recovery from individual to industrial scale should be made available if necessary and appropriate.

4.2 ADOPTION

As seen in the previous section, technologies can be in different stages of application and practice. New technologies must overcome various challenges and obstacles to develop from an idea to full-scale operation. As such, it is necessary to investigate the characteristics of typical adopters and innovators of technologies in order to understand how the speed of adoption and pool of adopters can increase.

Everett Rogers' concept of Diffusion of Innovation can assist when exploring the themes of adoption. The first publication on the topic is from 1962 and it has been updated with new editions since then, the last being the fifth edition in 2003. Rogers divides adopters into five different categories: innovators, early adopters, early majority, late majority and laggards. When plotted over time on a frequency basis, research shows that the adoption of an innovation follows a normal, bell-shaped curve (Rogers, 1983) as seen in Figure 4.2. The figure illustrates the adoption of an innovation over time by the members of a social system. The percentages in the curve symbolize approximate percentage of adopters in each category.

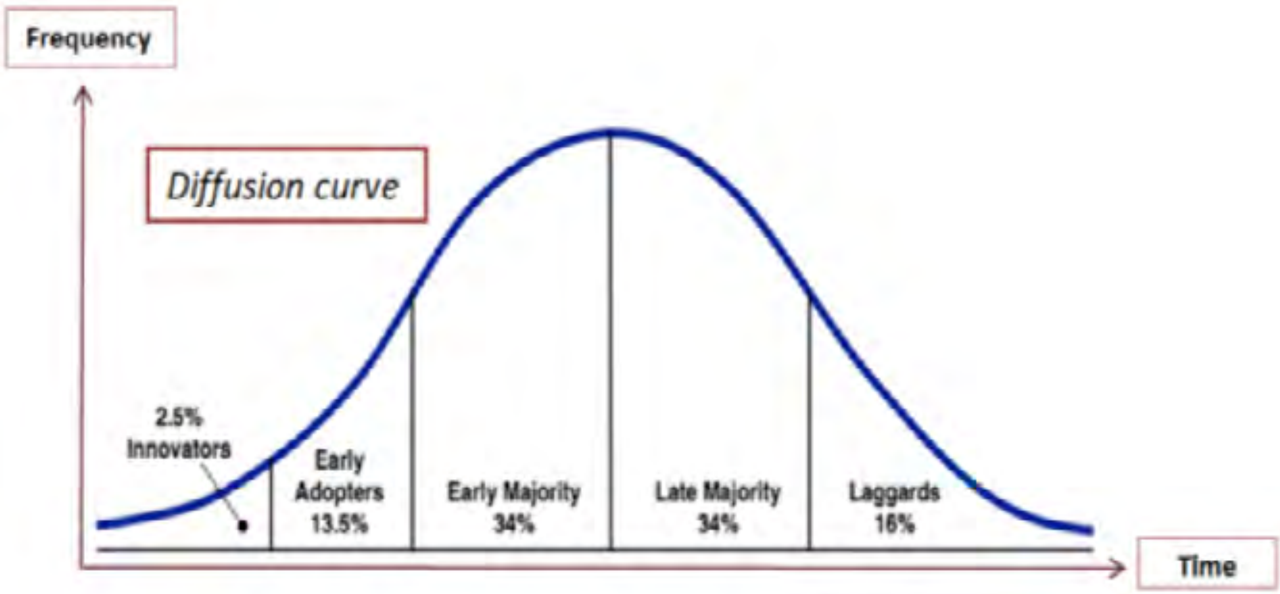

Figure 4.2 Diffusion Curve (Adapted from Rogers, 1983).

Innovators are described as venturesome and keen on trying new ideas. They typically have a close connection with the scientific community, interact with other innovators and have control over financial resources (Rogers, 1983). The ability to balance risk and uncertainty are traits that set the different categories apart. Innovators must be able to cope with a high degree of uncertainty and be able to manage implementation risks. Innovators are not afraid of failing.

Early adopters follow innovators. The group of early adopters are key when introducing innovation to a broader potential group as they serve as role models for other members in a social system. They are also willing to take risks and they typically have a broad social network. Furthermore, early adopters might have funding for testing and may already have potential customers. Through adoption, the early adopters decrease the uncertainty of an idea or innovation.

The group of early majority provide interconnectedness in the system. They frequently interact with their peers and constitute an important link in the diffusion process. Their innovation-decision period is typically longer compared to that of early adopters. While the early majority adopt ideas just before the average member in a social system, the late majority embraces new innovations just after the average member. The late majority first need proof and recognition from earlier adopters to verify that the introduced idea is functional and feasible. The pressure of peers is necessary to motivate adoption for this group, and they usually cannot afford a big financial loss in testing a technology or idea.

The last group of people to adopt an innovation in a social system are laggards. This group of adopters is commonly more focused on tradition. They require time and evidence from various sources to feel secure that an idea is worth investing in. As the laggard's resources are scarce, they need to be certain that a new idea will not fail before they try it. In regard to risk, laggards typically view the implementation risks as too big of a barrier when the benefits are uncertain.

4.3 OPPORTUNITIES AND OBSTACLES FOR INNOVATION AND ADOPTION

There are multiple opportunities and obstacles for both innovation and adoption and these can vary in time and space. Driving forces behind the initiative to adopt a technology can differ in geographical context as well as at the stage of implementation. In the case of phosphorus recovery for example, it has been suggested that early stages of development are driven by legislation and technical feasibility while economic viability, environmental stability and social acceptance are the most important factors for full-scale implementation (Stark, 2004).

Actors can also vary depending on the country or local context. In the discussion on sludge management for example, the water industry is the main actor in the Netherlands, while in Sweden the influencers are politicians and environmentalists; Italians value technical aspects as more important (Stark, 2004). The private sector, through its collaborations with governments and through public-private partnerships, is said to help leverage innovation and adoption of new science and technology (BASD, 2011). Some target businesses as the primary source of innovation which, provided with the right environment, is a critical player in the development, demonstration, commercialization and dissemination of technology.

4.3.1 OPPORTUNITIES

4.3.1.1 New Technologies

An opportunity for innovation and adoption of resource recovery can be the technologies themselves. Development of new technologies and perfecting existing technologies can help proceed both on the innovation scale and on acceleration of the diffusion curve. There is a need to identify novel resources that can be recovered and to investigate how such resources can be recovered using already ongoing processes. Technologies are more likely to be adopted if they are easy to use, appropriate to the local context and meet specific demands.

A way to move forward within the field of resource recovery is applying technologies in different places and being open to try new ideas. One Australian farmer started irrigating the family's farm with recycled water. The idea proved to be fruitful, and the farm won a productivity award for growing the most sugar cane per hectare (Po et al, 2003). After the recognition, recycled water was made available for irrigation to the entire region for crop irrigation, farming, pastures, sports fields and tea tree plantations.

It must also be acknowledged that technologies that provide multiple benefits are more likely to be implemented compared to those that provide a single primary benefit. The economic incentive and profit of such is likely to be higher. A multipurpose technology would further increase its potential pool of adopters and clients. A phosphorus recovery technology, for example, that can generate sludge with an improved ability of dewatering is likely to be more attractive compared to its competitors as it reduces sludge hauling costs. An economic case for nitrogen recovery cannot currently be made in many countries but, if recovering this compound in conjunction with phosphorus for example, it could become more financially feasible and increase investments. Developing technologies which are able to recover multiple resources therefore provide manifold positive developments.

4.3.1.2 Data

Developing and upgrading existing technologies can be related to the amount of readily available information and data. Knowing the physical quality of the recovered product can help develop technologies further. One example of advancing available techniques is at the University of British Columbia where a research group is working on studies relating to the improvement of crushing strength and size of struvite pellets (Fattah et al, 2012).

In advancing resource recovery it is necessary to identify resources that can be recovered as well as recognize the market of these resources. A comprehensive market study exploring the strength of the current and future market is crucial. It should identify established and competing products and investigate the generated impacts if all used water treatment facilities in one area produced the same product. Information is, therefore, a key component in the development of resource recovery. If there is an understanding of the market, it is easier to develop technologies that suit the upcoming need in an appropriate manner. An evident example is the diminishing future availability of resources of some varieties of metals and nutrients, which accelerates the market for recovered resources of such types. The widely known fact that phosphorus is now considered a non-renewable resource calls for incentives. The spread of this knowledge can lead to adopters increasing in quantity and geographical scope, thus simultaneously moving component recovery up the innovation scale. The better the ability to respond to the known market and the wider the market for a specific product is, the more attractive the technology will be. Knowledge of resources which are to be recovered will also lead to better targeted technologies. It is, therefore, useful to investigate currently unknown areas and to use this as a backdrop to leverage initiatives indicating what areas should be elaborated upon.

Example of information that could be beneficial to distribute is data on costs, amount of resources that can be recovered and energy balance of technologies. Information-sharing could facilitate an appropriate development and application of technologies. Life cycle assessments (LCA) can further be of use for emerging technologies. These also can depend on the amount of and access to data and information.

4.3.1.3. Environmental Aspects

There is not only a demand for the raw materials and products themselves, but also a need for suitable technologies providing these. The fact that the technologies can result in decreased environmental impacts, such as reduced amounts of greenhouse gases, is a major factor in the development of resource recovery. In the example of phosphorus, mining of this rock inevitably increases the amount of cadmium to the biosphere which results in severe local environmental effects. By providing technologies that recover such nutrients, the mentioned hazards are automatically offset (Stark, 2004).

4.3.2 OBSTACLES

4.3.2.1 Finances

Lack of finance has been documented as a major barrier in both providing new technologies as well as transitioning lab-scale devices to large-scale application. This notion can be seen in the different categories of resources to be recovered. In metal recovery there are high start-up and operating costs, and one of the key hurdles for growth of commercial PHA applications is the price (Anterrieu et al, 2013). Onsite wind and solar technologies on treatment plants further require large capital investment. The majority of the respondents in the IWA survey specifically noted that lack of finances hinder resource recovery development. Resource recovery technologies have also to compete with long established industries. Recovered resources need to be at a financially competitive stage with current practices, which can be difficult as many existing practices are subsidized. In some regions the traditional oil and gas industry benefits from a wide variety of tax benefits. These were implemented decades ago for reasons suitable for the time but not any longer applicable (G. T. Daigger, personal communication, July 2014). For example, petroleum is much cheaper compared to the same quantity of algae based biodiesel (WERF, 2013). Innovations can therefore be at a disadvantage financially as some of them are seeking to replace methods which are partially subsidized. Another example is that of PHAs, the production of which has not been considered a viable, cost-effective alternative to inexpensive production of petroleum-based plastics. This has altered its establishment and adoption as a recovered resource, even though the environmental benefits of PHAs have been known for decades.

Prediction of price for new technology can also halter innovations. The economic value and advantages of innovative technologies is often understated while the costs involved in evolving new ideas or approaches are overstated in relation to already proven technologies (Daigger, 2011). Economic aspects can as such be an obstacle for resource recovery.

An economic limit can further rely in the market niche. For example, different recovered phosphorus products, such as iron phosphate and calcium phosphate, do not have the same market value. There is an intrinsic risk that the resources with the highest market value will be recovered while technologies for reusing other compounds will be left unexplored. The market for recovered products must be developed, which requires financial incentives as well. Furthermore, different technologies and recovered products can be priced differently across the world, creating barriers in some regions while not in others.

A survey carried out by WERF (2013) concluded that other barriers can be overcome given sufficient funding. Money for investment can be derived from different sources. Some argue that there is a need for the public sector to provide financial support for private sector investments, such as risk sharing in critical early phases and catalytic funding (BASD, 2011). It is predicted that such action will help support development cooperation and economic growth. One IWA research respondent stated that the financial crisis has been one of the biggest developments within resource recovery as it led to companies realizing that it is time to innovate. Financial incentives could be created through calculating economic feasibility and efficiency of recovered resources.

4.3.2.2 Lack of Data

As beneficial as data is towards improving technologies and understanding the market, the lack of data is detrimental in efforts of doing the same. For example, information gaps regarding nutrient accumulation, release and extraction prevents development of the performance benchmarks and cost data which are seen as necessary if nutrient recovery is to be implemented as part of an integrated nutrient management plan. Absence of information can easily further lead to lack of understanding which negatively affects social acceptance and the drive for legislative action.

4.3.2.3 Technology Design

The design of technologies and its feasibility for full-scale application can also limit innovation and adoption. Developed technologies that are not suitable for the local context may be left unused. The size of technology can be another barrier as a minimum size is required before efficiency of delivery can be achieved. CHPs for example require a large volume of biogas in order to operate, thus restricting their implementation in small used water systems (Mo and Zhang, 2013). Another example is heat pumps. The resources offset from these can only be applied onsite or where there are heating or cooling demands in nearby communities which is due to the fact that heat recovered from heat pumps cannot be delivered over long distances. A similar limitation can be seen with biogas and compressed natural gas (CNG) and liquid natural gas (LNV). The current biggest barrier to CNG or LNG conversion is lack of widespread infrastructure for gas filling stations. Another example is reclaimed water which needs a pipeline system for its distribution. Depending on the distance between reclaimed water supply and major agricultural demand area or municipality or golf courses, this could further be a barrier. Providing infrastructure that is suitable to applied technology can be costly (Mo and Zhang, 2013). A way to overcome this is by integrating new appliances into already existing infrastructure.

For metal recovery, it is typically more efficient to remove metals that are in higher concentrations. Consequently, there is a risk that metals with lower concentrations are not recovered.

4.3.3 REGULATIONS AND POLICIES AND SOCIAL ASPECTS

Regulation and policies can both act as a promoter and barrier for innovation and adoption. Different social aspects, such as acceptance can also help enhance or halter a development. For further discuss on these topics see Chapter 3: Demand, Regulation and Policy and Social Aspects.

4.4 GOOD EXAMPLES

Although technologies exist and are being applied in practice, this is not being done in sufficient magnitude relative to its existing potential (Daigger, 2011). Investigating current applications and learning from good examples is one way to overcome this. The following section will investigate four different examples which can be seen as role models in their respective fields. For water an example from California, USA is looked at, while the example of energy is from a used water treatment plant in Austria. The Netherlands showcases unique methods to recover nutrients, and a Danish example demonstrates resource recovery at an integrated level. It must be noted that these are just four out of multiple inspiring examples that exist. There are further practices from sectors, such as the metal and mining industry, that are not touched upon here but that serve as good examples. Moreover it must be acknowledged that trade-offs exist in all technologies. For example, a technology can recover metals in a very effective manner while consuming a lot of energy in the process.

4.4.1 WATER

One example that acts as a role model for indirect potable reuse is Orange County Water District. The Orange County Water District (OCWD) was formed in 1933 and serves more than 2.3 million residents in Orange County **[5]**. It came about as an act of the California State Legislature and is responsible for managing and protecting groundwater basins in Orange County. The main source of water of the basin is replenishment from the nearby Santa Ana River and imported water from sources such as the Colorado River. Since the inaugural year, OCWD more than doubled the groundwater basin's yield. An overview of the area can be seen in Figure 4.3.

OCSD purifies secondary effluent. Together with Orange County Sanitation District (OCSD), OCWD has developed a Groundwater Replenishment System (GWRS). The system began operations in January 2008 and the GWRS is today the world's largest used water purification system for indirect potable reuse (Chalmers and Patel, 2013). Their treatment facility, known as the Advanced Water Purification Facility (AWPF), discharges treated water into groundwater aquifers to later on be used as drinking water for residents in the surrounding area. The system can produce 265,000 m^3/day, which supplements existing water supplies in the Orange County Groundwater Basin. It further meets the need of 600,000 residents in the northern and central parts of Orange County. Apart from the AWPF, the system consists of a pipeline connecting the treatment facilities to recharge basins and of a seawater intrusion barrier (see Figure 4.3). The first phase of the GWRS project cost USD 481 million, which was equally divided between OCWD and OCSD.

The AWPF uses a three-step purification process which includes microfiltration, reverse osmosis (RO) and a combination of ultraviolet light and hydrogen peroxide. Microfiltration is a low-pressure membrane filter that separates out bacteria and protozoa while the RO remove dissolved minerals and pharmaceuticals **[6]**. The last step with UV-light destroys potential harmful constituents through penetrating cell walls of organisms and thus inducing cell death. The addition of hydrogen peroxide results in oxidizing organic compounds for ultimate removal from water. Calcium hydroxide, hydrated lime in powder form, is added along with cationic polymers to stabilize and buffer the final product water (GWRS, 2013).

The predecessor of the GWRS was Water Factory 21, which was implemented in the 1970s (Chalmers and Puntel, 2013). It focused mainly on recharge to the basin and was already then introducing new concepts and technologies. Among other things, it was the first to apply RO in 1976 and to introduce microfiltration as a pre-treatment stage to RO in 1993 (Law, 2003). The Factory was also the first in the world to perform advanced treatment of used water for injection into coastal drinking water aquifers (Lenker et al, 2014).

One of the advancements of the GWRS is the seawater intrusion barrier (see Figure 4.3) (Lenker et al, 2014). As more water is being pumped out of the basin, the risks of salt water seeping into the basin increases (GWRS, 2013). 114,000 m^3 per day out of the 265,000 m^3 per day that is being produced is pumped into injection wells where it serves as a barrier for seawater. The rest of the water is distributed to percolation ponds designed for the water to pass through gravel and sand beds before augmenting the principal drinking water supply aquifer. The groundwater is later pumped to over 400 wells used

Figure 4.3 Map of the Ground Water Replenishment System (Dunivin et al, 2010)

by cities, local water agencies and other groundwater users. The overall production of water is projected to increase to 379,000 m^3 per day by 2015 (Dunivin et al, 2010).

There is an extensive monitoring and evaluation system in place at GWRS. Experience and results from the first two years of operation were used as a backdrop to design the plant's expansion. Evaluations from the first two operational years resulted in intentions to operate 24 hours a day as well as to accommodate higher flows. Apart from the annual production of water increasing, a physical enlargement of the plant was further the result of the first evaluation period. The original infrastructure design was constructed to allow for such an expansion.

In the preceding chapter, recovered resources have been discussed through the lens of demand, regulations and policies and social aspects. When investigating such themes for OCWD and GWRS one can see that one of the main drivers for the project was the demand side (Law, 2003). There was a demand to increase the available pool of water, to decrease the demand for imported water as well as to prevent seawater intrusion.

The GWRS is well positioned to be in compliance with the updated regulations related to monitoring and operation of groundwater recharge reuse projects in California (Dadakis et al, 2011). Prior to the planned expansion, the regulations were investigated in order for the upgrade to meet all the current requirements. Changes in requirements in subsurface retention time and unit process monitoring would, for example, impact GWRS operations and, therefore, need to be continuously checked. The water that is produced through the process exceeds drinking water standards on both state and federal levels (GWRS, 2013).

In regards to social aspects, the District made noteworthy efforts in gaining public acceptance which resulted in community approval of the project. The GWRS hosted 4,000 visitors in 2010 (Markus et al, 2012) and provides lectures to people interested in the project **[7]**. Strong community support has been one of the project's major keys to success (Chalmers and Patel, 2013). The public outreach program began already in 1997, years before the system was designed, to educate people about the positive aspects of water reuse. The public further elect the ten people who serve on the Board of Directors for OCWD, and thus, the public is involved at different stages and levels. One reason of the heavy involvement of the public is southern California's record of high-profile projects in the area being cancelled due to lack of public acceptance.

OCWD and GWPS have been praised worldwide for their work. Among other recognitions, OCWD received the Lee Kuan Yew Water Prize in 2014 **[8]**. The prize acknowledged the District's work in groundwater management and advanced technologies in water reclamation. The international award is distributed to recognize contributions which aim at solving global water problems through applying innovative technologies or through implementing policies and programmes that benefit humanity. The award was further given to OCWD for their accomplishments in public policy and community outreach. The GWRS has additionally been acknowledged with Stockholm Industry Water Award (2008), American Society of Civil Engineers Outstanding Civil Engineering Achievement Award (2010) and Water Recycling Agency of the Year Award (2008), distributed by the WateReuse Association (GWRS, 2013).

4.4.2 ENERGY

An example of a good practice in terms of energy comes from Austria and the used water treatment plant of Strass. The facility in Austria is best known for its goals and achievements in becoming energy self-sufficient.

The idea behind Strass started as early as in the 1990s when the used water treatment factory began to focus on achieving energy-positive status by producing more energy than the treatment process required (Crawford, 2010). The rationale behind this was based on the fact that used water contains significantly more energy than needed to treat it. By 1996 the plant produced more than half of the energy it used, and in 2005 the production had exceeded the daily consumption. The plant serves 31 communities and is located in Strass Valley of Austria. The population the plant provides treatment for ranges between 60,000 to 250,000 during a year. The fluctuation in population size is due to a peak during the tourist season, an aspect which was taken into consideration during the design of the facility.

There are a number of measures that have led to the energy self-sufficiency at the plant. One of the reasons is the usage of a two-stage biological system, also known as the Adsorption-Belebung (A/B) process. The system treats on average loads varying from 90,000 to more than 200,000 population equivalent (PE) weekly, depending on the season (Wett et al, 2007). The A-stage removes about 55-65 percent of the organic load with a solids retention time (SRT) less than half a day (Nowak et al, 2011). The SRT in the B-phase is around 10 days, which results in a nitrogen elimination of about 80 percent (Wett et al, 2007). An online ammonia analyser controls the air-flow and aeration periods, and all activated sludge tanks can be operated aerobically if necessary (Nowak et al, 2011). The process results in maximum transfer of organics to the digesters.

The excess sludge is thickened, anaerobically digested and dewatered. The method also results in a high nitrogen load in reject water from sludge dewatering. One unique aspect of the Strass treatment plant is the implementation of biological deammonification in the DEMON® reactor which has been implemented on full-scale side-stream treatment since 2004 (Joss et al, 2009). The system uses the anaerobic ammonia-oxidizing (anammox) bacteria (Innerebner et al, 2007) and consists of two steps. In the first step in the process part of the ammonium converts to nitrite (nitration) through oxidation, while the second step is the anammox reaction which oxidizes the remaining ammonia using nitrite (Joss et al, 2009). The system involves sequencing batch reactors (SBRs) for a combined nitration/anammox process. The process was gradually scaled up in three different steps during a period of two and a half years (Wett, 2006). Apart from lowering the energy requirements for nitrification, the conversion to use the DEMON® process further allowed most of the influent organic load to be available for conversion to biogas within the digesters instead of being used for denitrification. The DEMON® process does not require a carbon source, which further sets it apart from its predecessors.

Besides the A/B-process and the side-stream nitrogen removal, the introduction of a new engine for the combined heat and power (CHP) unit was an important factor in terms of energy production as it increased overall usage and electrical efficiency. The new unit converted gas to electrical energy with an average efficiency of 38 percent (Wett et al, 2007). The combined measures significantly increased the percentage of energy self-sufficiency.

In order to increase the electricity production from biogas, the treatment plant started co-digesting in 2008 (Nowak et al, 2011). The amount of energy produced and consumed in the plant prior to this year can be seen in Figure 4.4. The figure further illustrates the ratio of energy production to energy consumption. Surplus electricity, when the production exceeds consumption, is delivered to the grid. In February 2005 for example, the energy production exceeded the plant's energy consumption. Prior to 2008 the used water treatment plant was energy self-sufficient; after 2008, production exceeded consumption with help from external organic substrate.

The treatment plant does not solely owe its success to the technologies involved in the plant. From the outset of the project, people had a rigorous and holistic vision of the end product. Furthermore, there has been a strong partnership with local industry including sectors such as research and development. The workforce consists of highly skilled individuals who, apart from being in charge of overseeing maintenance in their respective area of expertise, have also been active in the public forum.

Drivers for the plant are two-fold: reduction of cost for the treatment plant and reduction of greenhouse gas emissions (Wett et al, 2007). In terms of regulations, Austrian used water treatment plants have been encouraged to be part of the benchmarking process that the country uses in place of regulations. The benchmarking program is set up so that participating plants submit their data that are then compared with the overall gathered data. This aims to stimulate competition. Between the 5-year period of 1999 and 2004, the plant's relative energy cost had shrunk by 30 percent. On an organizational level for the treatment plant, benchmarking metrics have been set to target and communicate priorities. The plant has further established its own metrics. For secondary treatment, for example, the metric used is how much energy is produced per amount BOD removed rather than per treated amount. These metrics all fall under the plant's envisioned scope and aims for sustainability.

4.4.3 COMPONENTS

A treatment plant in Olburgen, the Netherlands, presents a good example of a current successful practice in which components are being recovered. Apart from the technologies that are employed at the facilities, the partnership

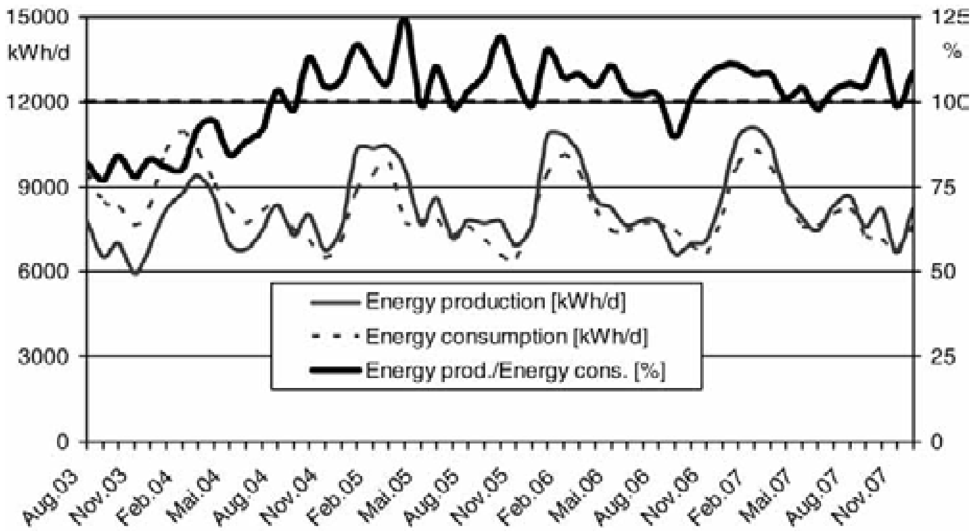

Figure 4.4 Energy data for Strass treatment plant (Nowak et al, 2011).

between different stakeholders is also noteworthy. The end product is a fertilizer in the form of struvite.

The treatment plant treats used water from a nearby industrial treatment plant, reject water and industrial effluent. The used water and reject water is treated in a separate treatment plant before discharging the industrial effluent to a sewage treatment plant. The reject water is from the sewage treatment plant, while the used water comes from the Aviko potato processing plant (Schultz, 2009). Aviko is today one of the four largest potato processing companies in the world **[9]**. Each year they process 1,200,000 ton of potatoes **[10]**. Water from the potato processing plant contains proteins, starch and phosphorus in amounts that equal 160,000 PE (Schultz, 2009). In particular, potato peel contains a lot of phosphate which can be recovered (van Iersel, 2014). The ability to have two separate treatment plants was found most cost- and energy-efficient compared to a traditional treatment process (Abma et al, 2010). It was made possible by the public-private partnership between the waterboard and Waterstromen BV, a Dutch company which operates the treatment plant and which is an affiliate of the waterboard. The plant was designed by Paques, and the construction of the plant with separate treatment plants was completed in 2006.

Figure 4.5 illustrates the treatment procedure. Reject water from the sewage sludge that has been processed in the digester enters the PhospaqTM reactor where it is mixed with used water from the potato processing plant which has been treated in the UASB reactor. The UASB technology has been in function since 1982 at the treatment plant, and it removes the majority of organic components through anaerobic treatment. The effluent still contains considerable amounts of phosphorus and ammonium, which are removed through the PhospaqTM and one-step Anammox® respectively. PhospaqTM removes phosphate to over 80 percent, while Anammox® eliminates ammonium up to 90 percent. It is the first time that these two processes have worked in combination on a full-scale (Abma et al, 2010).

Magnesium oxide is added to the PhospaqTM reactor to stimulate the formation of magnesium-ammonium-phosphate (MAP), also known as struvite (Remy et al, 2013). Air is further added, and the aeration system provides for efficient mixing and enhancing stripping of carbon dioxide, a process that is advantageous for struvite formation. The removal efficiency and struvite formation capacity depends to a large extent on concentrations of magnesium, ammonium and phosphate and on the

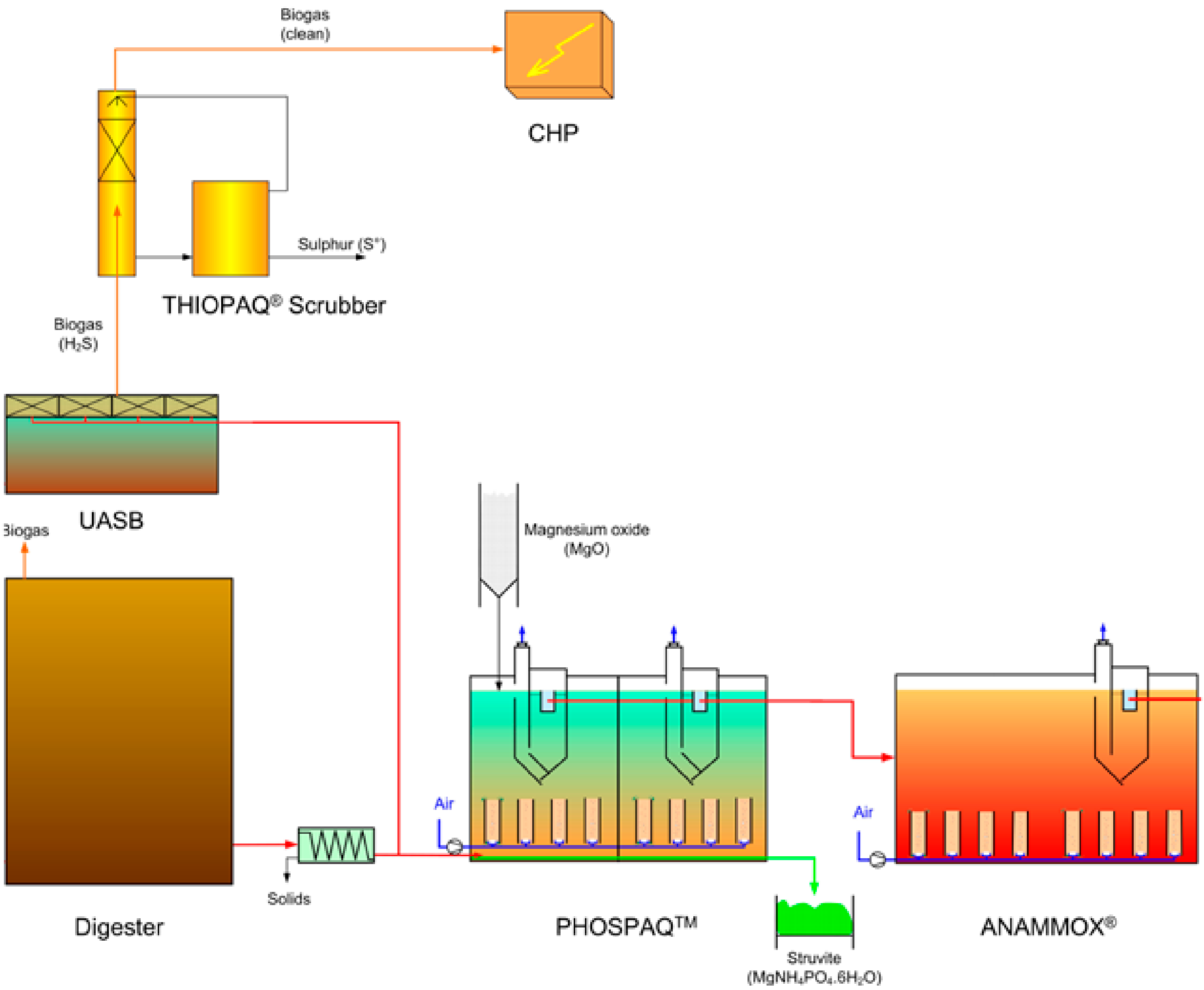

Figure 4.5 Schematic Layout of Treatment System (Driessen et al, 2009).

pH-level of the water (Abma et al, 2010). Over 1,200 kg of struvite is produced daily (Remy et al, 2013), with an average yearly capacity of 400 ton (Schultz, 2009). The average particle size is 0.7 mm (Remy et al, 2013), and the end product is used as raw material for producing fertilizers for agriculture and for usage on grass fields such as golf courses [11].

In the Anammox® reactor the ammonia in the water is converted into nitrogen through a combination of nitration and anammox bacteria (Abma et al, 2010). Air is added to the process, and the aeration flow is adjusted in order to obtain the desired effluent quality. Effluent from the reactor is delivered to the sewage treatment plant where it is treated there to reach the quality suitable to discharge into surface waters.

Apart from struvite, the process further generates energy. In the UASB reactors, the majority of the organic components are converted into biogas [12]. Hydrogen sulphide is removed from the biogas using the Thiopaq® process, which results in both cleaned biogas and elemental sulphur (Abma et al, 2010). The latter can be used as a sulphur fertilizer [13]. The biogas can be utilized in the CHP unit due to the removal of hydrogen sulphide. Part of the energy that is produced is delivered to the Aviko processing plant (van Iersel, 2014).

Partnerships have proven to be useful for the process of recovering resources in the plant. The company operating the plant, Waterstromen has a collaboration with the Waterboard, thus creating a successful public-private partnership. Aviko has further partnered with treatment plants that have linked with the market. Resale of products is carried out by third parties, including Melspring International B.V. The fertilizer that is produced not only contains phosphate but also nitrogen and a number of other minerals. Phosphate from the treatment works is sold on the market under the name of Vitalphos® [14] and is patented in Europe.

In May 2014, Waterstromen, Melspring International B.V. and Lumbricus came together to create a new fertilizer by the name of Marathon Vitalphos®. The dried struvite was upgraded through addition of natural ingredients [15]. One of the places to sell the product is Green Care, which is part of Melspring International Ltd. Apart from the success of gathering multiple stakeholders the combination of technologies at the plant has also proven useful. Usage of both the Anammox® and the PhospaqTM processes has resulted in annual discharge savings of 1.5 million. In order to accommodate the different needs from the variety of customers, both small- and large-scale, struvite is sold in different quantities [16].

As with the previously demonstrated projects, cost reduction and reduced environmental impacts have been drivers for the project. At the outset, Aviko sought to reduce their discharge costs. Furthermore, regulations played an important role in the development of the treatment plant. The main reason for the plant to upgrade itself with separate treatment plants was to reach compliance with the European Water Framework Directive in regards to nitrogen and phosphate concentrations in the discharge (Abma et al, 2010). The treatment plant now meets both Dutch and European regulations (Remy et al, 2013; Shultz, 2009). The product quality is further in compliance with European legislation for fertilizers (Remy et al, 2013). The struvite has, for example, a concentration of heavy metals that is 20 times less than the EU standards for fertilizers (Abma et al, 2010). The producers of the struvite fertilizers also take pride in meeting demand for phosphorus through recovering resources from a Dutch source, rather than mining the non-renewable material elsewhere which would require transportation [17].

4.4.4 INTEGRATED RESOURCE RECOVERY

While some treatment plants focus on one resource or one aspect of resource recovery, there are a few examples in which multiple resources are recovered and in which an integrated approach has been taken from the outset. One such example is the Billund BioRefinery, situated in Denmark, which produces three products: clean water, organic fertilizer and energy in the form of biogas.

The project is realized through the collaboration of several stakeholders. The main implementers are Krüger A/S, part of Veolia Water Technologies and Billund Vand A/S [18]. Other partners are the Danish Ministry of the Environment and the Foundation for Development of Technology in the Danish Water Sector (VTU). Among others, the Danish government and VTU have provided financial support of DKK 15 million. The preliminary design of the project was prepared during the fall of 2013, and the physical construction began in August 2014.The plant is an upgrade of the existing wastewater treatment plant of Grinsted, Denmark [17b]. The aim is to put the new facility in operation by March 2017 [18].

The plant has two different treatment lines, one for wastewater and the other for biomass (see Figure 4.6) [19]. These work in synergy as biomass is produced through the wastewater treatment line. Organic waste is collected from farms, households and industries. Industries include restaurants, slaughter houses, catering centres and shops. Manure is collected from the agricultural sector. Billund BioRefinery will annually handle 4,200 tons (DC) of organic waste and sludge from the wastewater treatment plant with a total capacity of 70,000 PE [20]. The mixture of organic waste from different sources enables more effective treatment.

While the organic waste is transported to the energy factory, wastewater from households is delivered to a wastewater treatment plant where it is treated. The quality of the treated water is in compliance with Danish and EU regulations and the water is discharged into a river located nearby the treatment plant [21]. Sludge resulting from the treatment process continues to the biorefinery plant for additional treatment [20].

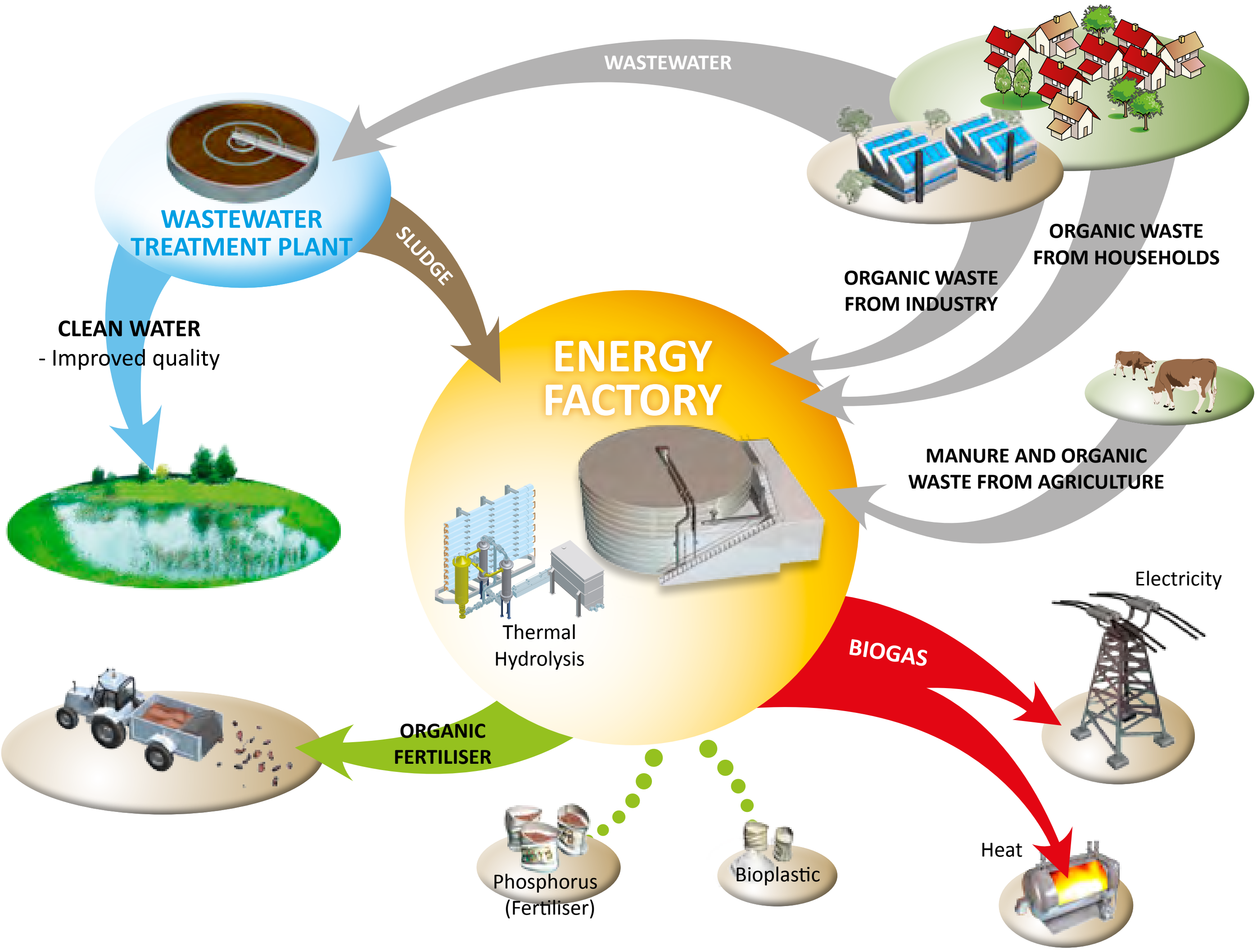

Figure 4.6 Principal drawing Billund BioRefinery [22]. Reprinted with permission from Billund BioRefinery.

The Energy Factory is considered the heart of the operation. It uses a process which combines thermal hydrolysis and anaerobic digestion **[23]**, resulting in an increase of 30-50 percent in biogas production (Veolia Water, 2013). The technology is called ExelysTM and Billund BioRefinery is one of the first plants to apply it on a large scale (Krüger, 2014). ExelysTM, which is an enhancement to anaerobic digestion, can treat different types of organic products, industrial or municipal sludge as well as handle grease.

Exelys™ is a continuously thermal hydrolysis process which was developed to reduce costs and energy consumption (Gurieff et al, 2011). Results indicate that Exelys™ is as effective as traditional batch thermal hydrolysis but comparatively more energy efficient. The process is an effective way to increase biogas production and solids destruction in the anaerobic digestion system (Krüger, 2012). At Billund, the Exelys™ technology is coupled with a Digestion-Lysis-Digestion (DLD) configuration, patented by Veolia in 2009. Before treated with the Exelys™ process, the waste is pre-digested and dewatered, which reduces the energy input while at the same time maximizing the energy production **[19]**. Figure 4.7 provides an overview of how the dewatered sludge is continuously pumped under pressure into a reactor tube (Veolia, 2014). The sludge is heated in the reactor by steam injection. As the sludge further flows through the reactor tube it is exposed to pressure and high temperatures. The hydrolysed sludge is then cooled down in the heat exchanger and through adding water before it is transported to the second digester. The end product of the entire procedure is biogas which is converted to both electricity and heat which is sold to the public district heating system and to local customers. Clients include industries, farms and households. Currently 700 private households are supplied with electricity produced from their own waste, a number that is predicted to increase **[24]**. DLD on mixed sludge has proven to increase biogas production and electricity production by 50 percent while decreasing final sludge volume 30 percent **[25]**. The production of energy at the plant exceeds the consumption of energy used on waste and sewage.

As with previously described technologies, Billund BioRefinery uses annamox bacteria for converting nitrogen from organic material to nitrogen gas (Krüger, 2014). Reject water from the centrifuges highly loaded in ammonia use the AnitaTM-Mox process which builds on the Moving Bed Biofilm Reactor (MBBR). An aerobic and anoxic process is combined in this process which further uses both conventional nitrite producing bacteria as well as specific anammox biomass. The ammonia removal efficiency of the procedure is over 80 percent.

The end products from Billund BioRefinery will be a hygienised organic fertilizer containing nutrients from biowaste and sludge **[26]**.

The plant is further investigating the possibility of producing bioplastics **[27]**. Another future development might include using produced methane and hydrogen for the operation of fuel cells and biofuel for cars.

Apart from having a holistic view on resource recovery, an integrated approach is also necessary regards to operation. Optimal performance is ensured through continuous operation and simple maintenance (Krüger, 2012). Overseeing the entire production and management is Krüger's suite of intelligent software system called STAR Utility Solutions™®. The system ensures that wastewater is treated optimally with a minimal use of energy and chemicals while optimizing energy production (Krüger, 2014).

The Danish government predicts that the plant will set the stage for resource recovery, both nationally and internationally. One of the acknowledgements that Billund BioRefinery has received is the Water Reuse Project of the Year, which was distributed at the Global Water Summit 2014 **[28]**.

As with the other highlighted projects, multiple stakeholders are involved in the process. As organic waste is collected from households, the process requires people to properly sort their waste. This entails an understanding of the associated benefits. Social aspects are also extended to working with industries as waste is further collected from them. By presenting the plant as a business, the procedure is a win-win situation for the parties involved. The project also invites the academic sector as it welcomes postdoctoral students to conduct research at the plant. In terms of regulations and policies, the plant will meet all the ambitious requirements that Billund Municipality has, which are stricter compared to the regulations on a national level.

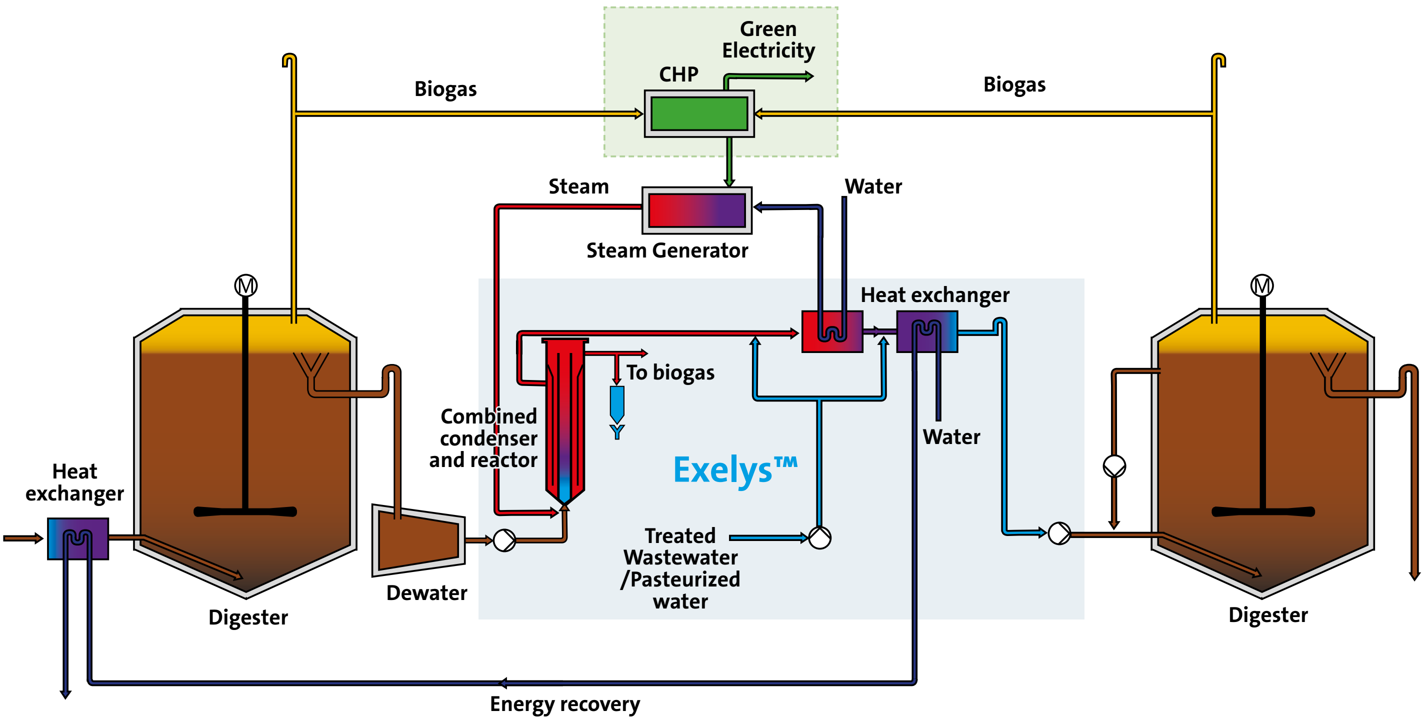

Figure 4.7 Continued thermal hydrolysis (Krüger, 2012).

4.5 SUMMARY

The dire need and huge demand for water, energy and components has been touched upon in the previous chapter. Reasons why the market is not seeing an overflow of products for recovered resources can be correlated to the speed of innovation and adoption. Innovation and adoption are critical components when it comes to developing and enlarging the pool of resource recovery technologies and applications. It is important to acknowledge this and include such traits in order to strategically plan for further development.

The provided examples of treatment plants all demonstrate different features that have made them role models within their field of resource recovery. One is that they were all early adopters in one way or another, taking a risk and succeeding. Previously discussed opportunities should be leveraged to overcome the obstacles and limitations.

The need for collaboration has been discussed as a vital component in previous chapters, and the examples showcase the importance of it. The example from Orange County demonstrates successful cooperation between the Water and Sanitation District, while an effective public-private partnership can be seen in the example from the treatment plant in Olburgen where an entire value chain has been created.

Learning from others is another proven successful trait. Examples can be spread from places, countries and regions with an extensive and elaborate resource recovery agenda to places yet to develop a similar approach. The process of internal learning, reached through continuous monitoring and evaluation, should further not be ignored. In the case of GWPS for example, an expansion was thought of already in the original planning and design, and the development of the system was built upon results from the first applications. The case of Orange County in California also demonstrates the value of learning lessons from the past. Ideas similar to the District's had previously failed due to lack of public acceptance, a component which was highly integrated in the above example.

In order to be a successful pioneer in resource recovery, it is not only important to be willing to take risks, collaborate and learn from others, but also to keep updated with emerging themes within the field. It is therefore of value to explore future trends.

5. Conclusions, Future Trends and Role of the IWA Cluster

There are certain developments and themes that are recurring in emerging discussions on resource recovery. Below we summarise the compendium, explore some of the most prominent new trends and discuss the role of the IWA's Resource Recovery Cluster in future developments.

5.1 CONCLUSIONS

The usage of recovered resources can be a method in curbing current trends of exhausting the biosphere, a notion increasingly accepted and realized in multiple sectors. The pool of technologies recovering water, energy and different types of value-added components are continuously expanding. This movement is positive, as a gap between consumption and worldwide supply of certain resources is evident and is predicted to become even more severe.

Several opportunities and obstacles within the field of resource recovery have been touched upon in the report, mapping out ways in which different aspects can act as both promoter and barrier for sustained development of resource recovery. Regulations and policies and social acceptance are important factors that need to work in favour of continued innovation and adoption. It is important to continuously encourage resource recovery. This can be done through education and awareness-raising campaigns, increasing funding for research and implementing supportive regulations. Collaboration between multiple stakeholders is further a key component which can accelerate both innovation and adoption of technologies and practices.

The process of resource recovery from water requires certain inputs and results in certain outputs. Figure 5.1 provides a schematic view of what such a procedure could look like. Apart from having resources to recover, advantageous regulations and policies are needed, as well as a demand and acceptance of the recovered product and recovery techniques. The act of recovering a resource also requires resources, such as financial capital, workforce and knowledge. An appropriate technology is further necessary which is targeted to the local setting and context. Products, which could be potable and non-potable water, different types of energy and commodities, are examples of outputs. Environmental and social benefits are other outcomes, which entail, for example, a decrease in greenhouse gas emissions and an increase in job opportunities and food security. Another output of recovering resources could be that developments encourage further initiatives, and thus the innovation cycle can be started anew. The inputs and outputs can be categorized into a 'hard' and a 'soft' side whereby the former includes tangible resources and the latter consists of more abstract and conceptual indicators. Environmental and social benefits can incorporate both hard and soft outputs. Inspiring examples in the domain of resource recovery from water need to be highlighted in order to encourage others.

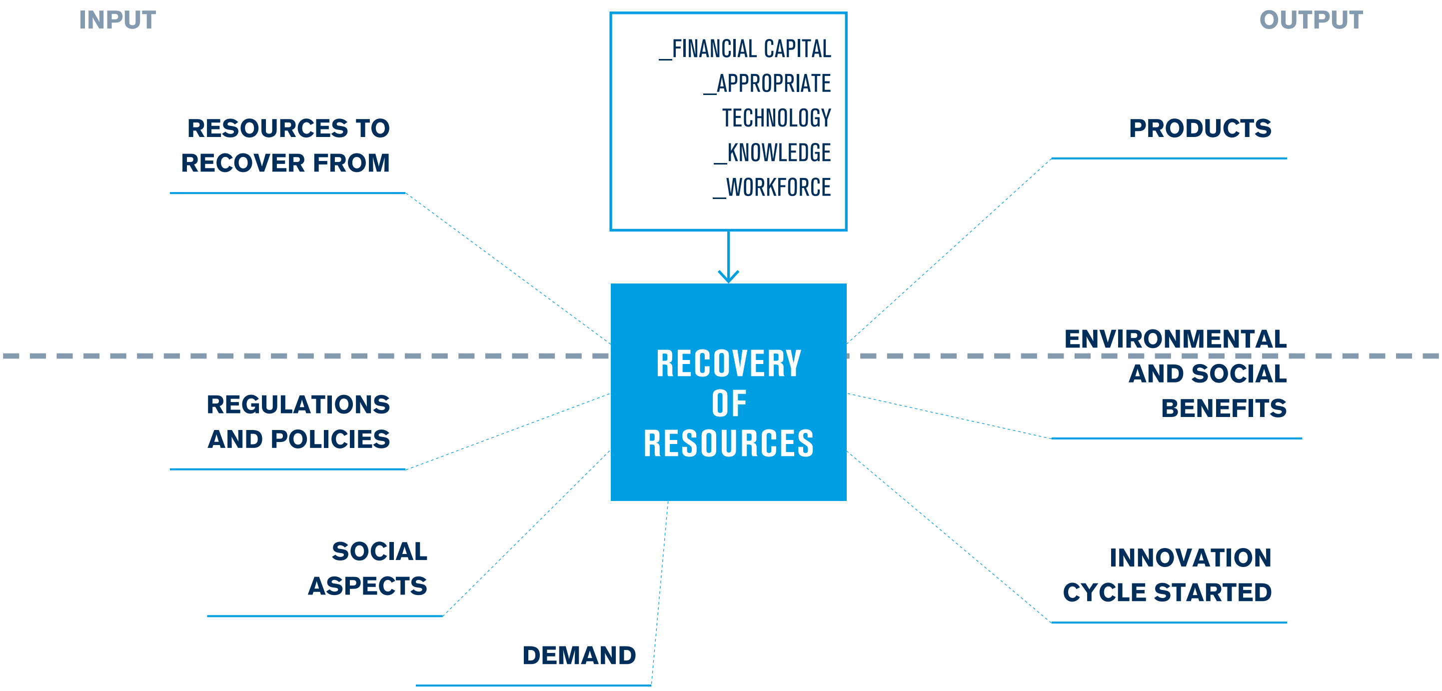

Figure 5.1 Schematic View of Resource Recovery

The figure can be modified according to the context, and certain aspects may be more important in some regions or industries. No matter what alterations are made, the graphic illustrates that resource recovery goes well beyond having a technology and needs to be viewed in a holistic manner. Such a framework can also be used to help determine what should be recovered, as opposed to just focusing on what can be recovered. The inputs can also be viewed as barriers which limit resource recovery. The outcomes must therefore be favourable in order to outweigh any potential restrictions.

5.2 FUTURE TRENDS

Apart from a continuous flow of technological advances, advancing resource recovery requires using an interdisciplinary and integrated approach and incorporating sustainability measures in treatment plants. These phenomena are becoming more common and are examples of future trends in the field of resource recovery.

5.2.1 INTEGRATED RESOURCE RECOVERY AT THE CENTRALIZED LEVEL

A phenomenon that has evolved in recent years and that is predicted to further develop is using a holistic approach when planning and implementing resource recovery technologies. Integrated resource recovery (IRR) requires features such as appropriate regulations, existing infrastructure, investment, social acceptance and a willingness to work together. The philosophy of IRR is expressed in a collection of methods and approaches compiled by the Government of British Columbia, Canada (Carter, 2009). Among other things, it is an effort to overcome the siloed and non-intersecting nature of sectors (Daigger, 2011). A holistic view is needed, not only in theory but also in education in order to ensure collective thinking in future practitioners, decision-makers and marketers. The water factory of the future will need to have dimensions of scale that allow to employ qualified people capable to deal with considerable capital expenditures and to generate top level products at moderate operational expenditure. Multiple stakeholders must be considered in a supply chain.

There are other benefits of IRR apart from increasing collaboration between disciplines and sectors. Costs can be offset, for example in infrastructure. If, for example, potable water demand can be reduced by using reclaimed water for non-potable purposes, a delay can be seen in the expansion of potable water supplies and distribution systems, which saves costs.

5.2.2 INTEGRATED RESOURCE RECOVERY AT THE DECENTRALIZED LEVEL

Decentralization of treatment plants has also become an observed trend. Instead of locating treatment plants far away from society, treatment facilities for municipal use are instead implemented in close proximity to, or even within, the centre of communities. New technologies in sewage treatment plants have enabled this process (Carter, 2009). Benefits of decentralized plants include localized energy production and reductions in transmission losses and costs. One example is the treatment plant Dockside Green development, located in the middle of the community of Victoria, British Columbia, which annually saves in municipal sewage management charges. Reclaimed water from the plant is used for residential non-potable purposes such as flushing toilets and irrigation as well as for the area's water features. Their sewage and water usage was one of the reasons why Dockside Green was awarded a Leadership in Energy and Environmental Design (LEED) Platinum certification for new construction, and has the aim of becoming the first LEED Platinum community in the world (FirstCarbon Solutions, 2013; Inhabitat, 2013).

5.2.3 INCORPORATION OF SUSTAINABILITY MEASURES

A further predicted tendency is that of the 'Sustainable Wastewater Treatment Plant' (WERF, 2013). Apart from adjusting their operations to local and regional contexts, these plants would also be self-sufficient for energy and cost effective while recovering new material and have water quality which meets or enhances set uses. The initiated effort would lead to minimizing the carbon footprint and greenhouse gases emissions. An idea is to further create a certification with a specific environmental management system for such facilities which can promote their sustainability and good stewardship. In order to create such an accreditation life cycle assessments (LCAs) will likely increase, a trend which is already seen in companies and projects.

5.2.4 IWA SURVEY REPLIES

In the IWA's survey, when asking respondents to identify future trends, multiple researchers chose to highlight specific technologies. Others touched upon broader topics such as energy and water efficiency, decreased costs and an increase in impact evaluations. Respondents in the utility sector mainly focused on legislative and financial incentives as means to increase resource recovery. A pressing call for greater collaboration between professional societies was noticed among both researchers and utility respondents.

5.3 ROLE OF IWA CLUSTER

The major tasks that the IWA, by means of its Cluster on Resource Recovery from Water, should address are as follows:

1. Provide a sound science and technology basis for Resource Recovery from Water: create awareness about the fact that a variety of options for recovery of resources from used water are possible, and deserve support for scientific exploration and technological development.
2. Demonstrate the potential interests and benefits from the pull side: interact with the markets dealing with primary produc tion, with manufacturing of commodities, with utilities rendering services to society, to learn about their technical needs, their dynamics of scale and the economical frameworks in which they operate.
3. Stimulate to establish clear-cut situations where the consumer profits from Resource Recovery from Water: interact with the general public and particularly learn from the consumer to what extent he/she is favourable/unfavourable to issues of beneficial re-use and to further understand aspects of non- acceptance of recycled commodities. Develop platforms of interaction and consultation so that cases can be highlighted and the overall acceptability of re-use can be raised in the mind of the public.
4. Join forces acting towards the goal of establishing a cyclic economy: establish a broad network with other fields serving the general public so that the water sector is in synergy with other societal movements and can contribute to the cyclic economy.
5. Encourage appropriate policies and legal frameworks empowering Resource Recovery from Water: inform various agencies and individual influencers to create the political and legal frameworks which facilitate the overall education, research and development, technological implication and effective application of re-use of resource from water.

Ultimately, the cluster aims to influence the way recovered resources are being viewed and recognized by the public, by researchers, by investors and by decision-makers. Promoting good practices and ways to approach and collaborate upon the topic are issues at which the cluster will take aim, along with encouraging appropriate concepts of resource recovery, whether social, economic, political or environmental.

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