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ANNEX

SURVEY OF WASTE AND RESOURCE RECOVERY RELATED APPROPRIATE AND INNOVATIVE TECHNOLOGIES

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Disclaimer

The report was prepared as a background document for the forthcoming “Regional workshop: Innovative technologies for waste management in the Arab Region – paving the way for the transition to a green economy”. The opinions expressed are those of the authors and do not necessarily reflect the views of ESCWA. The document has been reproduced without formal editing.

Acronyms :

C&D :	Construction and demolition
C&I :	Commercial and industrial
CDM:	Cleaner development mechanism
Co-EAT:	Co-Digestion Economic Analysis Tool
CNEDS:	Centre national d'élimination des déchets spéciaux
EPR:	Extended Producer Responsibility
FEC:	Fond de développment communal
FODEP :	Fond de dépollution industrielle
GEPreC :	Outil de gestion efficace et profitable des ressources et de leurs coûts
GIZ :	Coopération Internationale allemande
HTO :	Hydothermal oxidation
IAA	Industrie agro-alimentaire
LAS:	League of Arab States
MBT :	Mechanical biological treatment
MDE :	Ministère Délégué chargé de l'Environnement
MRF :	Material recovery facility
MSW:	Municipal solid waste
NPO:	Non product output
PGPE :	Programme de Gestion et de Protection de l'Environnement
PROGRESS :	Programme allemand en faveur d'une utilisation efficace des ressources
RDF :	Refuse derived fuels
SCWO:	Supercritical waste oxidation
SIE	Société d'investissement énergétique
SNDD :	Stratégie Nationale de l'Environnement et du Développement Durable
WtE:	Waste to Energy
WWTP :	Wastewater treatment plant

1 MIXED WASTE TECHNOLOGIES

Broadly, technologies for processing mixed waste generally concentrate on separating and treating the organic fraction (often the food). If recyclables and green waste are removed from the domestic waste stream, the largest remaining proportion is food waste.

These technologies are generally large scale and mostly designed to process municipal solid waste using a variety of techniques. They ultimately produce a compost type material and some have the capacity to extract recyclable materials left in the residual waste stream. Food, and sometimes other organic waste, is processed either aerobically (with oxygen and therefore avoiding the generation of methane – a greenhouse gas) or anaerobically (without oxygen and with methane gas capture and electricity generation).

1.1 Digestion

Digestion is the reduction of solid organic materials through decomposition by microbes, which results in the production of liquids and gases. The digestion process may be aerobic or anaerobic – depending on whether air (containing oxygen) is present in the process.

Anaerobic digestion is the decomposition of organic matter by microbes in the absence of oxygen. Anaerobic digestion is commonly a component of mechanical biological treatment (MBT) technologies. These technologies generally incorporate a mechanical sorting process and a biological digestion process. The process produces 'biogas' and a liquid fertilizer (digestate). The biogas produced in the anaerobic digestion process comprises mostly methane and carbon dioxide, and can be burned in an internal combustion engine to generate electricity.

During aerobic digestion of municipal and commercial waste, the organic fraction is metabolized by microbes in the presence of oxygen. During aerobic digestion, temperature and pH increase and carbon dioxide and water are liberated and pathogens are destroyed. Anaerobic processes operate at much higher rates than aerobic processes, but generally do not produce useful fuel gases.

1.1.1 Two-stage digestion

The two-stage digestion system has the advantage of adjusting the environmental settings to the optimum requirements of the microorganisms. First of all, the pH value and loading rate can be adjusted individually. The spatial separation allows a directed acidification of the input substrate in a first vessel. The following Figure 2 illustrates a schematic layout of a two-stage biogas plant.[1]

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[1] Voelklein, M. (2015), Introduction to innovative technology of biogas production, http://blogs.qub.ac.uk/atbest/2015/03/23/introduction-to-innovative-technology-of-biogas-production/

The most fundamental difference and substantial advantage compared to the one-stage system is represented by the separate gas collection of each vessel. This allows an active influence on the concentration of individual gas compounds or even a separated utilization of the produced biogas. Figure 3 shows a comparison of a one and two-stage biogas plant system.[2]

The gas compounds of an acidification reactor consists mainly of carbon dioxide, hydrogen sulphate and hydrogen. The composition can be influenced by parameters like retention time, loading rate, pH value and temperature in order to gain high carbon dioxide stripping. Due to this removal during acidification, a biogas with enhanced methane content is received in the methane reactor. For substrates like food waste or renewable raw materials a methane content of 60 to 70 % can be achieved. Therefore, the previous carbon dioxide stripping in a two-stage digestion system, enhances the efficiency and reduces the costs of a following biogas purification facility.[3]

The investment costs for the two-stage fermentation are higher than for a one-stage fermentation. The exceeding costs have to be refunded by advantages regarding the process stability and higher rate of substrate degradation, leading to higher biogas yields from the same amount of substrate.

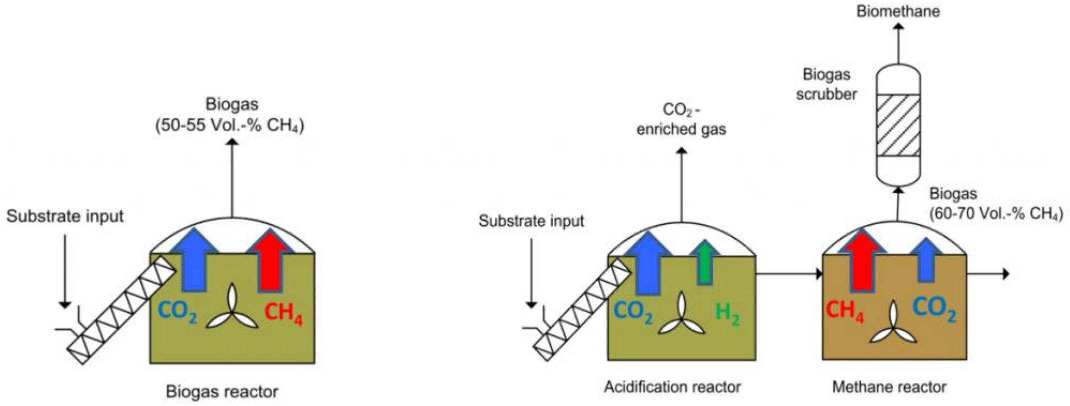

Figure 2 : Two-stage digestion

1.1.2 Co-digestion

Co-digestion[4] is the simultaneous digestion of two or more organic waste feedstock. The anaerobic co-digestion process can be defined as the simultaneous treatment of two – or more – organic biodegradable waste streams by anaerobic digestion offers great potential for the proper disposal of the organic fraction of solid waste coming from source or separate collection systems.[5] This type of treatment offers the

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[2] Voelklein, M. (2015), Introduction to innovative technology of biogas production, http://blogs.qub.ac.uk/atbest/2015/03/23/introduction-to-innovative-technology-of-biogas-production/

[3] Voelklein, M. (2015), Introduction to innovative technology of biogas production, http://blogs.qub.ac.uk/atbest/2015/03/23/introduction-to-innovative-technology-of-biogas-production/

[4] EPA (2015) Organics:Anaerobic Digestion Resources, http://www.epa.gov/region9/organics/ad/resources.html

[5] Thanikal, J.V. et al. (2015), Anaerobic Co-Digestion of Vegetable Waste and Cooked Oil in Anaerobic Sequencing Batch Reactor (ASBR) , Int'l Journal of Advances in Agricultural & Environmental Engg. (IJAAEE) Vol. 2, Issue 1 (2015) ISSN 2349-1523 EISSN 2349-1531 http://iicbe.org/siteadmin/upload/9428C0315120.pdf

possibility of using existing anaerobic reactors in wastewater treatment plants, with minor modifications and some additional requirements. By bringing together the treatments of two problematic wastes i.e. organic part of municipal solid waste and paper pulp sludge higher yield in the production of biogas can be achieved. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates.[6]

1.1.3 Co-Digestion Economic Analysis Tool (CoEAT)

The Co-Digestion Economic Analysis Tool (CoEAT) assesses the initial economic feasibility of food waste co-digestion at wastewater treatment plants for the purpose of biogas production. Co-digestion is when energy-rich organic waste materials (e.g. food waste and/or FOG) are added to an anaerobic digester currently processing less energy-rich organic waste (e.g. sewage or manure). Co-digestion allows facilities with excess digester capacity to save and make money while reducing greenhouse gas emissions, providing a renewable energy source, and diverting valuable resources from landfills and/or sewer pipes.[7]

CoEAT is designed for decision-makers with significant technical experience, including municipal managers, engineers, and wastewater treatment plant managers. CoEAT is available as a Microsoft Excel Spreadsheet. For instructions on how to use to tool, see the CoEAT User's Guide.

CoEAT does not require pre-existing WWTP digesters, and will calculate results with no pre-existing digester in place, however the model was intended to help WWTP operators assess the viability of implementing food waste co-digestion with existing anaerobic digesters.[8]

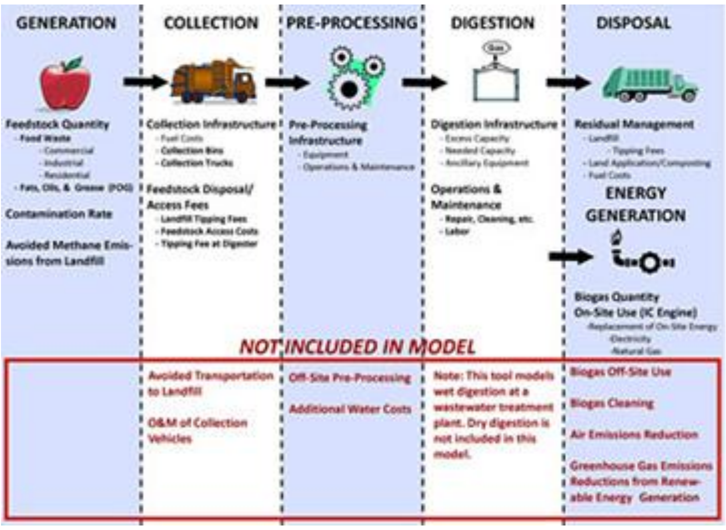

Figure 3 : Co-Digestion Economic Analysis Tool (CoEAT)

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[6] Wei Wu (2008) Anaerobic Co-digestion of Biomass for Methane Production: Recent Research Achievements, http://home.eng.iastate.edu/~tge/ce421-521/wei.pdf

[7] EPA (2010) Co-Digestion Economic Analysis Tool (CoEAT), http://www.epa.gov/region9/organics/coeat/

[8] EPA (2010) Co-Digestion Economic Analysis Tool (CoEAT), http://www.epa.gov/region9/organics/coeat/

1.2 Hydrolysis

Hydrolysis is very important for the anaerobic digestion process since polymers cannot be directly utilized by the fermentative microorganisms. Hydrolysis is a chemical reaction whereby water reacts with another substance to form two or more new substances. It involves the biological or chemical partial breakdown of the complex molecules within the waste. Hydrolysis technologies for the treatment of municipal and commercial waste incorporate acid-catalysed reaction of the cellulose fraction of the waste (e.g. paper, food waste and garden organics) with water to produce sugars which are fermented to methanol. This technology is normally only used in conjunction with other methods. Interest is growing however, in the potential of this technology to produce alternative fuels such as bio-oil, bio-diesel and ethanol from wastes.[9]

1.2.1 Sonication of biomass

The use of ultrasound for pretreating lignocellulosic biomass is already used to improve producing ethanol from lignocellulosic materials. Ultrasonication is a potential alternative to conventional pretreatments of lignocellulosic biomass. Sonication has also been shown to facilitate hydrolysis of cellulose and hemicellulose to fermentable sugars; and the fermentation of sugars to bioethanol.[10]

1.3 Autoclaving

The auto-claving process involves waste being sealed and treated with steam at 140-160C in an autoclave. After the steam has been injected the pressure is maintained for 30-40 minutes. This sterilizes the waste. When the treatment is complete the residue is discharged and subject to screening. This separates out the fine material about 65 per cent from the larger fraction - the metals and plastics. The fine fraction is then separated out into a lighter material (organic fibre) from heavier material (glass and grit). The metals and plastics can be sent for recycling, some waste can be recovered for aggregate material, some will be sent to landfill, while the organic waste can either be made into a fibre material to be used in the construction trade or into fuel. Municipal Solid Waste Autoclaving is one of the waste treatment process that is being used to pre-treat waste, and it is often applied to the residual waste after all recycling has been done. However, it can also be used before recycling, which helps by reducing volumes, shrinking all plastic film, and making the waste easier to separate in a recycling facility. Autoclaving uses a combination of heat, steam and pressure, for general residual waste it is used along with the mechanical action of rotation. Ultimately, the aim of waste autoclave process is to reduce the impacts residual waste has on the environment when sent to landfill.

In addition to these recent uses, autoclaving has long been used on a variety of smaller scales for all sorts of sterilization duties. Medical waste is one such type of

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[9] Australian Ministry for the Environment, Heritage and the Arts (2009) Waste Technology and Innovation Study, Final Report, http://bit.ly/1irSj2P

[10] Muhammad Saif Ur Rehman1 , Ilgook Kim1 , Yusuf Chisti2 , Jong-In Han1, (2012) Use of ultrasound in the production of bioethanol from lignocellulosic biomass, http://www.silascience.com/articles/29112012044258.pdf

waste. This waste must be treated and managed quickly in order to ensure public safety and to remain in compliance with applicable regulations and laws. As a result every day untreated medical waste leaves a facility there is a significant liability risk to the generator.

1.4 Bioreactor landfills

Bioreactor technology accelerates the biological decomposition of food, green waste, paper and other organic wastes in a landfill by promoting conditions necessary for the microorganisms that degrade the waste. The most important factor in promoting waste decomposition is the moisture content of the waste. Liquids must be added to the waste mass to obtain optimal moisture content, which ranges from 35 to 45 percent water by weight. Liquids that are added include: landfill leachate, gas condensate, water, storm water runoff, and wastewater treatment sludges.[11]

2 WASTE TO ENERGY

Because of a relative scarcity of landfill airspace and a greater political emphasis on environmental sustainability, several countries in Europe have deployed thermal treatment of municipal and solid wastes as a means of volume reduction as well as for the generation of electrical power or combined heat and power. Denmark, Germany, and other European countries have developed policies that encourage the recovery of energy from municipal solid waste, certain industrial solid waste streams, and agricultural biomass. Denmark is an outstanding example of what can be done in terms of reducing the amount of solid waste going to landfill, with approximately one fourth of the waste produced in 2005 being incinerated for heat and power production, approximately two thirds being recycled, and only 8 percent going to landfill.

Conversion technologies described herein were evaluated according to the overall objective of diverting MSW that is not currently recycled from landfill disposal by converting the non-recycled material into energy or other beneficial products. Waste to energy projects should be implemented as a supplement to, not a replacement for, recycling efforts.

2.1 Incineration

Incineration is a thermal process wherein the combustible components of a solid waste stream are thermally oxidized to produce heat energy that can be used to create steam for generating electrical power, for industrial process, or for district heating. The incineration process also produces bottom ash, fly ash, and flue gas, which may contain a number of regulated pollutants.[12] Incineration is not a highly efficient way to generate power, as most of the energy is lost as heat and in flue gas.

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[11] Waste Management (2004) Bioreactor Program, The Bioreactor landfill – next generation landfill technology, http://www.wm.com/thinkgreen/pdfs/bioreactorbrochure.pdf

[12] Waste Incineration and Public Health; Commission on Life Sciences, National Academies Press (2000) http://www.nap.edu/openbook.php?record_id=5803&page=20

There is also significant potential for air pollution with flue gases containing particulates, dust, NOx, acid gases, dioxins, furans, polyaromatic hydrocarbons and heavy metals. Reducing the emission of these materials into the atmosphere adds significantly to the cost of this technology.

Additionally, incineration has been criticized for discouraging recycling due to it being more economically viable to simply combust all the waste than spend effort and resources in sorting and reprocessing recyclable materials. These factors and the risk of pollution have led to decreased social acceptance of this form of waste disposal.

Refuse-derived fuel (RDF) burn incineration, as the name implies, refers to the practice of sorting the incoming waste stream by removal of recyclables and hazardous materials and non-combustibles such as metals, glass, rock, concrete, and sheet rock. In RDF facilities, wet and low British thermal unit (BTU) materials such as green waste are processed separately. With this minimal sorting, the average calorific values of the RDF is higher and the ash production lower than in mass burn mode, all other factors being equal. For example, the average calorific value of the RDF is 6,500 BTU per pound with some seasonal variation in moisture content.[13]

2.2 Pyrolysis and Gasification

Pyrolysis and gasification, like incineration (combustion), are forms of thermal treatment that convert waste into energy-rich fuels by heating waste under controlled conditions in contrast to incineration where waste is fully converted into energy and ash. The processes deliberately limit the conversion to energy and ash so that combustion does not take place directly. Rather, waste is converted into valuable intermediates that can be further processed for materials recycling or energy recovery. These technologies promise to extract more energy from waste than is possible with traditional incineration, and to do it more cleanly.[14]

Pyrolysis and gasification plants can deliver about 1MW/hr of electricity for every tonne of waste and can be twice as efficient as incineration, depending on the waste used. The basic technology is not new and generally, specific processes have been developed and optimized for feedstock of varying properties and quantities such as for waste tires, sewage sludge or mixed municipal waste.

2.2.1 Pyrolysis

Pyrolysis is thermal decomposition occurring in the absence of oxygen. It is also the first step in combustion and gasification processes where it is followed by total or partial oxidation of the heated material.[15] In pyrolysis, lower process temperatures

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[13] Enviropower Renewable, Inc. (2014) Comparative Assessment of Gasification and Incineration for Integrated Waste Management Systems, http://www.eprenewable.com/uploads/files/63_5__Gasification_White_Paper_10-08-2014.pdf

[14] Juniper, Pyrolysis and Gasification, http://www.biomassinnovation.ca/pdf/factsheet_Juniper_Pyrolysis&Gasification.pdf

[15] Bridgewater, Anthony (2004): Biomass Fast Pyrolysis UDC:662.73/.75 http://www.doiserbia.nb.rs/img/doi/0354-9836/2004/0354-98360402021B.pdf

and longer vapor residence times favor the production of charcoal. High temperature and longer residence time increase the biomass conversion to gas and moderate temperature and short vapor residence time are optimum for producing liquids.

2.2.2 Gasification

Gasification is a process wherein organic carbonaceous materials are dissociated at high temperatures in an oxygen-starved thermal reactor to form a gas known as synthesis gas (also designated as syngas, or producer gas). The syngas is composed of mainly carbon dioxide, carbon monoxide, hydrogen, methane, and water vapor. If the thermal reactor is air fed (as opposed to oxygen fed only), the syngas stream also contains nitrogen gas. Gasification technology appears to be subject to significant research and commercial effort and investment, perhaps due to the possible synergies with sequestration of clean char in soil.[16]

2.3 Plasma Arc

Plasma arc gasification is a waste treatment technology that uses an electric arc to produce high temperatures within the reactor to convert organic fuel material to synthesis gas and melt the residual inorganic materials, which form a vitreous solid upon cooling.[17] The electric arc is maintained between electrodes in a firing device designated as a torch, or in some cases, between the torch electrodes and the walls of the reactor (transfer arc mode).

Plasma gasification is a multi-stage process which starts with feed inputs – ranging from waste to coal to plant matter, and can include hazardous wastes. The first step is to process the feed stock to make it uniform and dry, and have the valuable recyclables sorted out. The second step is gasification, where extreme heat from the plasma torches is applied inside a sealed, air-controlled reactor. During gasification, carbon-based materials break down into gases and the inorganic materials melt into liquid slag which is poured off and cooled. The heat causes hazards and poisons to be completely destroyed. The third stage is gas clean-up and heat recovery, where the gases are scrubbed of impurities to form clean fuel, and heat exchangers recycle the heat back into the system as steam. The final stage is fuel production – the output can range from electricity to a variety of fuels as well as chemicals, hydrogen and polymers.

Plasma recycling is still a new technology and it's too early to say whether its benefits (the potential to supply energy, reduce fossil fuel consumption, and reduce or restore landfills) will outweigh its drawbacks (any toxic gases or solids that remain after treatment, the high cost of investment in a relatively untried technology, and any potential impacts on local communities). But with ever-increasing consumption, growing pressure on the environment, and the local unpopularity of incineration,

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[16] Enviropower Renewable, Inc. (2014) Comparative Assessment of Gasification and Incineration for Integrated Waste Management Systems, http://www.eprenewable.com/uploads/files/63_5__Gasification_White_Paper_10-08-2014.pdf

[17] Plasma Gasification. National Energy Technology Center http://www.netl.doe.gov/technologies/coalpower/gasification/gasifipedia/4-gasifiers/4-1-4-1a_westinghouse.html

landfill, and digestion, governments are bound to see plasma recycling as a relatively clean solution to a polluting problem.

Plasma gasification of MSW is a fairly new application that combines well-established sub-systems into one new system. The sub-systems are waste processing and sorting, plasma treatment, gas cleaning and energy production. The integration of these systems is rapidly maturing, but has still not been built in large industrial systems. Demonstration and pilot-scale systems are running successfully in Japan and Canada[18] with more starting in the US and Europe[19].

3 GREEN WASTE AND OTHER ORGANIC MATERIAL

3.1 Composting

Composting reduces the waste mass by about 40% (by evaporation of moisture). This is not the only process that suits the treatment of organic waste (see anaerobic digestion). With the addition of some low-value paper products, composting and anaerobic digestion can handle 50% or more of the waste stream.

The technologies can be grouped into the following categories:

- Turned windrow composting: the waste is accumulated into long stacks called "windrow" which are regularly mixed and manipulated for various purposes (figure a).
- Aerated static pile composting: similar to windrow composting, but the waste is not displaced and is aerated, actively or passively, while remaining in place (figure b).
- Covered composting channels: the waste is usually confined between parallel walls of any type, and regularly moved and returned with suspended machinery (figure c).
- Composting in closed container: any technology through which waste is enclosed in a chamber where the environment is tightly controlled (figure d). Composting systems in the closed vessel include fixed, mobile and even non-rigid vessels. These systems may or not include internal systems of agitation or in-process maceration and usually have internal monitoring and adding oxygen systems.

3.2 Vermicomposting

Vermicomposting refers to the breakdown of organic material that, in contrast to microbial composting, involves the joint action of different species of earthworms and micro-organisms and does not involve a thermophilic (high heat) stage. As the agents of turning, fragmentation and aeration, the worms consume organic wastes such as food waste, animal waste, greens and sewage sludge to produce a soil conditioner. Waste materials that are high in moisture content are best treated by vermicomposting, as various worms can tolerate between 40% and 85% humidity levels.

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[18] Plasco Energy Group. http://www.plascoenergygroup.com/

[19] Advanced Plasma Power - http://www.advancedplasmapower.com

Windrow composting with turner(a)

Open windrow composting(b)

Covered composting channels(c)

Composting in closed container(d)

Figure 4: Composting technologies

4 OTHERS INNOVATIVE TECHNOLOGIES

4.1 Mixed recycling

In many western countries, the comingled collection of mixed recyclables is common. Developing countries have become aware of the value of waste and the role of resource efficiency, and some have started to sort and recycle their waste. Among the current technologies are:

Routing machines: needed when recyclables are collected in plastic bags. There are a wide variety of devices on the market. There is currently no device that can effectively break down and reject plastic bags. Therefore, the process requires a first manual separation of plastic wrap.

Air classifiers / sorting by weight: low air jets are used to separate lighter materials from heavier materials.

Sorting drums / sorting by size: Inclined rotating drums which separate materials by rotation and screening. Smaller objects (dirt, chippings, bottle tops, and broken glass) are stirred and fall through the perforations of the drum and are thus separated from the larger objects.

Disc separators (star): commonly used in various sorting applications

Optical sorting technology, which separates materials by colour, density and opacity, is now commonplace for many already separated streams of small particles.

4.1.1 Mixed waste glass processing

This technology consists of mechanical sorting of broken glass. This technology is more common in large glass reprocessing facilities, where large flow capacities can justify the investment costs needed to purchase equipment. Optical sorters are generally effective for pieces of glass from one to four centimeters. Sorting equipment is used to remove the mixed flow of a ceramic or glass separated by color mixed glass. New technologies include the decolourisation and colourisation of molten glass to increase cullet availability and enhance the economics of the glass value chain and crushing and remelting cullet to produce decorative glass and other glass grades for other purposes. [20]

4.1.2 Waste plastic processing

New technologies for the sorting of rigid plastic waste include optical systems that identify and separate plastics by density and opacity. The plastic properties can be captured and identified by transmission or reflection. The identification transmission (X-rays, visible light) is widely used to distinguish resins and colors in the plastics recovery plants where the material flow is controlled. This technology can also be used in some MRFs where contamination of the inlet flow is limited. Individual and mixed plastics can be recycled into composite ‘timber’ and can also be reprocessed into pellets, or post consumer resin, which can be used as feed stock for a variety of products such as new bags and films, pallets, containers, crates, pipes, household and electrical goods, textiles and toys

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[20] Waste Online (2009) Glass recycling information sheet, http://www.wasteonline.org.uk/resources/InformationSheets/Glass.htm

4.2 E-waste

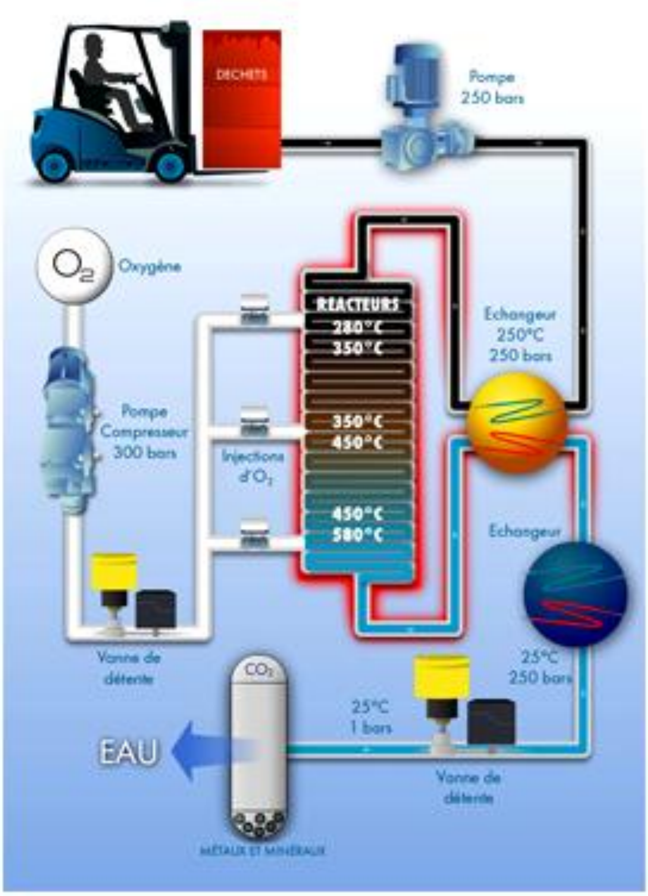
Disassembly systems are currently used worldwide and employ a variety of crushing and separation methods, including eddy currents and magnets, to break apart electrical waste into its basic components such aluminum, copper, silver, lead and gold. Plastics are separated using density separation. Recovered plastics can be used for the production of vineyard stakes, fence posts and plastic sleepers There are several facilities in Australia disassembling e-waste and many of the components are shipped overseas for further processing.

- **Chemical and Electrokinetic Treatment** – Chinese research has shown that copper metal and a lead concentrate can be recovered from printed circuit boards (PCBs) by Supercritical Water Oxidation (SCWO) combined with an electrokinetic (EK) process. The SCWO process decomposes organic compounds of PCBs and oxidises lead and copper.[21]
- **Pyrolysis** - Spanish research has found that pyrolysis of electronic waste under nitrogen at high temperature decomposes electronic waste to obtain polymer free metals, gases as a potential energy source for the plant, and liquids as a potential energy or chemical source. A char by-product may also be used as a pigment, activated carbon, low quality carbon black or a component of asphalt fabrics.[22]

4.3 Toxic industrial waste

Hydrothermal Oxidation, HTO[23] is a high-performance ecological waste treatment method which is finding commercial application in the treatment of aqueous organic residues, and is particularly relevant for breaking down synthetic oils (including industrial cutting fluids and engine oil). Such effluents are almost impossible to treat thoroughly using traditional techniques due to the high rupture strength of the emulsion, whereas supercritical water oxidation achieves close to 100% destruction of toxic content at very high processing rates.

The technique exploits the extreme oxidation characteristics of supercritical water, (defined as 221 bar and 374 ºC). Under these conditions oils become soluble, and a single homogeneous reaction phase is obtained in which the organic compounds and oxygen are brought into contact. This results in



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[21] Xiu, Fu-Rong and Zhang, Fu-Shen (2009) Recov
supercritical water oxidation combined with electr
1002-1007

[22] de Marco, I., Caballero, B.M., Chomón, M.J., Lar
Pyrolysis of electrical and electronic wastes Journ

[23] Metalworking Fluid Magazine (2006), Hydrotherm
water oxidation from University of Cadiz, http://mv

an almost instantaneous break down of organic substances into harmless products, essentially water and CO_2 (without the formation of NOx, SOx, CO or other products of incomplete oxidation). This technology offers improved operational flexibility, including treatment of insoluble wastes, and is now available for commercial exploitation.

4.4 Hospital waste

This innovative technology has been developed for the collection, sterilization and elimination of hazardous waste produced on healthcare hospitals.[24] Directly installed on-site, it automatically converts infectious medical waste into regular municipal waste. It is based on microwave technology to proceed to the waste disinfection. Thanks to its dual-phase process (grinding and disinfection) it enables medical waste bacterial inactivation in around 30-35 minutes and needs only 5 to 10 operator time.

Loading of the biohazardous waste (manual or automatic).

Grinding step to reduce the waste volume.

Heating for sterilization using microwave solution.

Transfer of the grinded/sterilized waste into a container.

4.5 Tyre waste

There are a number of technologies for processing and treating waste tyres. These predominantly involve shredding or mechanical grinding of whole or split tyres to prepare the rubber for recycling or reuse. Others are more complex and include devulcansation, microwave technology and some other physico-chemical processes. Tyres are also currently used a fuel for cement furnaces.

4.5.1 Mechanical processing

Whole or split tyres can be reused for engineering applications such as barriers and walls, soil reinforcement and erosion control. However, shredding, grinding and crushing after freezing produce a range of crumb sizes with a variety of applications, including athletic track surfaces, play ground surfaces, brake linings, landscaping mulch, carpet underlay, absorbents for wastes, shoe soles, adhesives, asphalt filler, bollards, barriers, kerbs and other drainage applications among others.

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[24] Sterilwave, http://www.sterilwave.com/technology/principle-process/

4.5.2 Devulcanization

Heat and or chemical treatment of tyres can produce devulcanised rubber, which has the potential for use in a variety of industries. The process of devulcanizing waste rubber can be broken down into two separate sequential and integrated steps. The first (or pre-processing) step is size reduction. The waste is reduced in size so that it can be fed into the system that actually performs most if not all of the chemical bond-breaking. The second step is the devulcanization process, or the breaking of the chemical bonds (primarily the sulfur bonds). The output product from the process is devulcanized rubber. Devulcanization system suppliers may supply only the devulcanization process itself, or in combination with a size reduction process.

4.5.3 Emerging technologies

Various other technologies are emerging to deal with waste tyres including:

- **Microwave technology** - Advanced Molecular Agitation Technology has developed a prototype system that breaks the tyres into their original components; steel, carbon and oil which are all recoverable. The amounts of emissions produced are minimal. The first commercial scale prototype has a capacity of 2,000 tonnes of tyres a year;
- **Continuous reductive distillation** - this is a type of pyrolysis which involves continuous heating;
- **High pressure water** – This technology developed by Aquablast in the UK uses high pressure water jets to remove tyre rubber from the reinforcing steel in earthmoving tyres. All the tyre components can be recycled including the water used in the jets.
- **Gas phase halogenation** – This US technology oxidises the rubber tyre surface to make crumb suitable for a limited number of alternative applications;
- **Steam gasification** – Tests of steam gasification on dry, 2 mm particles of waste tyres in a rotary kiln reactor produced both a char, which could be used as a feed for further processes, and a hydrogen-rich syngas with possible fuel cell applications.
- **Pyrolysis** – Tyres subject to pyrolysis in test conditions produce a solid residue which when was combined with ground dry sludge produced activated carbon adsorbents which could be used in the treatment of wastewater