Waste-to-Energy as an integrated part of Circular Economy

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ABSTRACT

Resource efficiency and circular economy require prevention and treatment of wastes for recovery of materials and energy.

For waste management a general "Waste Management Hierarchy" has been proposed and partly implemented, which requires integrated technologies including thermal treatment processes such as pyrolysis, gasification and combustion.

Paper and cardboard recycling processes are in need of sustainable and energy-efficient co-generation for supply of electricity and process steam, which can preferably be energy from waste such as combustion of rejects from waste paper sorting and residues from necessary wastewater treatment.

Residual mixed wastes (after source separation and sorting for material recovery from waste) with a calorific value similar to lignite coal, but potentially hazardous constituents such as POPs (Persistent Organic Pollutants) require as a preferred option resource efficient waste-to-energy based on controlled combustion with integrated cleaning of flue-gas and treatment of liquid and solid residues.

The integration of a polluted airflow (e.g. from chemical processes or pre-treatment of wastes) into the incineration process allows for an optimum environmental performance according to the philosophy of circular economy and as proposed for different integrated waste-to-energy processes with recovery of energy, metals and other inorganic materials.

Circular Economy includes energy from waste as a means for efficiency in recovery operations, as stated in the White Book "Waste-to-Energy in Austria", published by the Federal Ministry for Sustainability and Tourism (previously the Ministry for Agriculture and Forestry, Environment and Water Management).

KEYWORDS

Waste-to-Energy (WtE), Circular Economy, Zero Waste, Integrated Technologies, Reuse, Recycling, Recovery, Landfills, Disposal, Emissions, Greenhouse gases, Sustainability, European Commission.

INTRODUCTION

> *"I have a severe problem with people – egoisms, violence and greed, ignorance as seen by waste dumping and littering, atmospheric and aqueous emissions, irreversible environmental pollution by pesticides and other POPs, soil erosion, irrevocable extinctions of unique species in flora and fauna, biological and nuclear hazards, exploitation, poverty, humanitarian disasters."*
>
> (Status on the Planet Earth, 2018)

> *"Even if I knew that the world would perish tomorrow,*
> *I would still plant an apple tree today."*
>
> (Statement attributed to Dr. Martin Luther, 500 years ago)

Henderson Island, UNESCO World Heritage, only 37 km² area, is one of the most polluted beaches in South Pacific with wastes from China, Japan, Peru, Chile (J. Lavers, University of Tasmania, 2017)

Figure 1: Pollution of planet Earth (Photos: UNESCO, Jennifer Lavers and Copernicus / ESA)

We face global problems on Earth and spend money to search for another planet - correct?

Robots in the deep sea are scanning the waste on the ground of the oceans: They are already measuring the thickness of the layer of garbage and large big plastic patches covering increasing volumes of the oceans. Yet this is only a small visible part of our problem. Currently more than 8 million tons of plastic garbage end up in the oceans, and studies indicate that 90% of plastic polluting our oceans comes from just 10 rivers (Gray, 2018).

Satellites are screening land areas already covered by waste dumping. Leachate contaminating the ground and surface water bodies needed for drinking water, enormous air pollution by covered and open fires, landslides on waste dumpsites and increasing emissions are causing diseases with premature deaths and contributing to Greenhouse gas emissions. Sustainable waste management and resource efficiency are missing in most regions in the world. Even urgently needed measures to reduce hazardous health impacts by severe pollution are not being taken due to inappropriate management (e.g. as addressed by ISWA President Dave Newman in his Statement to the United Nations Environmental Assembly in Nairobi, 2016). However, appropriate technologies based on proven technical solutions are available for development and implementation of tailor-fit regional waste management.

This presentation describes measures related to circular economy and the popular – as well as unrealistic - request for zero waste, ignoring the absolute valid principles of thermodynamics. Referring to more than 60 years experience with “Waste-to-Energy” in Austria (BMLFUW 2015: Whitebook - Figures, Data, Facts – published as 3rd edition in 2015, by the Federal Ministry for Agriculture and Forestry, Environment and Water Management) the need for proven technologies for waste treatment in a circular economy is addressed.

CIRCULAR ECONOMY AND ZERO WASTE STRAGETIES

Laws and standards

European legislation and environmental standards are very complex and are often presented as the best practical examples for waste management all over the world. However, local and regional conditions, culture (including awareness, education of public, expertise in management and technologies), and economic and political systems may differ, thereby influencing specific requirements for policies and legal framework and thus determine appropriate technical solutions for implementation of sustainable waste management. Because of this, carefully tailored investigations and sound feasibility studies are necessary at the outset of each project. Singular waste management projects are unlikely to be successful without an integrated waste management plan. Such plans are needed for organisation units such as major industrial sectors as well as for geographical regions, which can be specified for model industries and regions with high interest and potential for improving waste management practices.

The transition of a “linear” economy from production, use and disposal of consumables to the “circular” strategy as defined by European Waste Framework Directive 2008/98/EC should be a guiding principle in every waste management plan for improvement strategies. The so-called waste management hierarchy is useful as a guiding principle, but as for the practical application, careful assessment as already expressed in the EU Directive “… where in insofar as they are the best ecological options” is required.

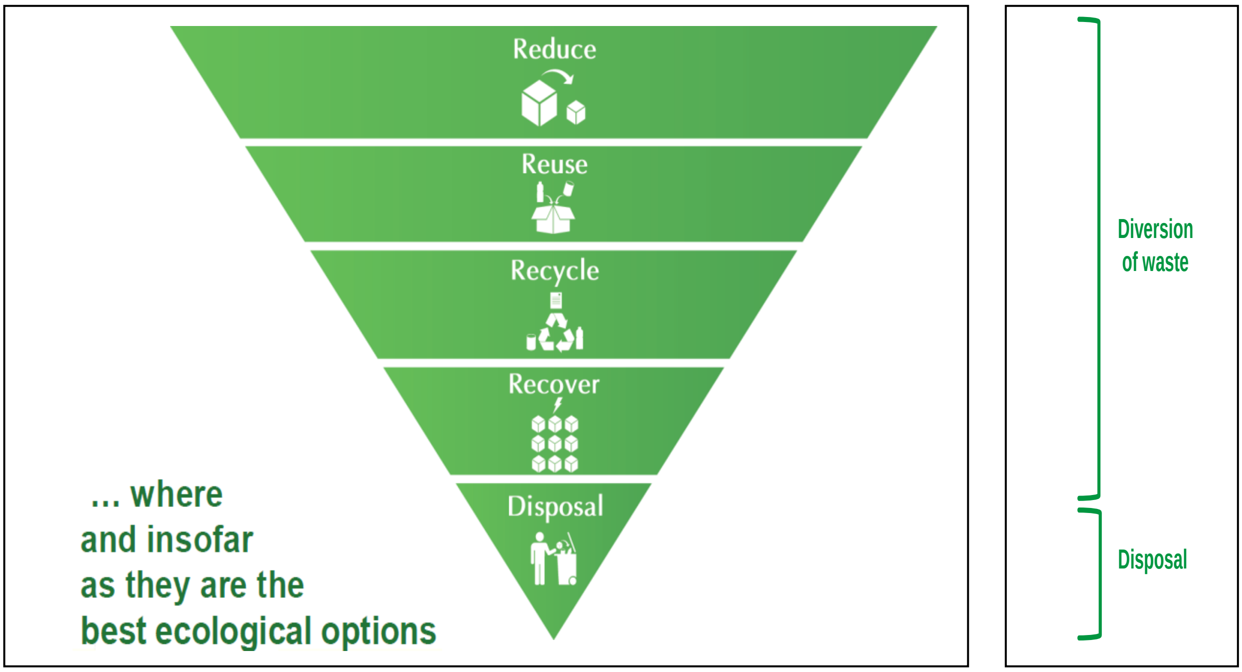


Figure 2: The general Waste Management Hierarchy (Source: EU Directive 2008/98/EC).

According to the EU Communication (European Commission, 2017), the waste management hierarchy also broadly reflects the preferred environmental option from a climate perspective: disposal - in landfills or through incineration with little or no energy recovery - is usually the least favourable option for reducing greenhouse gas (GHG) emissions. The EU Member States have some flexibility in the application of the hierarchy, as the ultimate goal is to encourage those waste management options that deliver the best environmental outcome.

The European Automobile Manufacturers' Association (ACEA) describes this complexity in their Position Paper on Circular Economy (www.acea.be):

- Promote holistic approach to product design for sustainability
- Encourage innovation and ensure technological neutrality
- Recognise achievements in remanufacturing – the limitations of recycling
- Recognise recycling as a tool, not as an environmental target in itself
- Improve implementation of existing EU waste legislation
- Recognize the technical, economic and environmental limitations of resource-efficiency targets.

Why not zero waste

In reality, zero waste and zero emission are not possible. As stated in EU communication: "even in a highly circular economy there will remain some elements of linearity as virgin resources are requested and residual waste is disposed off" (BMLFUW, 2015).

Waste management is also subjected to the absolute validity of the 1st and 2nd Law of Thermodynamics. (Please note: The 1st Law describes the validity of mass and energy balances and the 2nd Law describes an increase of "entropy" in any given system. Entropy is a measure for "disorder", or as described by Bertrand Russel: "You can't unscramble eggs", though it is rather easy to scramble an egg. Similarly, you cannot "unmix" the mixed residual waste with cross contaminations between the various wet and sticky wastes.)

No element in the waste streams will vanish; therefore, substances like mercury and other hazardous heavy metals will be circulating inside a system or emitted to the ambient environment. The same is valid for persistent organic pollutants (POPs) and substances such as asbestos – if they are not safely destroyed or permanently captured and immobilized in a reliable waste treatment process.

The need for thermal waste treatment processes within a circular economy is evident due to manifold reasons, such as the need to destroy potentially hazardous (organic; e.g. POP's) as well as to immobilize potentially hazardous (inorganic) residues or to recover materials and energy in an environmentally safe and resource efficient manner (e.g. from biodegradable organic or mixed residual wastes). In a circular system, there is besides the demands of hygienisation and inertisation, the need for a "sink" to accumulate hazardous substances into a fraction with high concentration in order to apply highly effective waste treatment processes with possible recovery of energy and materials (minimizing potentially harmful concentration in the remaining streams with a "circular economy"). Thermal processes isolate harmful substances contained in waste, ensuring their removal from the eco-cycle (ubiquit biosphere) through either destruction (e.g. cracking of POP's) or safe disposal and intermediate storage for future material recovery (recycling processes) of inorganic substances (Braungart, 2002; Thome-Kozmiensky, 2014, European Parliament, 2018).
Summarizing, it allows for performing "urban mining" by recovering the energy and materials contained in nonrecyclable residual waste streams as an indigenous and local (national) source of energy and resources.

THE ROLE OF WASTE-TO-ENERGY

Why is waste-to-energy needed?

A frequently expressed assumption is that the use of renewable resources, recycling and composting will not require any waste incineration. However, the reality is that on one hand thermal energy (e.g. process steam, preferably from steam boilers with co-generation of electricity and low-pressure steam) is needed for various production processes, (e.g. for manmade cellulose fibres, for paper and cardboard, for particle board, etc.), and on the other hand residues from recycling processes (e.g. rejects in paper and cardboard recycling, residues from necessary waste water treatment, post consumption wastes such as unhygienic used sanitary articles made from cellulose) will require waste-to-energy as the best available technical option to provide necessary public hygienic standards as well as maximum energy recovery before final disposal.

The following Figure 3 illustrates for the example of wood (as a biomass derived from photosynthesis and CO_2 plus H_2O) the useful purpose and role of waste-to-energy in a circular economy, with a “cascade” use of the valuable renewable resource wood.

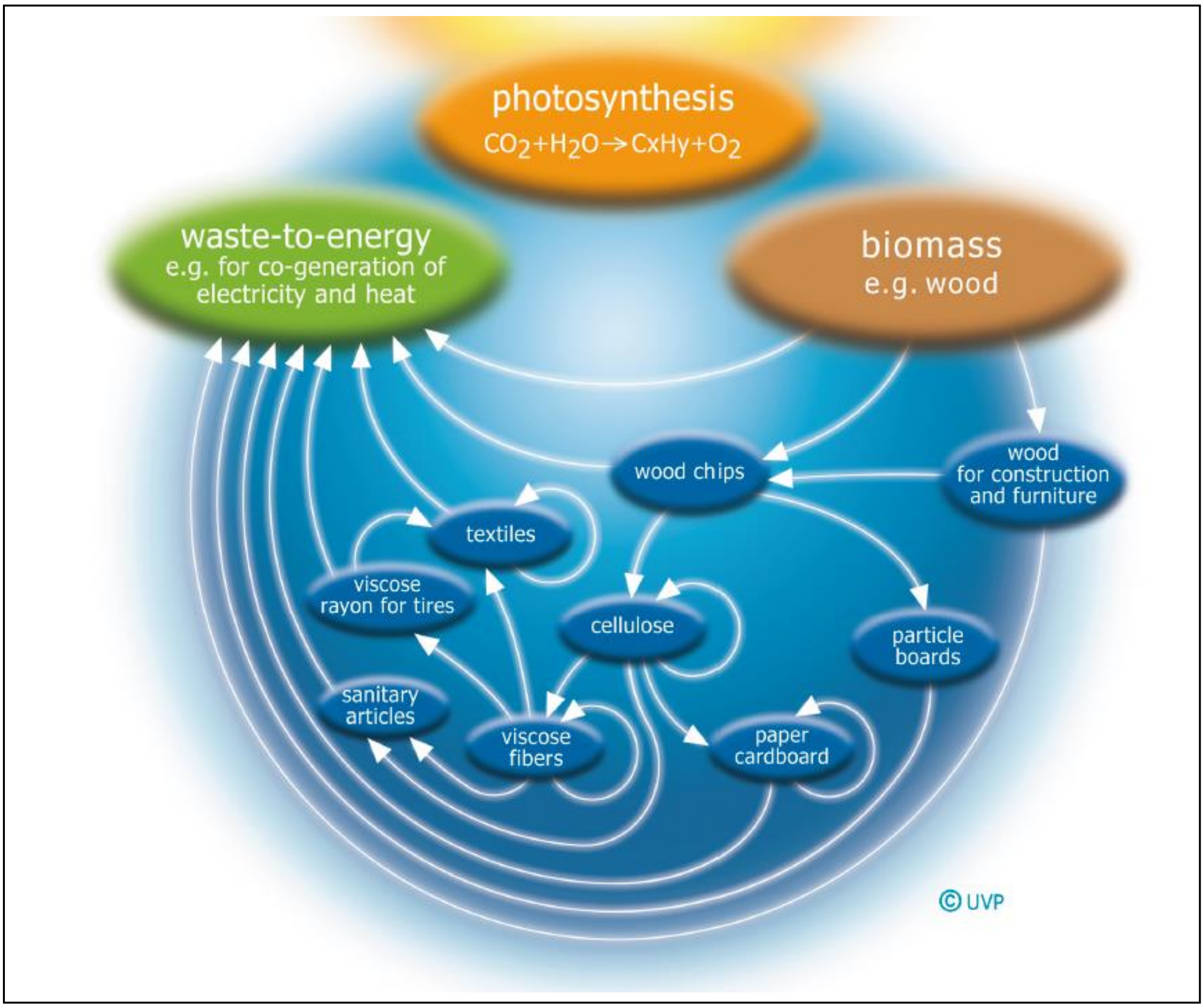


Figure 3: Waste-to-energy in a circular economy for the renewable resource wood (BMLFUW, 2015).

The role of waste-to-energy is similarly important in the case of non-renewable resources such as mineral oil, coal and natural gas, as illustrated in the following Figure 4 (by substituting non-renewable sources with renewable sources such as waste-streams). According to renowned energy statistics it is obvious that globally about 90 % of all mineral oil is directly consumed in various combustion processes, e.g. for jet fuel, gasoline, diesel, light and heavy heating oil.

According to 2nd Law of Thermodynamics, “recycling” of organic materials is always a “down-cycling” due to production-induced additives and doped impurities while utilization and change of chemical matrix during life-time and mixing during collection and transfer. Instead of using fossil resources instantly in combustion processes, a priority could be the production of valuable polymers and other petrochemical products. For example, plastic and compound materials can be used in different sectors, including in civil engineering works, for insulation and protective coatings, and for making vehicles lighter and thus more fuel-efficient. Furthermore, appropriate plastic packaging can effectively reduce waste and losses in transport and intermediate storage of various powdery, granular, liquid, pasty and solid as well as hygienically sensitive products.

Of course, littering can become a serious problem, but this is lack of awareness and civilized culture, often combined with lack of infrastructure and inappropriate incentives. For example, shopping bags should not be given for free (as they are not without cost). A (politically popular) legal ban would generally not be a solution for lack of integrated waste management. Shopping bags might be reused, and finally serve as a garbage bag. The municipalities must provide infrastructure for collection of different municipal solid waste fractions and for waste-to-energy capacity for residual municipal waste. Design of waste-to-energy must consider high efficiency in energy recovery, preferably by co-generation of electrical and thermal power at appropriate sites with continuous thermal energy demand (e.g. industrial production site for pulp, paper, cardboard and textile, refineries, various chemical industries, municipalities with district heating network and/or district cooling demand, etc.).

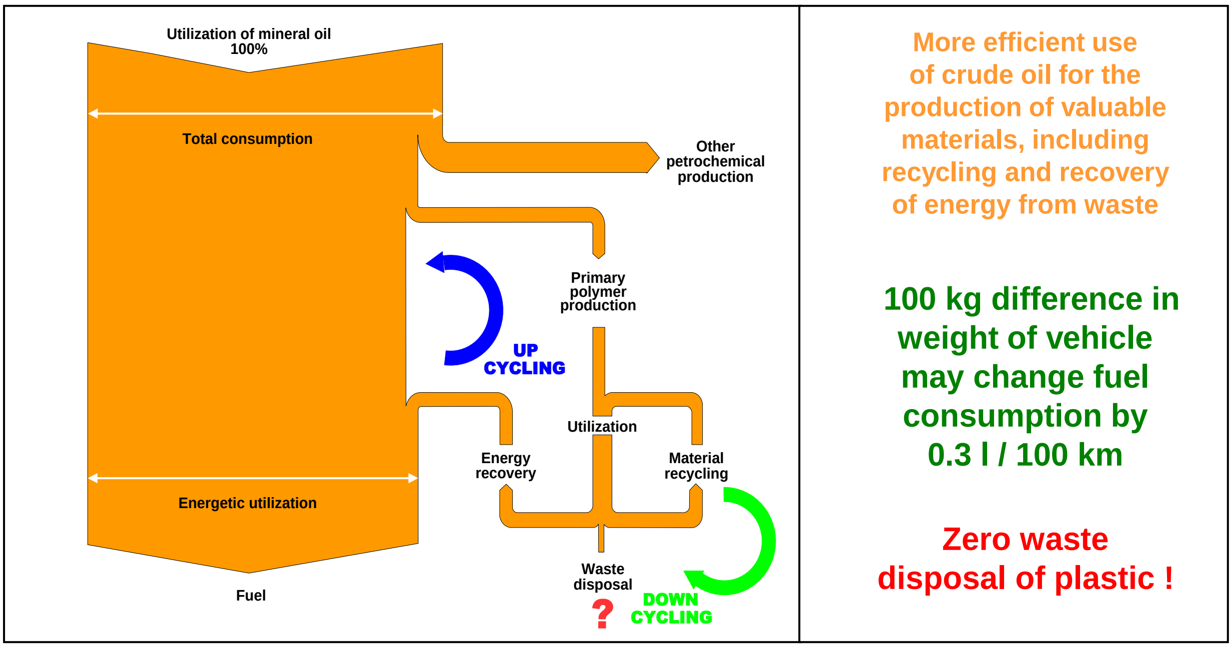


Figure 4: Efficient use of non-renewable resources, e.g. mineral oil for ”up-cycling” by primary material use in various productions, some “down-cycling,” and final energy recovery (BMLFUW, 2015).

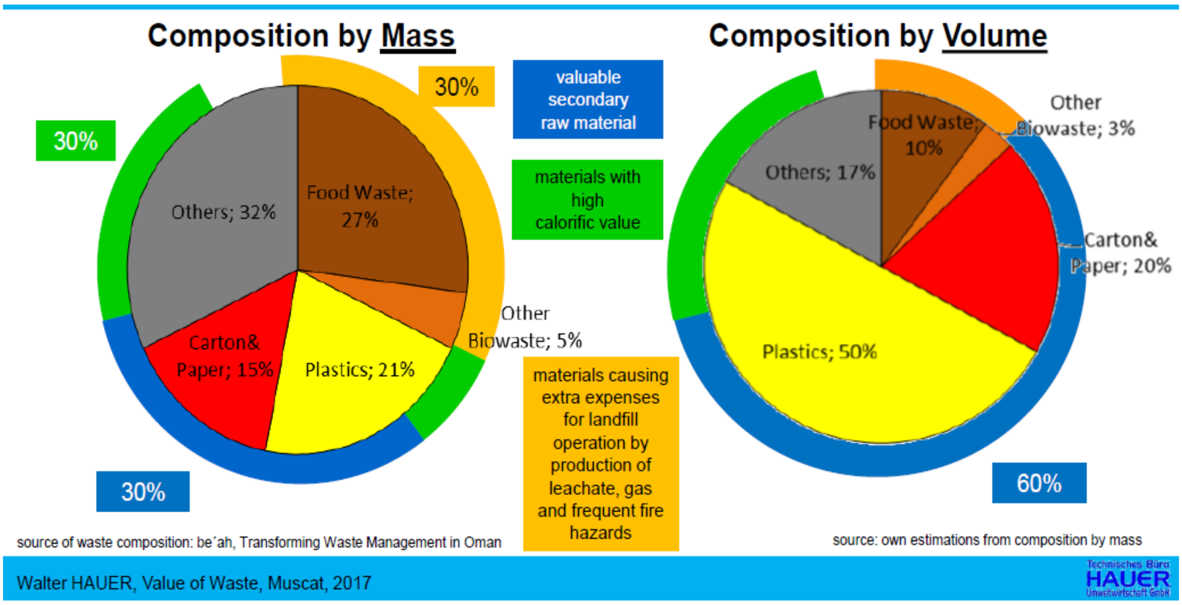
Composition of household wastes and what should not be kept in a circular loop

In advanced municipal waste management systems with additional collection of source separated waste fractions for recycling and composting, a considerable part of total municipal solid waste, defined as residual waste, remains as a mixed waste stream. This includes residual waste streams from separate collection such as plastic bottles, metals, biodegradable organic wastes, paper and cardboard. The residual waste may contain considerable parts of so-called rejects, i.e., materials rejected and extracted during processing.

For example, recycling of waste paper and cardboard requires separate collection (to ensure highest quality recycling which enables to re-circulate the recyclate with well-defined technical charcteristics into high quality products by substituting raw (int his case virgin wood-fibre) material), sorting, mechanical treatment, and recovery of pure fibre fractions for re-use in paper or cardboard machines. This process yields approximately 10 to 15% residues (rejects, mechanically dewatered sludge from wastewater treatment), which should be used for recovery of energy.

Figure 5 shows the typical composition of municipal solid wastes by mass and volume at present in the Sultanate Oman. Some 60% to 70% of residual waste is biologically degradable (including moisture). Approximately 20% by mass (and 50 % per volume!) consists of plastics; approximately 10 to 20% consists of inert materials, including glass. About 3 to 4% consists of metals and about 2% classified - in chemical terms – as hazardous household wastes (e.g. left-over medicines and pharmaceuticals, batteries, pesticides incl. contaminated packaging, oils, WEEE (Wastes of Electric and Electronic Equipment), etc.). According to experience gathered in Austria (BMLFUW, 2015), 1 ton of residual waste typically contains 1 to 3 g of mercury, approximately 10 g of cadmium, 3 to 5 kg of sulphur and 6 to 12 kg of chlorine. These substances are in all fractions of residual waste in a variety of chemical compounds.

Taking these hazardous substances out of a “circular” loop is essential. For this reason, the requirements for technical systems ensuring safe residual municipal solid waste treatment are highly complex. Co-combustion in industrial facilities without adequate flue-gas treatment and control is not acceptable from a viewpoint of necessary environmental protection (e.g. atmospheric pollutants).



source of waste composition: be´ah, Transforming Waste Management in Oman

source: own estimations from composition by mass

Figure 5: Example for a composition of MSW by mass and by volume (data for Oman, 2017)

The sink for potentially hazardous substances and pollution by POPs

Maximising the concentration of hazardous elements and substances in a small volume is a key function in integrated waste management.

According to European practical experiences for more than 100 years with more than 400 operative waste-to-energy plants, even ashes from waste combustion in fluidized bed or grate systems are separated in fractions to be recycled (metals, optionally also glass and gravel for civil works and road construction). Only a small fraction from flue-gas treatment with the accumulated hazardous substances needs further treatment for safe disposal. This fraction accounts for about 3 to 5 % of the waste input for WtE.

No other recycling process can provide such a function of highest material concentration due to impurities and accompanying substances. Concentrations at mines for virgin raw-material extraction are predominantly lower compared to WTE-residues. Therefore, WtE is a necessary and logical integrated part of the waste hierarchy following the waste framework directive.

What types of waste should be incinerated?

Residual and other mixed wastes with sufficiently high calorific value (e.g. residual municipal waste) should be treated in suitably equipped plants at appropriate sites for recovery of energy.

The question of whether a certain type of waste should be treated primarily for material or for energy recovery can only be answered on a case-by-case basis, as the specific waste composition and available treatment technologies must be considered with special attention on mass and energy balances, resource conservation, and environmental impacts.

At any rate, thermal treatment (with highest rates for energy recovery) becomes necessary whenever organic pollutants contained in the waste are to be destroyed, as this may be necessary due to the quality requirements for material recovery or disposal of residues. Residues from municipal wastewater treatment plants, for instance, inevitably fall under this requirement, since (due to their composition) they pose a potential environmental and health hazard in case of agricultural application. This has become evident already for many years due to extensive Central European experiences in Municipal Waste Water Treatment, its residue disposal followed by monitoring and analytical campaigns.

Large volumes of the following types of waste with relevant organic content can be treated by incineration for energy recovery (grate, fluidized bed and rotary kiln):

- Residual waste and similar commercial waste (municipally collected household refuse)
- Pre-treated bulky waste, commercial, production, and construction specific waste
- Residues from municipal and commercial wastewater treatment
- Waste wood and other contaminated waste products from wood processing
- Residues from waste material recycling (e.g. rejects from paper and cardboard recycling)
- Shredder residues from the scrap processing industry (e.g. from ELV and WEEE)
- Residues from waste oil processing, wastes containing oil and contaminated organic solvents
- Organic wastes with relevant POP contents (e.g. halogenated flame retardants, DDT, HCB, PCB)

Can residual waste be incinerated without auxiliary fuel?

Yes. Despite the separate collection of different waste fractions, the typical calorific value of residual waste continues globally to rise and is at approximately 10 to 12 MJ (Mega Joules) per kilogram in Industrial Nations. This means that 1 ton of residual waste is roughly equal to 1 ton of brown coal or 250 litres of heating oil in terms of calorific value.

The average calorific value of residual municipal waste fluctuates over time and may differ by region. This is especially true of rural regions with solid fuel for cooking and heating, where residual waste has a lower calorific value since wastes with high calorific value (e.g. cardboard, waste wood taken from bulky waste) are rudimentary gasified and partially burned by incomplete combustion with manifold harmful atmospheric emissions and due to the ash fraction from regular fuels (e.g. firewood, coal). Nevertheless, experience has shown this calorific value is still sufficient to allow the expedient use of the energy content of residual waste in suitably designed incineration plants.

The exact range of calorific value for auto-thermal combustion (combustion without auxiliary fuel) depends on the design and technology used for controlled incineration. While a typical grate firing facility requires a minimum calorific value of approximately 7 (or more) MJ per kg for auto-thermal combustion with maximum power generation, a suitably configured fluidized-bed incineration plant can achieve a range starting from approximately 3 MJ per kg.

The development of the average calorific value of residual waste over a number of years with its strong seasonal fluctuations must be carefully assessed. A typical example is the changes from 1970 to 1990 in the city of Milano, Italy: In this timeframe, the generation of municipal waste quantity and its specific calorific value increased by 100 % (from about 250,000 to 500,000 tons per year and from 5 to 10 MJ/kg) due to increased consumption and non-recyclable packaging wastes.

What are the technical alternatives to a WtE plant for residual wastes?

The proven technologies for Waste-to-Energy are different types of fluidized bed and moving grate systems, in specific cases rotary kilns. Throughout the last decades, several alternative concepts and technologies were proposed for various mixed wastes and implemented in pilot and demonstration plants. However, many of these plants have experienced severe technical problems (despite various positive academic assessment that those concepts being viable) and ended in financial bankruptcies (Clay 2016, Gleis 2010 etc.).

These alternative processes are of the following process groups of

- Pyrolysis for recovery of oil and coke
- Gasification for recovery of chemical raw material (e.g. for methanol synthesis)
- High-temperature Plasma Processes
- Liquefaction Processes
- Hydrothermal Processes

Due to technological and economic constraints, almost all of them eventually failed during the implementation. According to the report, ”State of the Art of Alternative Processes for Thermal Waste Treatment“ (by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) the conventional waste incineration is still (by year 2015) state of the art for mixed residual municipal waste. There are no alternative thermal processes available, which are capable to compete with waste incineration considering both economic and ecological aspects (FEAG 2015).

Mechanical-biological treatment (MBT) of residual waste allows only for reduced energy recovery rates due to the losses in the rotting process and internal energy consumption.

Biogas from anaerobic treatment of digestible organic wastes (e.g. sewage sludge, contents of grease traps, a semi-liquid fraction derived from mechanical pre-treatment of residual waste at high-pressure or with aqueous extraction) in closed systems allows for some energy recovery. Utilization of gas from sanitary landfills allows for energy recovery from waste in an even lesser degree (due to incomplete technical capture of only about 50 to 60% of the total landfill-gas emission). Thus, the overall energy recovery is factor 5 to 6 less than from direct waste incineration (BMLFUW, 2015).

What is the efficiency of a WtE plant?

Modern waste incineration facilities with co-generation of electric and thermal power and optimum energy integration can achieve an overall energy efficiency of more than 80%.

Figure 6 shows the importance of energy integration, utilizing the generated heat as process steam or heat in industrial processes (pulp and paper, desalination, district heating and cooling).

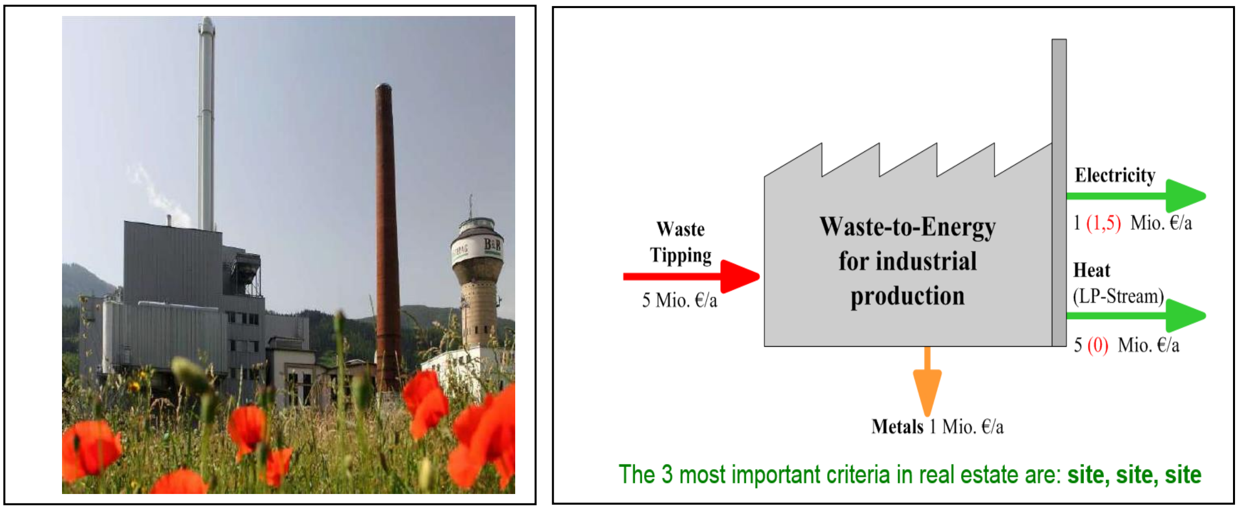
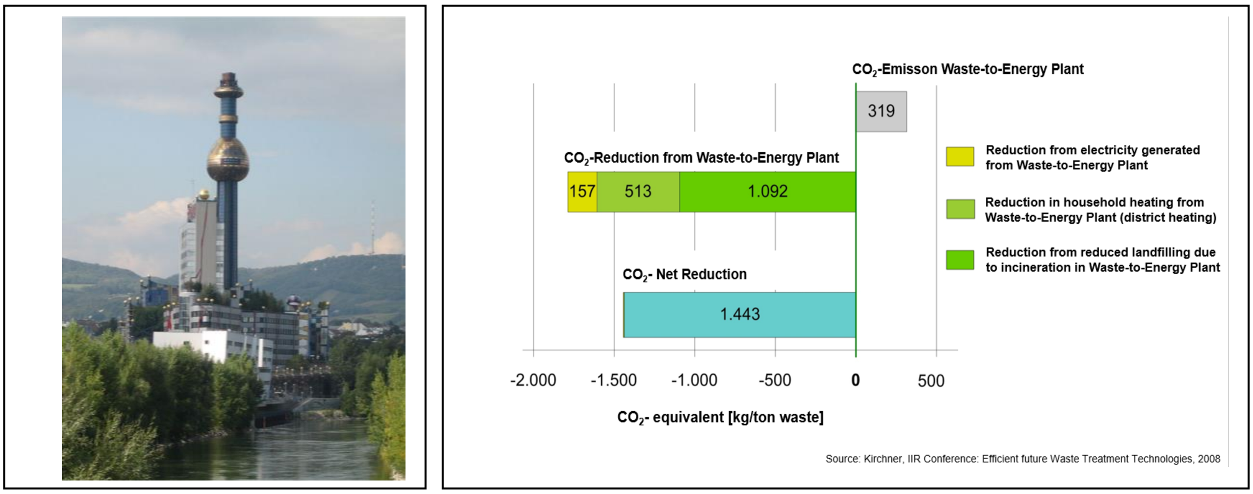


Figure 6: Example of the economic performance of a 100,000 tons / year waste incineration plant: Co-generation of electricity and low-pressure steam for paper production allows for an increase in annual revenue by 60 % (additional revenue for energy of 4.5 Mio € per year; data by C. Pusterhofer for ENAGES, Austria, 2014).

What is the impact of Waste-to-Energy on greenhouse gas emissions?

Investigations prove that properly designed WtE produces much less climate relevant gases compared to mechanical biological waste treatment or disposal in sanitary landfills (even with maximum recovery and utilization of landfill gases). Due to strict emission limits, WtE assures a safe treatment of residual wastes with recovery of clean energy for further use and substitution of otherwise needed fossil energy (BMLFUW, 2015).



Source: Kirchner, IIR Conference: Efficient future Waste Treatment Technologies, 2008

Figure 7: Greenhouse gas emission balance by municipal waste incineration in the Waste-to-Energy plant Spittelau in Vienna, Austria (BMLFUW, 2015)

How can a maximum diversion of residual mixed wastes from landfilling be achieved?

Closing dumpsites and the transition to circular economy with integrated waste-to-energy is one of the major future topics and challenges worldwide which severe lessons have been learned based on global experiences while best practice examples are available for many cases. Circular economy concepts will lead to a minimization of waste materials to be landfilled with minimum harm and risk to the environment.

Figure 8: The environmental and socioeconomic disasters of garbage dumps by hazardous atmospheric emissions and contaminated leachate (Photos by F. Neubacher, UVP: at the left Addis Ababa, 2004 and at the right Guatemala City, 2000)

CONCLUSIONS

Circular economy is not equal to zero waste. Appropriate design of thermal waste treatment by incineration processes will be a necessary part of circular economy and sustainable waste management for destruction of hazardous organic pollutants (e.g. POPs) as well as for recovery of energy and materials, as indicated in the process scheme in Figure 8.

The integration of a polluted airflow (e.g. from chemical processes or pre-treatment of wastes) into the incineration process allows for an optimum environmental performance according to the philosophy of circular economy and has already been proposed for different integrated waste-to-energy processes with simultaneous recovery of energy, metals and other inorganic materials (UVP, 2018).

This concept (see figure 9) is in harmony with requests of the EU Commission on the role of waste-to-energy in the circular economy:

- in the future as more waste is directed to recycling,
- improving energy efficiency of waste-to-energy processes,
- promoting those processes which combine material and energy recovery,

- contribute to decarbonising key sectors such as heating and cooling or transport, and
- to reducing greenhouse gas emissions from the waste sector.

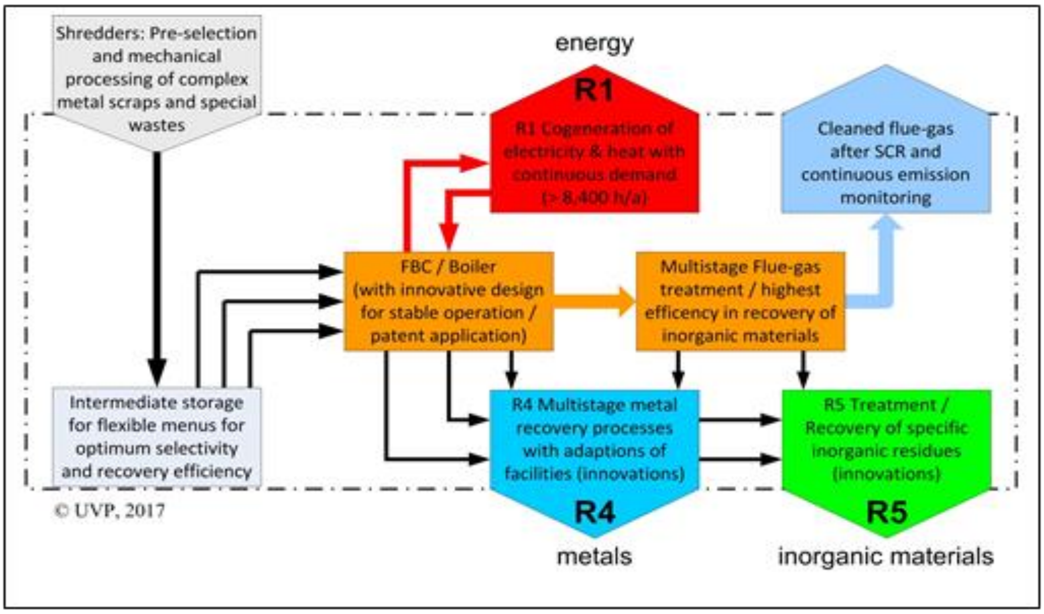


Figure 9: AR415 example for an integrated waste-to-energy process (UVP 2018) for highest resource efficiency in a circular economy - with utilization of polluted air (A) in combustion recovery of energy (R1), metals (R4) and other inorganic residues (R5).

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