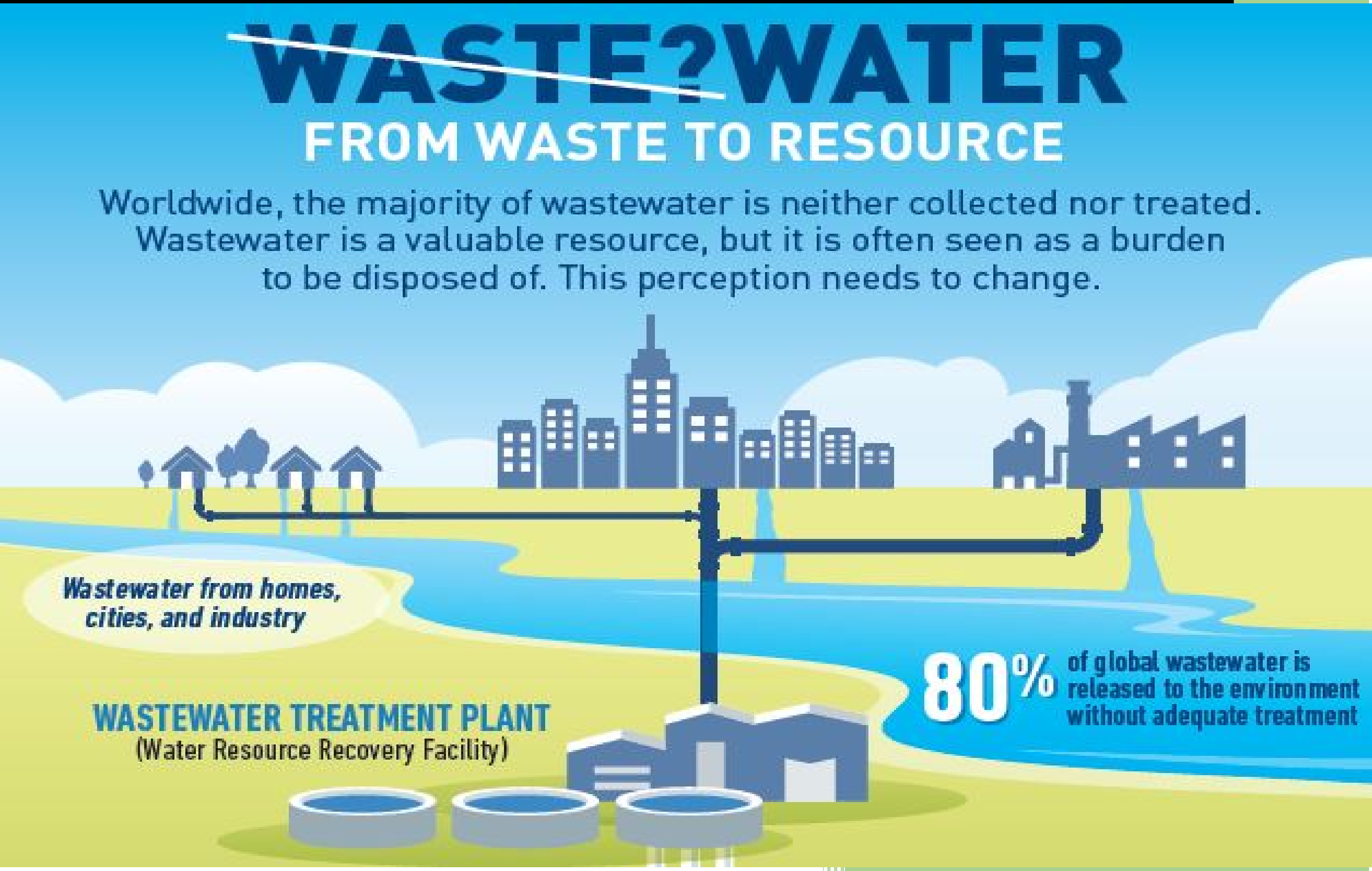
2018

RESOURCE RECOVERY FROM WASTE WATER



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<u>CERTIFICATE OF APPROVAL</u>

This is to certify that **PULKIT KUSHWAHA** with Roll No. (**001510401130**) has prepared the seminar paper entitled (**REOURCE RECOVERY FROM WASTE WATER**) under my supervision as a part of his pre-final curriculum of Department of Civil Engineering, Jadavpur University.

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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 valorization 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 practice, 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 odors, 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 crosscutting 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.

2. WASTE MANAGEMENT

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. 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. Increasing interest in using recovered water has further been noted for groundwater recharge and potable reuse

More than 99.5% by mass of used water consists of water, 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. 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. 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. Most commonly these include combinations of advanced oxidation processes, activated carbon and bio filtration or integrated membranes systems such as ultrafiltration followed by reverse osmosis. The first plant for indirect potable reuse was established in the Montebello Fore bay, California in 1962 while Windhoek, Namibia inaugurated the first direct pot able 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.

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. 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.

3. BASIC CONCEPT OF RESOURCE RECOVERY

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. 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.

Bio solids and Biogas

The chemical energy embedded in biosolids is theoretically enough to cover the energy necessary for treatment. 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 bio methane or 'green gas'. 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.

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. 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 3.1). The bacteria grow in the anode chamber while electrons react with the catholyte in the cathode chamber. 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.

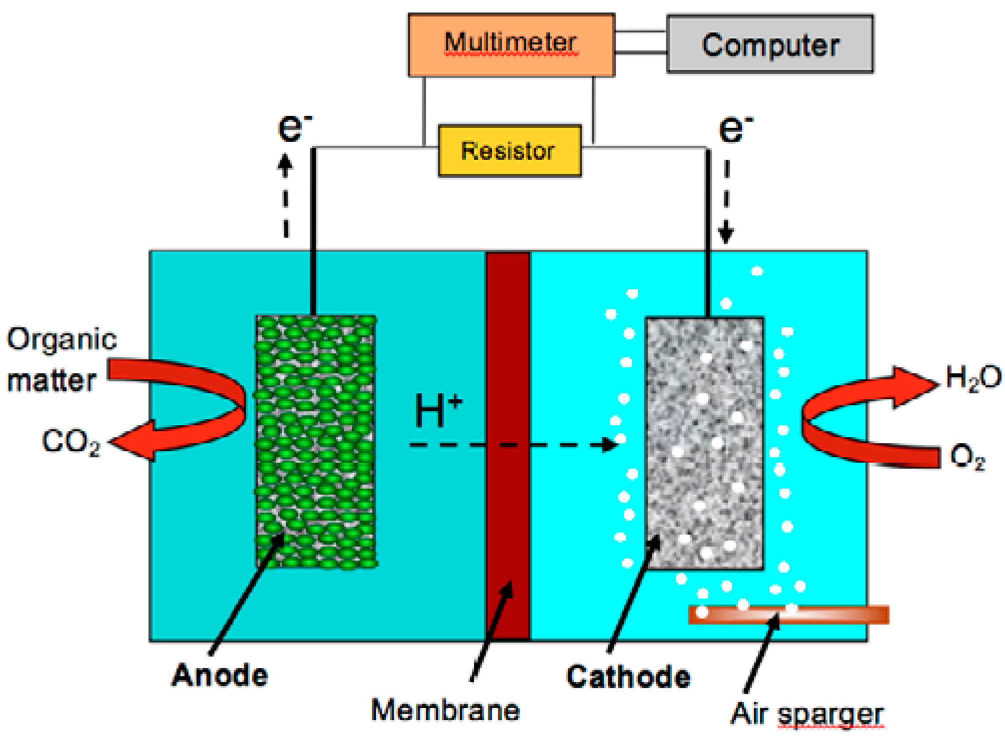

Figure 3.1 Microbial Fuel Cell

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. 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. 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. 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.

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.

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 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. The main focus on nutrient recovery has been on chemical phosphorus products.

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. 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.

The majority of the processes involved in recovering a phosphorus product need chemical consumption.

Crystallization has been proven to be the established technology with the highest percentage of recovered resource for phosphorus, with a recovery rate exceeding 90%.

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.

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. A technology of protein-based wood adhesives sourced from secondary sludge is further currently being investigated.

Fertilizer grade ammonium sulphate can be produced from the high ammonia-nitrogen concentration side streams 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. 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 electro dialysis (see Figure 3.2).The approach is to first concentrate nutrients into appropriate dialytic leaves in an overall electro dialysis cell and subsequently recover through a range of technologies, including precipitation, adsorption, desorption and air stripping. 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.

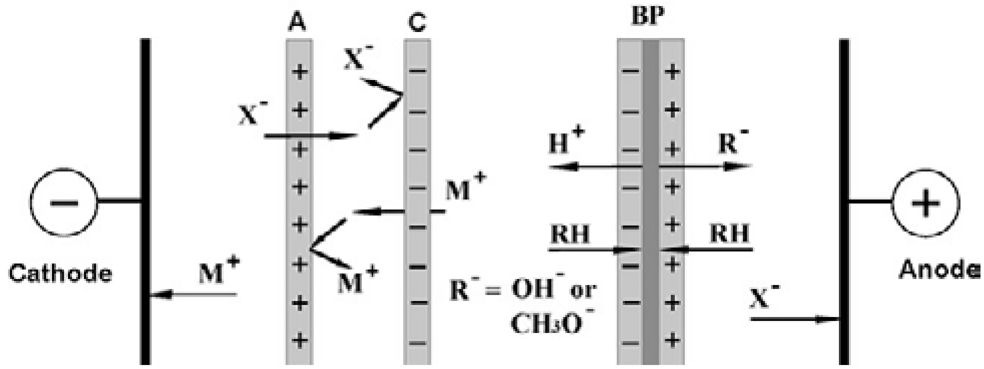

Figure 3.2 Electro dialysis
BP: bipolar membrane; A: anion-selective membrane, C: cation-selective membrane;
M+: cation; X-: anion; H+: hydrogen ion; OH-: hydroxide ion; CH3O-: methoxide ion.

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. 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. Chemical precipitation is most extensively used for metal removal from inorganic effluents. 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, Nano filtration and reverse osmosis, can be employed for metal recovery from used water. 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, 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.

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. 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.

Partition-release-recover concept

Verstraete proposed separation of streams into major and minor concentrated and dilute streams. The default sets of technologies identified were filtration based treatment (gravity-microfiltration-reverse osmosis), with treatment of solids and concentrate by anaerobic digestion, and recovery of the nutrients from digestate though (for example, electrodialytic nitrogen recovery, and phosphate precipitation). Verstraete also identified alternatives, including biological concentration through organisms that grow quickly such as heterotrophic activated sludge organisms.

This was further developed, as the "partition-release-recover" process, which uses biological agents to selectively remove nutrients and carbon from the liquid phase. This is a combined and scalable process, able to treat wastewater at essentially zero energy input, and recover nitrogen, phosphorous, and potentially, value-added organics or microbial products from the effluent. An overall scheme is shown in Figure 3.3.

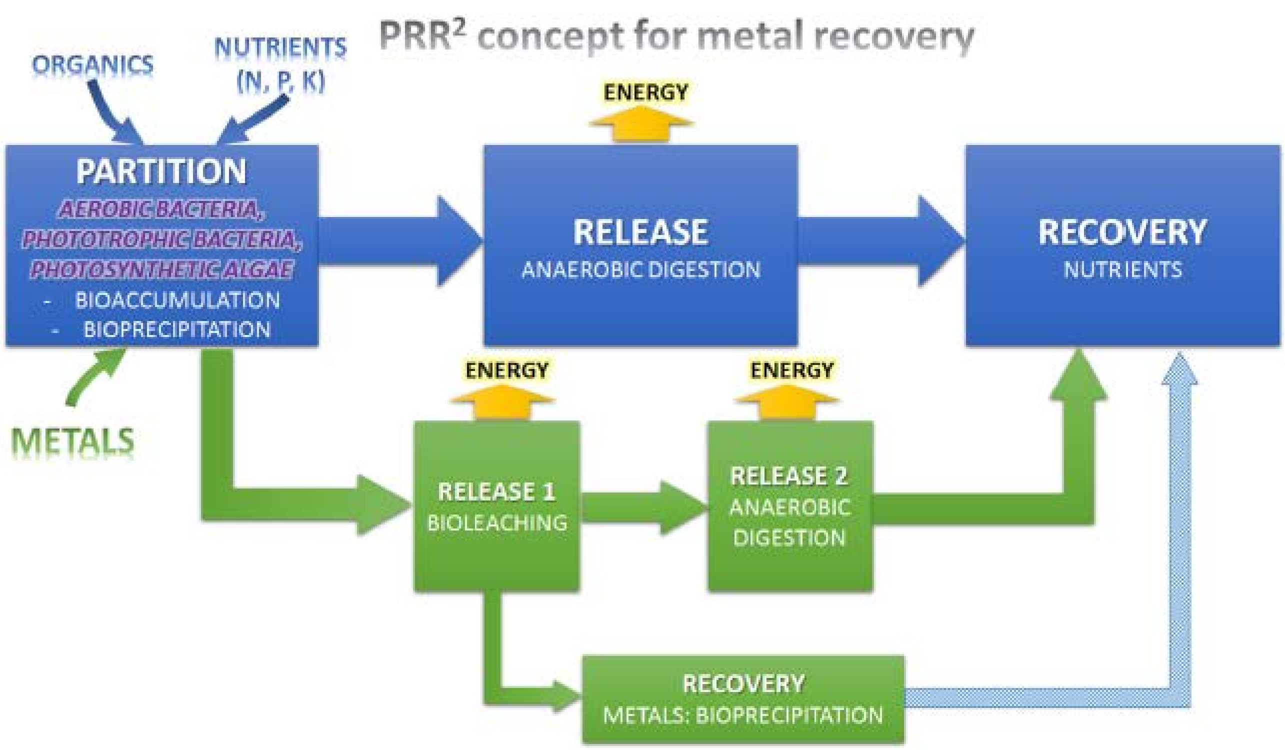

FIGURE 3.3 Enhancing the Partition-Release-Recovery concept for organic and metals recovery from wastewater (PRR2 concept).

This concept has been further developed by, and is summarized here. The overall process has a single entry point (wastewater), and four key discharges:

(i) Water, in which the main hydraulic load is dispersed through reusable water, with a defined discharge limit of nitrogen and phosphorous depending on reuse requirements, local regulations and technology options chosen. This is the main discharge from the “partition” stage. Partial nutrient removal with subsequent treatment may also be affected in the partition stage, with downstream treatment through low energy biological or chemical treatment.

(ii) Biogas, which is the main sink stream for excess chemical energy. This is the energy product from the “release” stage. This is a relatively low value energy stream and an ultimate better goal may be recovering organics as a higher value product

(iii) Biosolids, mainly composed by inert organics, non-recoverable nutrients and excess metals. This is the byproduct from the “release” stage. It seems to be critical to achieve almost complete anaerobic digestion, otherwise much of the benefits are lost in excess sludge production. However, biosolids can be also used as organic fertilizers if they are fulfill the requirements.

(iv)A fertilizer stream, which is the main sink for nitrogen, phosphorous, and possibly potassium. This is the valuable product from the “recover” stage.

Again, as commodity chemicals, these have relatively low 171 value, and a better ultimate goal may be generation of valuable products.

The key differentiating feature is the “partition stage”, with a number of different agents available for use. These include:

- Heterotrophic bacteria, where both energy and electron equivalents for growth are chemically sourced from the wastewater (with oxygen as catabolic electron acceptor). This is generally termed high-rate activated sludge, or A-stage treatment, and has been applied for 20 years.
- Phototrophic anaerobic bacteria (particularly purple phototrophic bacteria), where the energy for growth is sourced from light, but the electrons, carbon and nutrients from the wastewater. This has been demonstrated as a domestic treatment option in the laboratory. Technology Readiness Level (TRL) has to be upgraded before real application of the technology to achieve at least TRL .

- Algae and oxygenic photosynthetic bacteria, where the energy for growth and catabolism is sourced from light, electrons from molecular water, and nutrients and carbon (generally as carbon-dioxide). Particularly for heterotrophic treatment, this generally involves participation of aerobic bacteria, which nitrify and oxidize carbon to CO2. There are some examples of full-scale application of algae processes, though resource recovery is still not fully addressed (e.g. EU FP7 ALL-GAS project, nº ENER/FP7/268208).

Particularly phototrophic is embryonic in nature and algae is still under development, and with limited field application. All three have fundamental restrictions; in particular, energy input and carbon utilization efficiency for heterotrophic bacteria, the need for soluble carbon for phototrophic anaerobes, and light energy and footprint limitations for algae. However, all three enable the generation of value-added products in the form of biomass (and other byproducts) that represent enabling platforms for resource recovery.

Biodegradable Polymer

One non-traditional technology under development is the production of a biodegradable plastic. Poly hydroxyl alkanoates (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 3.4 illustrates a prototype used for manufacturing such biodegradable plastics using biosolids

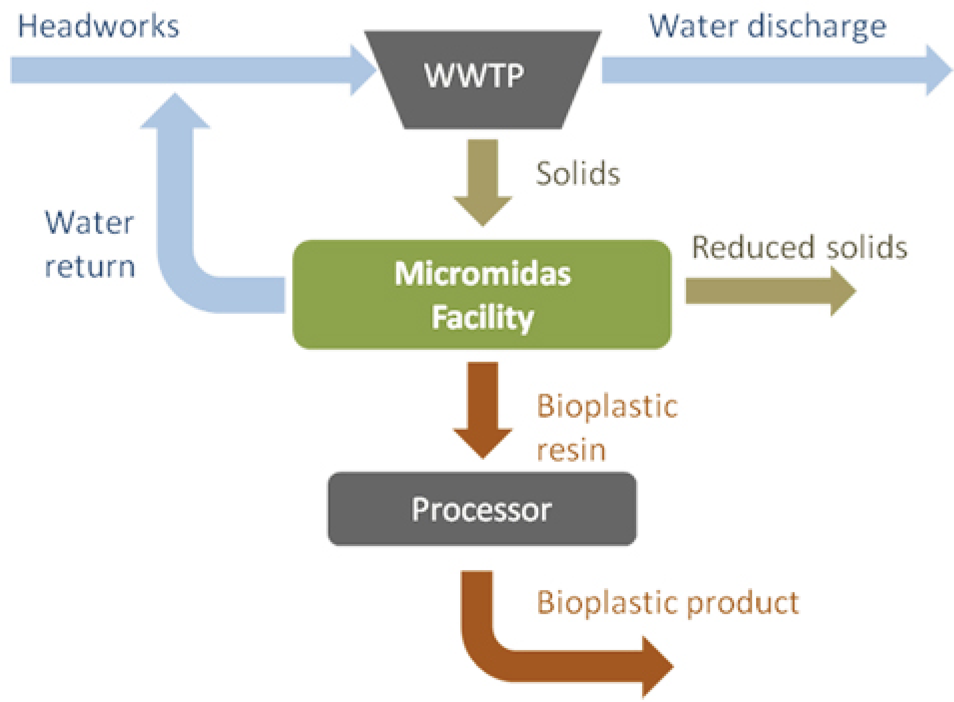

Figure 3.4 concept for manufacturing biodegradable plastics

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 channeled 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. As such, products typically requiring methane for its production can be produced even when methane is not accessible.

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.

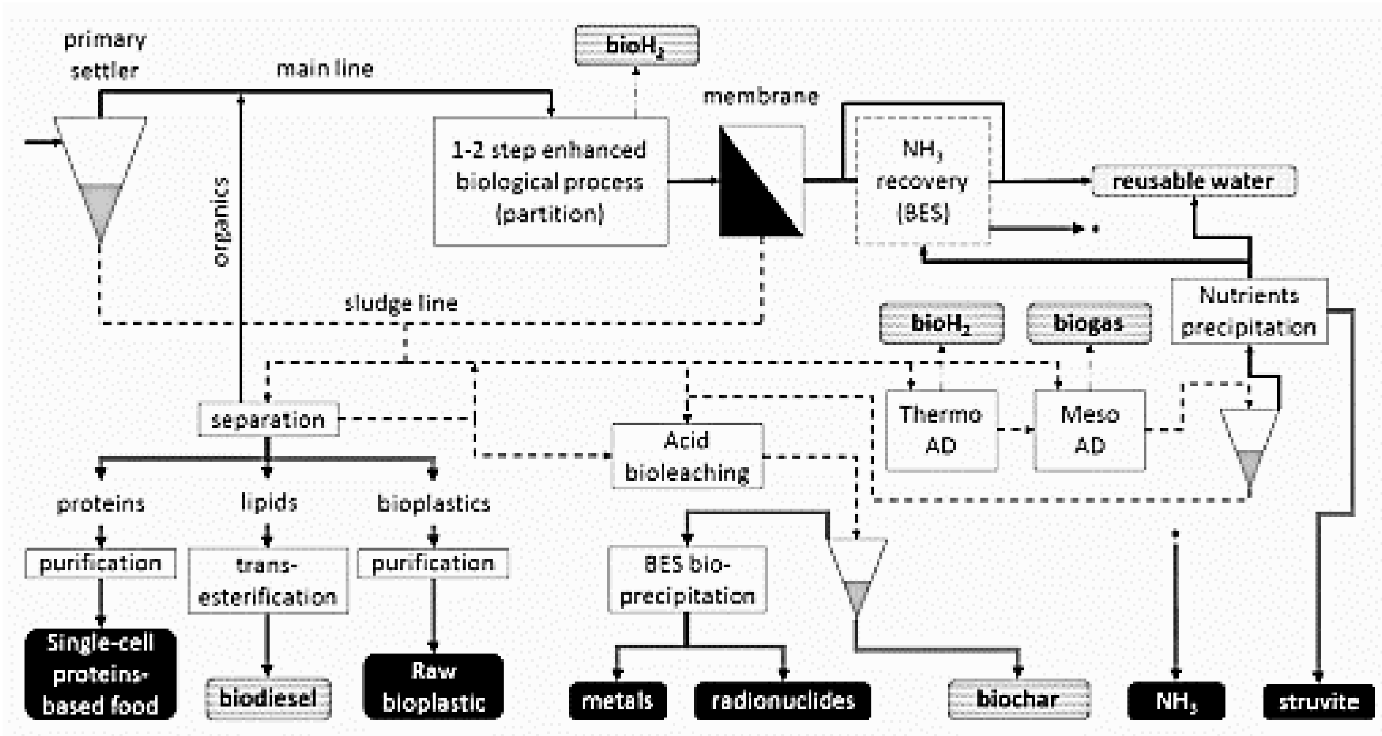

FIG 3.5 Conceptual overview of different biological technologies applied in wastewater treatment for energy and resource recovery.

4. APPLICATION OF RESOURCE RECOVERY IN MUNCIPAL SEWAGE

The two components in sewage sludge that are technically and economically feasible to recycle are nutrients (primarily nitrogen (N) and phosphorus (N)) and energy (carbon). As sewage sludge contains organic matter, energy can be recovered whilst treating it. There are a considerable amount of nutrients within sewage sludge, especially P and N. However, P is fast becoming the most significant nutrient due to depleting sources. Emerging technologies have been developed to extract this valuable resource including KREPO, Aqua Reci, Kemicond, Bio Con, SEPHOS and SUSAN, and are based on physical-chemical and thermal treatment to dissolve the P, with final recovery by precipitation. Other resources include the reuse of sludge for construction materials, heavy metals, poly hydroxyl alkanoates (PHA), proteins, enzymes and VFA. Table 4.1 gives an overview of resource recovery products from sewage sludge, their typical values and uses. Apart from the recovery products mentioned in Table 4.1, advances in technology have revealed innovative emerging products from treated sewage sludge and include VFA, polymers, and proteins in the form of worms, larvae and fungi. A short review regarding production, processes and further use is provided on each emerging product.

Nutrient recovery from sewage sludge

Treated sewage sludge may be used as an agricultural fertilizer, as they contain organic matter and inorganic elements. The recycling of treated sewage sludge to agriculture as a source of the fundamental nutrients and metals required for plant growth is going to be essential for future sustainable development, as it is estimated that there are only reserves of 50–100 years of P depending on future demand. When spread on arable or grassland, and provided that it is treated to the approved standards, treated sewage sludge may offer an excellent source of nutrients and metals required for plant and crop growth. Treated sewage sludge can also contribute to improving soil physical and chemical characteristics. It increases water absorbency and tilth, and may reduce the possibility of soil erosion.

Table 4.1 Resource recovery products from sewage sludge.

Products	Typical values and uses
Nitrogen	2.4–5% total solids
Phosphorus	0.5–0.7% total solids
Heavy metals	Typical recovery values: Ni 98.8%; Zn 100.2%; Cu 93.3%
Construction materials	Dried sludge or incinerator ash. Biosolid ash is used to make bricks
Bio-plastic	Microorganisms in activated sludge can accumulate PHAs ranging from 0.3 to 22.7 mg polymer/g sludge
Enzymes	Protease, dehydrogenese, catalase, peroxidase, α-amylase, α-glucosidase

Nutrient price equivalents of sewage sludge will depend on the nutrient availability and the FRV of the nutrients in the sludge. The FRV of nutrients in cattle slurry over time was calculated in Lalor *et al.* (2012) assuming a total N, P and K content in slurry of 3.6, 0.6 and 4.3 kg m^{-3}, respectively, and an assumption of respective FRV of 25%, 100% and 100% (Coulter, 2004). Of course in treated sewage sludge as in other nutrient streams, micronutrients used by the plant give added value to the product. In addition, factors such as transport and land application costs would also need to be considered in an overall assessment. It is therefore essential that such data are known for treated sewage sludge.

There is a good body of literature that has examined its fertilization potential. Siddique and Robinson (2004) mixed AD-treated sewage sludge, poultry litter, cattle slurry and an inorganic P fertilizer with five soil types at rates equivalent to 100 mg P kg^{-1} soil and, following incubation at 25oC for 100 d, found that AD-treated sewage sludge and poultry litter had a slower rate of P release compared with cattle slurry and inorganic P fertilizer. This may indicate that it may have good long-term fertilization potential.

One of the main concerns associated with the use of treated sewage sludge as an organic fertilizer on grassland are the loss of nutrients, metals and pathogens along a transfer continuum to a waterbody *via* direct discharges, surface and near surface pathways and/or groundwater discharge. More recently, so-called 'emerging contaminants', which may include antibiotics, pharmaceuticals and other xenobiotic, have been considered, as they have health risks associated with them. Therefore, nutrient recovery from treated sewage sludge must be considered against possible adverse impacts associated with its use.

Volatile fatty acids

Volatile fatty acids are short-chained fatty acids consisting of six or fewer carbon atoms which can be distilled at atmospheric pressure. Proteins and carbohydrates in sewage sludge can be converted into VFA to enhance methane, hydrogen and poly-hydro xyalkanoate production. The production of VFA from biosolids is an anaerobic process involving hydrolysis and acidogenesis (or dark fermentation). In hydrolysis, complex polymers in waste are broken down into similar organic monomers by the enzymes excreted from the hydrolytic microorganisms. Subsequently, acidogenesis ferment these monomers into mainly VFA such as acetic, propionic and butyric acids. Both processes involve a conglomerate of obligate and facultative anaerobes such as Bacteriocides, Clostridia, Bifido bacteria, Streptococci and Entero bacteriaceace

Polymers

Extracellular polymeric substances (EPS) are the major constituents of organic matter in sewage sludge floc, which comprises polysaccharides, proteins, nucleic acids, lipids and humic acids. They occur in the intercellular space of microbial aggregates, more specifically at or outside the cell surface, and can be extracted by physical (centrifugation, ultra-sonication and heating, for example) or chemical methods (using ethylene diamine tetra acetic acid, for example), although formaldehyde plus NaOH has proven to be effective in extracting EPA from most types of sludge. Extracellular polymeric substances perform an important role in defining the physical properties of microbial aggregates. There are many biotechnical uses of EPS, including the production of food, paints and oil drilling 'muds'; their hydrating properties are also used in cosmetics and pharmaceuticals. Furthermore, EPS may have potential uses as bio surfactants for example, in tertiary oil production, and as biological glue. Extracellular polymeric substances are an interesting component of all biofilm systems and still hold large biotechnological potential. A relatively new method for treatment of sewage sludge is aerobic granular sludge technology. A special characteristic of AGS is the high concentration of alginate-like exopolysaccharides (ALE) with different properties compared to converted activated sludge. Aerobic granular sludge technology produces a compound with similar characteristics as alginate, which is a polymer normally harvested from brown seaweed. Alginate-like exopolysaccharides can be harvested and used as a gelling agent in textile printing, food preparation and the paper industry. Lin *et al.* (2010) demonstrated that the potential yield of extractable alginate-like exopolysaccharides reached 160 ± 4 mg/g (VSS ratio). It was also found that they were one of the dominant exopolysaccharides in aerobic granular sludge.

Proteins

Vermicomposting (sludge reduction by earthworms) is a relatively common technology, especially in developing countries with small scale settings. The main product of this process is vermicompost, which consists of earthworm fasces that can be used as a fertilizer due to its high N content, high microbial activity and lower heavy metal content. Vermicomposting results in bioconversion of the waste streams into two useful products: the earthworm biomass and the vermicompost. In a study by Elissen *et al.* (2010), aquatic worms grown on treated municipal sewage sludge, produced high protein values with a range of amino acids. These proteins can be used as animal feed for non-food animals, such as aquarium fish or other ornamental aquatic fish. Other outlets for the protein could be technical applications such as coatings, glues and emulsifiers. The study also revealed that the dead worm biomass can be utilized as an energy source in anaerobic digestion. Experiments have shown that biogas production of worms is three times that of sewage sludge. Other applications include fats and fatty acid extraction. Treatment of sewage sludge using earthworms has been well documented; however, research studies on protein extraction of earthworms grown on sewage sludge are very limited.

Filamentous fungi are often cultivated in food industries as a source of valuable products such as protein and a variety of bio chemicals, using relatively expensive substrates such as starch or molasses. The biomass produced during fungal wastewater treatment has potentially a much higher value in the form of valuable fungal by-products such as amylase, chitin, chitosan, glucosamine, antimicrobials and lactic acids, than that from bacterial activated sludge process. The use of fungi for the production of value added products has been presented by several researchers.

5. APPLICATION OF RESOURCE RECOVERY IN INDUSTRIAL AND AGRICULTURE WASTEWATER

Increased demand for food and the need to sustain the ever increasing world population have led to massive increase in both agricultural and industrial activities. Agriculture is one of the most significant sectors of the Indian Economy. Agriculture is the only means of living for almost two thirds of the workers in India. The agriculture sector of India has occupied 43% of India's geographical area, and is contributing 16.1% of India's GDP. Agriculture still contributes significantly to India's GDP despite decline of its share in India's GDP. There are number of crops grown by farmers. These include different food crops, commercial crops, oil seeds etc., sugarcane is one of the important commercial crops grown in India. There are around 45 million of sugar cane growers in India and a larger portion of rural laborers in the country largely rely upon this industry. Sugar Industry is one of the agricultural based industries. Today, India is one of the first ten industrialized countries of the world. India, like any other developing countries, is faced with problems arising from the negative impact of economic development due to water or industrial pollution. Rapid progress made in industrialization without adequate environmental safety measures lead to pollution of water, which in turn, results in lack of good quality water both for irrigation and drinking purposes. Every human society, whether urban, industrial and most technologically advanced, disposes of certain kinds of by-products and waste products into the biosphere in large quantities, ultimately affecting the normal functioning of the ecosystem and have adverse effect on plants, animals and human. Awareness of environmental problems and the potential hazards caused by industrial wastewater has promoted many countries to limit the discharge of polluting effluents.

Treatment of Effluents from Sugar Cane Industry

Effective handling and disposal of the generated effluent is a major concern in all Indian distilleries since the units are required to meet the discharge standards laid down by CPCB. To comply with the disposal norms, it is recommended one or a combination of the following schemes to treat the generated wastewater.

The various methods of treatment are as follows

- **Anaerobic Process**

The high organic content of wastewater from sugar cane industry makes anaerobic treatment attractive in comparison to direct aerobic treatment. Therefore, bio methanation is the primary treatment step and is often followed by two-stage aerobic treatment before discharge into a water body or on land for irrigation. Aerobic treatment alone is not feasible due to the high energy consumption for aeration, cooling, etc. Anaerobic treatment converts over half of the effluent COD into biogas. Anaerobic treatment can be successfully operated at high organic loading rates; also, the biogas thus generated can be utilized for steam generation in the boilers thereby meeting the energy demands of the unit. Further, low nutrient requirements and stabilized sludge production are other associated benefits.

Anaerobic lagoons are the simplest option for the anaerobic treatment of distillery spent wash. It was reported that employing two anaerobic lagoons in series resulted in final BOD levels up to 600 mg/l. However, large area requirement, odor problem and chances of ground water pollution restrict its usage. These reactors offer the advantage of separating the hydraulic retention time (HRT) from solids retention time (SRT) so that slow growing anaerobic microorganisms can remain in the reactor independent of wastewater flow.

Aerobic treatment

The post-anaerobic treatment stage effluent still has high organic loading and is dark brown in color, hence it is generally followed by a secondary, aerobic treatment.

Solar drying of biomethanated spent wash is one option but the large land area requirement limits this practice. Further, in India, solar drying beds become non-functional during the rainy season. The other treatment options that have been demonstrated for biomethanated distillery effluent are Aquaculture, Constructed wetlands (CWs), Bio composting, Fungal Treatment, Bacterial treatment, and Algal treatment.

Physico-chemical treatment

Sugarcane molasses spentwash after biological treatment by both anaerobic and aerobic method can still have a BOD of 250–500 mg/l .Also, even though biological treatment results in significant COD removal, the effluent still retains the dark color .In this context, various physico-chemical treatment options have been explored.

Adsorption: Activated carbon is a widely used adsorbent for the removal of organic pollutants from wastewater but the relatively high cost restricts its usage. Decolorization of synthetic melanoidin using commercially available activated carbon as well as activated carbon produced from sugarcane bagasse was investigated.

Coagulation and flocculation: Coagulation studies on spentwash after anaerobic–aerobic treatment have also been conducted using bleaching powder followed by aluminum sulfate. The optimum dosage was 5 g/l bleaching powder followed by 3 g/l of aluminum sulfate that resulted in 96% removal in color, accompanied by up to 97% reduction in BOD and COD.

Oxidation process: Oxidation by ozone could achieve 80% decolorization for biologically treated spent wash with simultaneous 15–25% COD reduction. It also resulted in improved biodegradability of the effluent. However, ozone only transforms the chromophore groups but does not degrade the dark colored polymeric compounds in the effluent.

Membrane treatment: Pre-treatment of spentwash with ceramic membranes prior to anaerobic digestion is reported to halve the COD from 36,000 to 18,000 mg/l . The total membrane area was 0.2m2 and the system was operated at a fluid velocity of 6.08 m/s and 0.5 bar transmembrane pressure. In addition to COD reduction, the pre-treatment also improved the efficiency of the anaerobic process possibly due to the removal of inhibiting substances. In addition, reverse osmosis (RO) has also been employed for distillery wastewater treatment.

Electrodialysis: Electrodialysis has been explored for desalting spentwash using cation and anion exchange membranes resulting in 50–60% reduction in potassium content. In another study, Vlyssides et al. (1997) reported the treatment of vinasse from beet molasses by electrodialysis using a stainless steel cathode, titanium alloy anode and 4% w/v NaCl as electrolytic agent. Up to 88% COD reduction at pH 9.5 was obtained; however, the COD removal percentage decreased at higher wastewater feeding rates.

Evaporation/combustion: Molasses spentwash containing 4% solids can be concentrated to a maximum of 40% solids in a quintuple- effect evaporation system with thermal vapor recompression. The condensate with a COD of 280 mg/l can be used in fermenters. Combustion is also an effective method of on-site vinasse disposal as it is accompanied byproduction of potassium-rich ash that can be used for land application.

6. FURUTE PROPECT OF RESOURCE RECOVERY

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.

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. Among other things, it is an effort to overcome the siloed and non-intersecting nature of sectors. 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.

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.

7. COST EFFICTIVNESS OF RESOURCE RECOVERY

This review has focused on technologies which enable resource recovery. The drivers are clear, and are to translate technologies which would normally remove contaminants into a liquid or waste concentrate stream (or reactively dissipate them) into products that feed into the circular economy. This is not a massive shift from current practices, but instead of focusing the process on removal, it focuses on recovery. That is, multiple candidate technologies that would otherwise remove a contaminant are instead screened to those that allow the byproducts to be reused. As stated in section 2, this can be through a complete reimaging of the treatment process, or slight modifications (for example using activated sludge in its granular form).

The three classes of product are carbon/energy, bulk nutrients (NPK), and metals and trace compounds. Recalcitrant high-value organics such as pharmaceuticals, pesticides etc are not considered here. The main use for nutrients and metals is either as elemental inputs to the circular economy (not currently economic, but ultimately inevitable), and for use in carbon/energy products (generally economic if the carbon product is feasible).

A detailed economic analysis was done comparing conventional activated sludge with emerging technologies, including high-rate activated sludge, photo-membrane bioreactors, and mainline anaerobic treatment (Burgess et al., 2015). This used commodity products (e.g., electricity, nitrogen, phosphorous). This showed that next generation technologies (assessed as a complete wastewater treatment platform) are generally capital cost neutral vs existing technologies, and likely competitive particularly at larger scale. However, given the product value is relatively low (mainly electricity, bulk nutrients), there is not a strongly compelling economic driver to use next generation processes, given its higher risk. However, another consideration in the future is the value of carbon separate from the energy value in the wastewater. Until now, the focus has been on production of biofuels, particularly bio methane. This leaves bulk nutrients to be recovered (or more often, dissipated), and metals to be concentrated in sludge, mainly as metals sulfide. While this has resulted in resource utilization, ultimately, it dissipates the concentrated carbon to CO2 (albeit short-cycle CO2). We are now seeing a shift which recognizes the up valued nature of carbon in wastewater, with its use in generating byproducts such as biopolymers, liquid biofuels, commodity chemicals, and possibly even animal feeds as single cell protein. The latter even offers a vector to transfer macro and micronutrients back into the manufacturing and agricultural product chain. However, it is still soon to predict the real impact of recycling these bio products into a global circular bio economy. In most of the cases, the technology readiness level (TRL) of the enabling technologies is still low (below TRL5), needing dedicated economic analyses like Life Cycle Assessment once pilot or demonstration plants are implemented.

8. CONCLUSION

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.

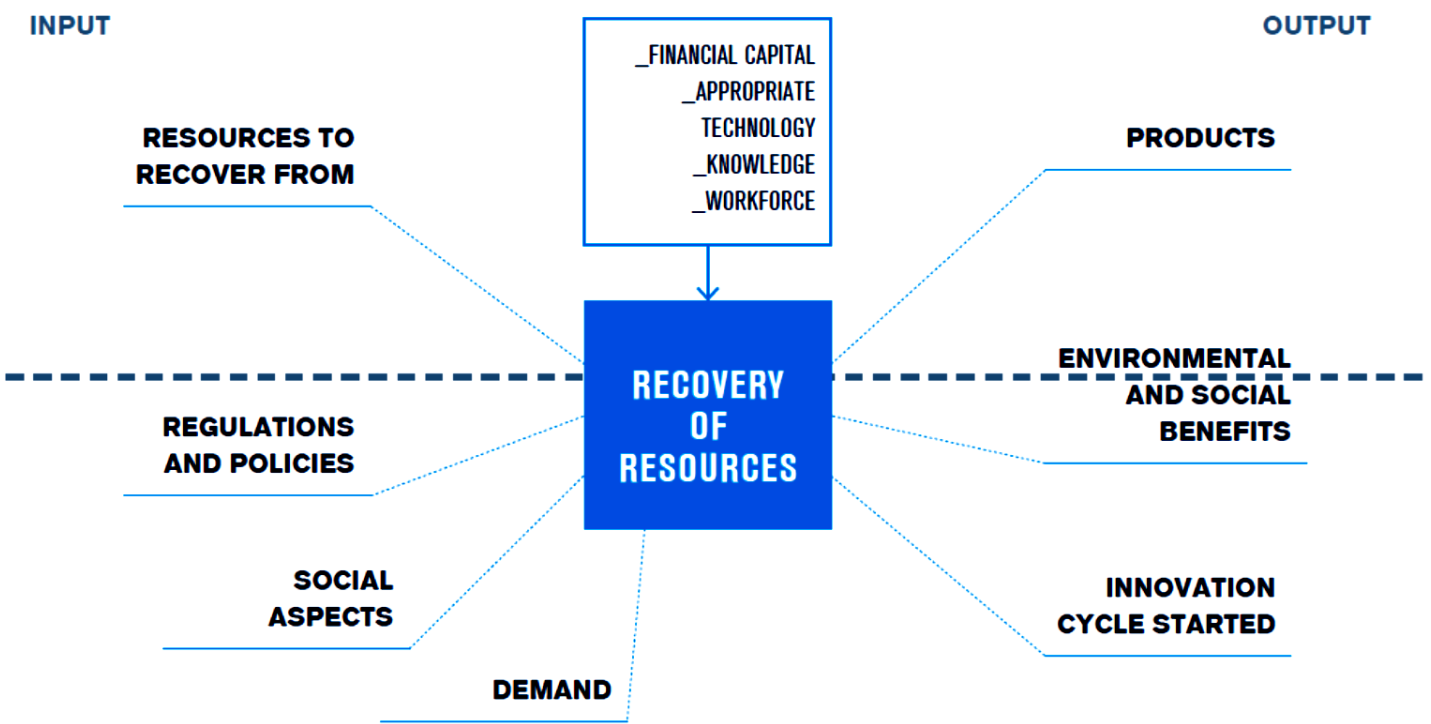

Figure 8.1 Schematic View of Resource Recovery

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 favorable in order to outweigh any potential restrictions.

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