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Waste to Energy Conversion Technology

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Annotation: With rapid urbanization and industrialization, the accumulation of municipal, agricultural, and industrial waste has emerged as a significant environmental and energy challenge worldwide. Although various waste management practices exist, the efficient conversion of waste into usable energy remains underutilized due to technological, economic, and regulatory barriers. This study explores diverse waste-to-energy (WtE) conversion technologies, including incineration, gasification, pyrolysis, and anaerobic digestion, emphasizing their thermochemical and biochemical mechanisms. Using a comprehensive analytical approach, the paper assesses the technical feasibility, environmental impact, and economic viability of each method across different waste streams. The findings underscore the transformative potential of integrating advanced WtE technologies into national energy and waste strategies. This integration not only reduces landfill dependency and greenhouse gas emissions but also contributes to sustainable energy production and circular economy initiatives, especially in developing nations.

Keywords: waste-to-energy, incineration, gasification, pyrolysis, anaerobic digestion, sustainability, renewable energy, waste management, circular economy.

1. Introduction to Waste to Energy

The growth of urban populations and industrialization is the major mechanism that drives waste production globally. The creation of waste is a result of increasingly intensive consumption processes in order to meet the daily needs of the community. Globally the waste sector contributes 3.5 percent of GHG emissions or 7.16 percent of the contributions of the waste sector in the world. With the increase of waste production in the working area the amount of methane gas generated from waste will also increase. Responsibly managing waste is necessary to reduce methane emissions from it. One alternative treatment of waste is to convert it to energy.

Waste to energy is the process of generating energy from waste. The conventional waste treatment approach consists of landfills and incinerators. In recent years, the alternative solution of the waste to energy process has been an attractive option. Waste to energy has been identified as treatment technology that provides various environmental advantages, recovers energy, reduces the volume of waste and production of greenhouse gas emissions. Technologies for waste-to-energy conversion are gasification, incineration, pyrolysis, and plasma arc gasification.

Plasma arc gasification and incineration technologies are already operating in particular areas. It is important to select the appropriate technology for waste to energy conversion correctly in order to achieve an optimal decision. There are various aspects to consider when selecting conversion technology from waste to energy. On the one hand, this decision aims to resolve problems related to waste and provide additional energy. On the other hand, this process can lead to atmospheric contamination. This study proposes a series of steps as a method of developing waste to energy. This method aims to characterize waste, considering energy possibilities that can be produced, and considering emission possibilities in the decision to choose waste to energy technology. [4][5][6]

2. Types of Waste to Energy Technologies

Waste to Energy (WtE) conversion technologies have played an important role in the sustainable waste management. A variety of waste to energy technologies around the globe exist. These waste-to-energy technologies currently used include biogas production from landfill and anaerobic digesters; combustion-based WtE (mass burn technology is the most common, whereas some other popular technologies are fluidized bed, gasification and pyrolysis); waste-fired district heating plants; RDF-fired electricity producing facilities; and co-incineration in cement kilns, and power producing plants. Furthermore, newer technologies are emerging too. These include plasma arc gasification, waste-to-wheels which is a new transport fuel from hydrogen derived from waste, and even production of fuel cells from RDF. Though these technological innovations have attracted much attention, they have not yet overcome many obstacles [7]. The majority of energy from waste processes involves direct burning of the waste, whether it is as a gas (Pyrolysis), solids (Incineration of MSW) or Pyrolysis under gravity spread of RDF starved of oxygen in the absence of external heating. These have the benefit of being able to incinerate contaminated, composite, or mixed wastes too hazardous for recycling or landfill.

Incineration is the most common and widely used process for WtE conversion at present. Modern incineration processes are comparable to coal combustion process in terms of their environmental acceptability. In recent years, development of the pyrolysis/gasification-based WtE technologies, which have process temperature being significantly lower than that of the common MSW incineration, has drawn a great deal of interest for examination by various engineering and consulting firms, academic research groups, municipalities and waste service companies. The first plant using plasma torch gasification started its commissioning in April 2018. These conversions are primarily being pushed by strict policy in the European Union of reducing emissions from incineration. Swedish experience however, has shown gasification to CRT in cement works to have inferior environmental output compared to incineration. Incineration is done at high temperatures to maximise energy recovery, and for effective break down of toxins, plastics or other materials of concern. Traditional gasification technology operated at a far lower of a sub 1,500 C where 30-40% less dioxins are destroyed with a good proportion forming heavy metals. This is a significant issue as one of the 12 most persistent organic pollutants, dioxins accumulate in the environment. Domestic and other incineration sources stack up poorly compared to medical waste incineration, and building additional incineration capacity is contrary to the current Waste Strategy 2000 which intends to promote recycling over combustion.

2.1. Incineration

Waste quantity, demand of energy and the future population development are the factors primarily affecting the choice of a recovery technology. For developing countries, quantity of waste generated is still small and not economically feasible for large investment. On the other hand, for these countries have the lowest level of energy consumption, the potential for energy recovery is still limited compared to developed countries. However, when the future population development is considered, both population and waste quantity will obviously increase. Thus, implementation of waste-to-energy technology has to be prominently considered.

When MSW is chosen to generate energy, a choice of technology to realize that goal is necessary. There are several ways of proposing how unprocessed refuse could be burned. Refuse could be fed to a furnace hot at temperatures of hundreds of degrees, as in a slagging coal gasifier, or it could be burned on top of a hot bed of sand or in a molten slag or even deep in a bed of hot sand. One cannot well mix in air, while the other promotes violent air and fuel mixing, as in fine shale or coal burning. It is possible to make some sort of facility which has a pretentious air of being fairly technological and stylish. Otherwise one can identify some very technical items, trendy problems and some detail aspects of design, but there is little point. On the whole one should stick to the simple, tried and tested approach, if one must burn garbage. Burning garbage, like burning any other material, requires a careful attention be paid to the combustibility and heating values of the material to be burned. Broadly speaking, there are two options of turns in using the garbage as fuel. Either it is burned as prepared RDF or as it comes, in mass burning. The former has been evaluated in depth and the consensus is that its employment should be adhered to. On the other hand, there is the possibility of turning gas and oil. [8][9][10]

2.2. Anaerobic Digestion

Waste-to-biogas conversion technologies have good economic potential with proper optimization. The insights on the current status, process challenges, energy yields, and economic potentials are summarized. Anaerobic digestion (AD), which is mostly used for treating solids, is the most energy-efficient technology among three biogas production methods, including thermochemical gasification and pyrolysis. A series of biological processing steps with the core conversion using the AD technology convert the complex organic matter in waste products to simple monomers by using a consortia of microorganisms. Currently, biogas is the most popular in producing electricity and heat. The technology possesses the largest number of operating facilities and remains the leader in terms of generating energy among other biomass-to-energy technologies. MT-AD most effectively processes solid waste products to biogas and has greater electrical and thermal energy production potential. MT-AD produces 6.95 thousand Btu per short ton of biochar. With complete ash recovery, 664 pounds of mineral-rich ash would be produced alongside every short ton of biochar. Biochar demands a net energy input of 8.29 thousand Btu per pound which can be provided by 0.31 pounds of a mineral-rich ash. Over the period of 2010-2019, biochar would require between 7.30-7.96 million tons of mineral-rich ash for it to be created in the large quantities such replanting practices would necessitate [11]. Anaerobic digestion (AD) is a series of biological processing steps for organic matter that converts it to biogas by their constitutive consortia of hydrolytic, acidogenic, acetogenic, and methanogenic microorganisms. Biogas technology is constituted from different parts and components, and each of them will have a mechanical or electrical efficiency that will lower with the passage of time. Diagnosing and evaluating the efficiency of each part will give information about whether the efficiency is within acceptable limits. This process of knowing or estimating the likelihood of occurrence of a specific vulnerability in exploiting the biogas technology (e.g., failure of a component in a plant unit or failure of the biogas plant as a whole system), and the consequences of that vulnerability occurring. The effluent liquid is rich in crop nutrients and is used as an agricultural fertilizer. The solid fraction that accumulates after drying the digestate remaining from the solid/liquid separation can be used either as dairy bedding or to convert into potting soil mixes [12]. The revenues and costs of the selected technology combination will depend on the quality, the sales price and the quantity of the products, as well as of the financial support, incentives, and other payments. Market conditions and their future outlook are highly uncertain. Moreover, the quantity of the energy products and biofertilizers is strongly influenced by the composition of the initial waste, animal by-products, waste manure, and digestates.

2.3. Gasification

Biomass is widely considered as a potential fuel and renewable energy resource because it is abundant in nature and has less environmental impact. The energy conversion of biomass through the gasification route is receiving attention, as it can potentially use various types of biomass. Gasification is one of the thermochemical processes which can convert waste to valuable synthesis gas. It is the conversion of carbonaceous material such as coal, organic waste, and biomass into synthesis gas. Gasification occurs in an oxygen deficient condition at high temperature. The process of gasification does not burn the feed material directly as happens in combustion, but instead the material undergoes incomplete combustion in where the burning is controlled and less complete. The partial oxidation process of biomass occurs at approximately 800°C. The biomass is subjected to high temperature and pressure with an insufficient amount of oxygen. Due to the process, materials decompose and blocked volatiles and a little amount of tar-oil are normally produced. The flexible joint between the nozzle gas pipe and the distributor helps reduce the bending moment at the connection with the reactor. For this reason, it is very important to bring the distributor gas pipe as close as possible to the center of the bed without disturbing the rotating motion of the bed. A stable pressure profile within the gasifier was observed, indicating minimal bed material loss due to optimized operation. Different cases were considered such as a 1.5 cm diameter hole with 3.75 m above bed level, a 2.5 cm diameter hole with 3.75 m above bed level, and the proposed nozzle gas pipe. The gasification system operated at 94% carbon conversion efficiency and 59% cold gasification efficiency, with an average power output of 6 kW. Several feed materials were tested such as rice husk, corn cob, coconut shell, and assorted bio-wastes over a wide range of tars. To achieve higher carbon conversion efficiency, the primary gas heating value and ashes content of the large bio-wastes feed material must be improved. A durable nozzle design that requires minimal replacement was also developed and installed for industrial application. [13][14][15]

2.4. Pyrolysis

The purpose of the present study was to investigate the potential of pyrolysis as a conversion technology for the distributed treatment of waste streams. Pyrolysis was viewed as an alternative to incineration. Initial investigations focused on the syngas and char potential of waste by determination of yield distribution from pyrolysis [16]. Additionally, feedstock, char, and gas fractions were to be characterised. Two feedstock types were used in laboratory investigations: sludge from a municipal wastewater treatment plant (SS) suffering high disposal costs and composted organic fines from mixed municipal solid waste (MSW) (OF). SS samples were pre-dried and in the form of pellets. OF samples were supplied after air-drying. Yield profiles were obtained by pyrolysing 100 g of feedstock at various temperatures from 350 °C to 700 °C at 50 °C intervals. Char and gas yields were found to decrease with increasing pyrolysis temperature. 450 °C pyrolysis was used to investigate the potential of SS and OF on a laboratory scale. Gas characterisation was carried out using a gas chromatograph. Char residues were characterised by elemental analysis, surface area, and pH. Gas characterisation was focused on the analysis of TOC, S, and NH3 volatilised from gas and liquid fractions. Test conditions were varied to explore how sludge reduction (<41% total suspended solids) and presence of activated carbon in the feed differed. Experiments took the form of isothermal koji drying in a conventional rotary dryer at controlled levels of forced air movement including natural convection and conduction generated by adjustable layers of wheat husk placed in the tray dryer. Aerated piles were stacked indoors in a hot and humid climate after dampening with controlled intervals of manual watering. Bioaerosol sampling is typically considered in terms of airborne bacteria and fungal spores. Generally bioaerosol samples are collected using slit-to-agar samplers which can be worn by individuals or placed at fixed locations. Finally, processing involves incubation and colony counting as in the slit-to-agar sampler. The following is a description of each of these aspects.

The pyrolysis tube reactor consists of a cylinder of quartz whose exterior was evenly wrapped with heavily insulated heating tape. A model electrothermal power regulator supplied the heating tape with AC electricity. The temperature specified on the power regulator is the desired surface temperature of the heating tape. The total length of the reactor cylinder is 600 mm and that of the heated section is approximately 350 mm. Consequently, solid feedstock cannot be fully pyrolised in the length of the heated zone and is only partially decomposed from each batch. One end of the reactor tube was open and sealable with a removable rubber stopper. The other end of the cylinder tapered to a ground glass fitting to match a reducer fitting. A 90° bend then followed, leading to the condenser section whose outer jacket was cooled via circulation of a refrigerated liquid maintained at a temperature near 0°C. A twin-neck round-bottom flask was connected below the condenser to hold pyrolysis liquids as they were collected. Temperature was measured using a sheathed J-shaped K-type thermocouple inserted into the reactor and positioned just below the level of feedstock. The thermocouple was shielded from excessive exposure to highly abrasive solids by use of a regular silica tube through which it passed. Heating proceeded at a constant rate until the power regulator indicated the requisite temperature had been achieved. Upon initiation of pyrolysis experiments, this corresponded to a maximum of 40 minutes from room temperature. Batch periods were marked from this point and run for approximately 5 hours. Experimentation showed that a delay of approximately 1 hour was required to reach a reconstitutable state following commencement of heating. The related liability cost of wastewater treatment takes on an increasing importance, comparable to the waste management discussed above. Composted organic fines collected over the period of ca. 1 year with approximate 50:50 dry weight mixing and vibrated to allow transport by walking floor were obtained from a recycling facility. Composted organic fines are defined as the fraction ≤6 mm derived by trommel-screening putrescible material after residual plastic and glass removal. This product is representative of organic waste after being processed by mechanical biological treatment. The products of pyrolysis include liquids, char, and gas. Liquid by-products could also be viewed as contaminants and are of environmental concern due to high volumes produced and toxicity. Liquid yield was found to increase with increasing pyrolysis temperature, with values of 60.2 wt.% obtained from SS at 700 °C and 20 wt.% obtained from OF at 450 °C. Char and gas yields were determined as 18.6–61.5 wt.% and 14.8–19.2 wt.% respectively. Char yield was found to decrease with increasing pyrolysis temperature. Char and gas yields were also determined by Pyrolysis-GC analysis of OF. High HHV gases were produced from OF at 450 °C. Solid residues were formed at higher temperature with enrichments of C and H and depletions of O detected. [17][18][19]

3. Feedstock for Waste to Energy

Municipal solid waste is a significant environmental challenge, particularly in urban areas, due to the rapidly increasing population and consumption. This waste typically consists mainly of kitchen waste or food waste, as well as yard waste and sludge waste. Municipalities face a challenge in handling these wastes, and waste disposal sites are filling up, becoming scarce and leading to harmful environmental consequences. Moreover, due to its organic composition, municipal waste can be converted into energy and valuable products through thermal and catalytic co-pyrolysis to address the above challenges. Catalytic co-pyrolysis studies of kitchen waste and tire waste at different temperatures (450, 500, 600, and 700 °C) were conducted under N2 atmosphere using 3% wt. Cerium oxide catalyst. Thermogravimetric coupled with Fourier transform infrared studies were conducted to confirm co-pyrolyzed gases composition. Catalytic co-pyrolysis at 500 °C produced the highest calorific value (9228.21 J/g) among the studied samples. The co-pyrolysis of kitchen and tire waste under N2 atmosphere with 3% wt CeO2 catalyst at 500 °C produced biogas with a high calorific value, an interesting outcome for bio-oil production and a good amount of char, suitable for activated char [20].

Various types of cereal wastes such as biscuits, bread, bun, snacks, and unused peanut crisp have been investigated as a new feedstock of the pyrolysis process. A thermo-gravimetric method with non-isothermal operation has been carried out in a nitrogen atmosphere at different heating rates of 10, 20, and 30 °C min−1. Pyrolysis was conducted at various temperatures of 500, 600, 700, 800, and 900 °C using a low-cost pyrolysis unit. The highest yield and composition of producer gas were obtained for the pyrolysis process using waste cereals and peanut crisps at 800 °C. The yield of peanut crisp biochar was 22% and its actual heating value was 31.44 MJ/kg, which is suitable in the industry for activated carbon application.

The production of bio-based products can be enhanced by resource-efficient refinery technologies rather than by conventional raw material processing. Gasification is a promising technique, converting biomass into biofuels without generating waste. In this work, the air gasification of wood pellets, wood chips, and grass pellets was studied at temperatures of 650, 750, and 800 °C. The carbon conversion of wood chips and pellets was 75% and 70%, respectively, in comparison to 30% for grass pellets. Economic aspects can be an obstacle when considering technologies for the efficient conversion of plastics into bio-based products. Therefore, a challenge of sustainable technology development is to maintain the value cycle of such restoration by ensuring innovative technological solutions. The recycling of used mechanically recycled poly (ethylene terephthalate) obtained from natural mineral water bottles was studied. UV-laser irradiation has been employed to improve the adhesion between the biobased coating and the recycled residue. [21][14]

3.1. Municipal Solid Waste

The annual quantity of solid waste generated in India has increased from about 6 million tons in 1947 to 90 million tons by 2009. It is expected that by the year 2047 the annual quantity of waste generated will increase to about 300 million tons. In the municipal sector also the slum population in India is likely to increase manifold in the coming years. Presently, about 90 million tons of waste is collected from 300 towns of India, and about half of this collected waste goes to public and private lands. Land area for land filling of waste will not be available in India with increasing population and urbanization. The management of municipal solid waste is commonly reduced by incineration, with mass reduction (70–80%) and volume reduction (80–90%). Incineration involves the combustion of organic compounds and inorganic pollutants existing in waste by thermal energy. Most of the organic materials in waste decompose at relatively low temperatures by evaporation of water. Generally, it is understood that organic polymers decompose in the temperature range of 250–450°C [20]. Under the current practice, the treatment of the municipal solid waste includes dumping on landfills, incineration and waste-to-energy treatments such as a biological process, a chemical process, and a thermochemical process. The burning of plastics in the form of shredded items, compared to other forms, is worth noticing. As fluidization provides uniform heating and mixing, it is more effective for handling shredded plastics. The fluidized bed is considered the most suitable incinerator for a particular type of feed. It offers good heat transfer coefficients in circulation, freedom from particle attrition and even feeding of the solids ensures a very uniform temperature around the fluidized bed. The use of the fluidized bed method does not produce dioxins and furans. The waste plastics are fed along with biomass in the fluidized bed to produce gas fuel [22]. The melting process is completed for ash with higher natural temperature. Plastic processing by incineration and gasification showed a dioxin formation value to be 10−18. Owing to the use of limestone, the SO2 in the gas phase can be removed from 95% before it leaves the system. SO2 is converted to CaSO3/4, The metals would remain in the ash effluent, among them, the levels of Pb, Zn, Co, Cr, Mn, and Cd are imperceptible. Fixed and non cellular carbon particles are blown out after complete combustion.

3.2. Industrial Waste

Solid, liquid, and gas waste are discarded by highly industrialized societies, with a certain increase of each type over years. Among the three types, solid waste is the most difficult to treat. Several waste-to-energy conversion techniques are available for solid waste treatment, including pyrolysis, gasification, incineration, and biological conversion. Incineration technology is the most widely used form of solid waste and biomass treatment technology to produce energy. This technology burns organic compounds, which are composed of carbon, hydrogen, and oxygen, and converts their chemical energy into heat energy at high temperatures without oxygen. The heat energy can be used to produce steam and electricity. Another part of the energy is emitted to the atmosphere as gas waste after purification.

Industrial solid wastes get attention all over the world because the amount increases every year along with an increase in industrialization. Indian industries generate a significant amount of hazardous residual waste, which is treated through incineration. Among various technologies, incineration is more popular because it treats a huge amount of hazardous waste and produces heat energy as a byproduct. On the other hand, the heat demand of various industries is about 40% of the total energy demand of India. The present study aims to incinerate hazardous residual waste, produce heat energy as a by-product, and use this heat energy to produce methane gas using the system to meet the heat requirement of industry. The generated in daily life and constructions comes under a mixed type of waste, and sorting is very difficult, so this technology can be used for reducing the volume and hazardous content of waste, treating the waste in an environmental-friendly way, and producing fluff as a by-product. The produced fluff is highly combustible and contains high-energy content waste, which can be used as an alternative fuel in various industries collectively referred to as refuse-derived fuel. [23][24]

3.3. Agricultural Residues

Use of agricultural residues as an energy resource is an important part of a country's economic growth. Thermochemical conversion techniques such as combustion, pyrolysis, and gasification have been introduced, using efficient devices for energy recovery. As an alternative to terrestrial biomass, marine biomass such as macroalgae, which is not a food resource, can have the advantage that there are no food supply issues. In industrialized countries, macroalgae production has increased annually as a waste problem. Macroalgae is rich in polysaccharides, which is why further treatment is difficult, therefore easily becoming organic waste. The waste macroalgae has high water content and is bulky to transport and store; but drying the wet macroalgae is energy-intensive. In the present, marine macroalgae is generally treated by bioconversion, such as anaerobic digestion, producing biogas. Technologies using thermochemical conversion have been developed for terrestrial biomass, but are rare for marine biomass. So far, supercritical water gasification has been proposed as a wet biomass treatment, but it requires complicated devices; it is not energy efficient in comparison to other thermochemical devices. With dried waste macroalgae as a feedstock, gasification can proceed efficiently; therefore, the use of waste macroalgae biofuel is promising.

The gasification of dried waste macroalgae using air gasifying agent was performed in the fixed bed gasifier. Tar, as an impurity in the produced gas, can be removed by water washing, with the gas. The gasification experiments of biomass were performed under various conditions in a bubbling fluidized bed. Gas circulation is proposed to be effective for thoroughly drying the feedstock and to activate the drying process of the feedstock on the hot bed materials. Using the sequences of gas circulation, a shorter time is required for drying of the feedstock and for the gasification reactions to reach steady conditions.

3.4. Sewage Sludge

Sewage sludge (SS), components including soapes, fibers, cells and macro- or micro-organisme, is the main waste in the municipal WasteWater Treatment Plant (WWTP). Many countries have produced SS extensive, but only a small part of it is applicated in the developed countries. Among various SS disposal methods, incineration is more commonly used. Firstly, its energy can be recovered by combustion process. Secondly, SS with a great reduction percentage can be obtained after incineration. Thirdly, the heavy metals and pollutants in the SS can also be reduced by incineration. All of these advantages make SS is one of the best wastes for incineration recovery. However, incineration will produce a series of problems, such as WasteGas, waste residue, chloride erosion and fly ashes. Therefore, many optimization schemes have been proposed and tested in the process of incineration, such as microwave treatment of sewage sludge incineration. Beside, SS is an unlimited resource in nature, and has not been well reused in economic development. So, the study of pyrolysis technology of SS may have a huge recovery value in the future. Pyrolysis is one of the thermochemical technologies consisting in letting the material decompose under inert atmosphere and at high temperature (350–900 °C). The energy content of the material is kept in the product. Therefore, pyrolysis is being evaluated in many countries as an alternative strategy for waste management with a long-term view of energy recovery.

Sewage sludge (SS) is the waste from WasteWater Treatment Plants (WWTP) mainly composed water and organic compounds with variable distribution depending on the origin. For each WWTP the amount of SS are different depending on the size of the city, the technology of the plant and the effectiveness of the WasteWater treatment. Some ways to manage SS are : landfills, agricultural application, dry and incineration ways. But these options can be decreased due to land and increasing energy demand. The agitation and heating of water and SS contaminated results in hydrothermal processing or thermal hydrolysis. It uses high temperature, high pressures and high water during a defined retention time to achieve the purpose of destroy microbiological cell and a better soluble organic compounds. The main benefits of THP (Thermal Hydrolysis process) to the anaerobic digestion (AD) increase the quantity of biogas (energy recover), improve the stabilization of the sewage, and decrease the case to dewater waste activated sludge process. The Thermal Hydrolysis process (200 °C, 30–60 min and 12 bar) is used commercially in WWTP to the activated sludge before the digesters [25].

4. Environmental Impact

The environmental sustainability of a waste-to-energy (WtE) process is mainly associated with the conversion technology, energy efficiency of energy recovery, emission control, and the end-of-life management of solid and liquid residues. Modern WtE systems typically deliver electricity for public supply. In combustion-based WtE systems, electricity is produced by a steam cycle, organic Rankine cycle or gasification process coupled to internal combustion engines or gas turbines. In the conventional steam cycle, thermal energy in flue gases is not sufficient for superheated steam production, so further energy recovery by bottoming cycles, such as ORC technology, lead to higher electricity generation.

Waste-to-energy (WtE) technologies seek to convert non-recycled municipal solid waste (MSW) into electricity to reduce waste disposal, while producing renewable electricity for public supply. The environmental implications associated with MSW management are investigated. Life cycle assessment is conducted for direct incineration, pyrolysis and gasification conversion pathways. Other stages in the MSW management chain are considered, including waste segregation, transportation, shredded, and residue landfill. Seven impact categories are considered, including routing to the water. It is found that the energy recovery is the dominant contributor to environmental burdens, leading an overall saving of about 97%, when electricity for public supply replaces the non-renewable electricity mix.

However, the environmental impacts of direct incineration are still of concern. Compared to direct incineration, the pyrolysis and gasification are effective to lessen the environmental impacts of terrestrial eutrophication, photochemical ozone formation, human toxicity, and ecotoxicity; however, they significantly increase the burdens of global warming and human toxicity. For a direct comparison of different WtE processes, gasification systems lead to a lower impact than pyrolysis systems. At the same capacities, moving grate combustion systems are inferior to fluidized and fixed bed combustion systems. Gas turbine/CC has outperformed steam turbine and internal combustion engine and becomes the most preferred energy utilization approach. The direct comparison between the pyrolysis and gasification processes, and various downstream energy recovery options is conducted. The overall impact is divided into four stage-wise contributors: net energy input, direct emissions, ash management, and energy recovery. This study revealed that when the organics are recovered, gasification equipped with fixed bed is the only incineration route with beneficial watershed impacts, showing a 1 to 47% reduction in relation to direct incineration. For these cases, final electricity and grid heat can be provided by WtE facilities per tonne of MSW.

4.1. Emissions and Air Quality

From 1996 to 2006, China produced 45.4 Mt of paper and consumed 6.84 PJ of energy in the paper manufacturing industry. Different than in some other countries, coal is the main energy source for Chinese paper mills instead of natural gas. As the thermal efficiency of small and medium sized coal-fired boilers is generally lower, traditional coal consumption accounts for a large proportion of the total production cost of the paper mills. As a result, combined heat and power (CHP) systems, which utilize coal to generate power and heat with a higher thermodynamic cycle efficiency, have been widely installed in the pulp and paper industry of many Asian countries except for China and Japan. Two of the largest mid-sized paper mills were studied in detail, focusing on identifying opportunities for energy efficiency improvement in an actual Chinese paper web. The analysis revealed that improved energy efficiency can be achieved with large potential and with several of the identified measures having a payback time of less than 3 years. On the overall plant level, it is found that the current specific chilled water consumption rate for air conditioning can be reduced by 29.74% with an internal rate of return of 545% [26]. For the paper machine, it is found that the specific steam consumption rate and the specific electricity consumption rate can be reduced by 17.87% and 35.46% respectively with a payback time of 0 month. In addition, five CHP technologies are evaluated from the aspects of energy performance and economic analysis, using biomass and coal as fuels. A framework is developed to facilitate the decision-making process in selecting the CHP technology for Chinese paper mills. After coal consumption, China imported 50.1 and 58.5 million tons of wood chips annually from 2008 to 2010. 180 paper mills in close proximity to Chinese ports were identified. A comprehensive overview of CHP systems with and without CHP-ORC technologies for large-scale pulp and paper mills is made. Real paper web production parameters from the two paper mills with the largest web widths in China are used to perform a levelized based modeling study to determine the potential of each CHP configuration. It is found that integrating the CHP systems with an ORC for power production is ineffective for eco-friendly pulp and paper mills. On the other hand, by considering the total useful and consumable energy cost savings, in addition to the operational costs related to the total patterns, the implementation of a topping CHP-ORC power cycle attached to a CHP system allows power and thermal energy savings of 47.3% and 22.1% to be incurred, respectively, with a payback time for the incremental investment of approximately 4.5 years. Various emission reduction measures are ranked from the aspect of production cost efficiency using the traditional Pollution Abatement Cost Curve. A new Analytic Cost Model is presented to estimate the corresponding production costs for technology based methods. This production cost is then divided by the physical output to determine the cost efficiency of the technology. The analytic results show that, given two production points, the corresponding abatement technologies will minimize the cost of reducing waste gas emissions. Overall, in the pulp and paper industry, methods that are less engineering intensive are most cost efficient.

4.2. Impact on Landfill Reduction

Recently, solid waste conversion technologies have intensified, striving to obtain energy with reduced environmental impacts. Industries are progressively engaging in the treatment of municipal solid waste, generating energy by using it as an energy source and reducing landfilling. The proposed facility complies with environmental licensing, coexisting facilities, emissions, and noise and odor levels [26]. It also contains its closure plan, with the estimation of post-closure utilization for 25 years. Modeling scenarios portray that the generated energy would render feasible the proposed energy-intensive installations, increasing the global efficiency of the cogenerative process and producing an additional income of up to 500 k€ per annum. The Government assigns important state funds to promote renewable energy production, and cogeneration is supported as priority. This study is performed in the context of a remodeled solid waste treatment 3+ MWe facility and the simultaneous re-launch encouragement scheme considering the determinants and the overall policy assessment. Modeling scenarios of increasing complexity are developed to study the impact of the facility under different perspectives. Moreover, long-term planning optimization is performed with the aid of the energy planning PLEXOS system, utilizing a significant spatial resolution coordination. It is demonstrated that the construction and operation of the facility could have significant positive effects on the social welfare gains, simulating positive health effects from reduced air pollution, global energy efficiencies and avoided effects related to climate change and energy imports. The results endorse the potential of the facility type and size for wider exploitation in big cities that valorize municipal solid waste.

4.3. Resource Recovery

In 2014 South Africa had a population of 54,000,000, rising at 1.2% per annum. It was previously 53,000,000 in 2012 with all these growth rates projected to 2030. This country has 2,900,000 km2 of land surface, of which 1,200,000 km2 is arid and of poor quality. Agricultural crops are generally rainfed and mostly consume water quality that conflicts with municipal and industrial demands. In 2012 there were 23.5 million people living in formal urban dwellings and 35.3 million with access to electricity, of which 30.0 million used it for lighting. Most municipalities and industries release untreated wastewaters. The Durban Green Corridor (DGC) on the other hand does great work to protect the environment.

There are a range of technologies that are used in practice or under development via films, papers, talks and posters. All of these convert a stream of inputs, I, into outputs, O, and include intermediations to go between I and O. It is also possible to define a technology where the inputs are not defined and which considers only the intermediate and output flows. This provides broad scope to describe energy recovery technologies. The categories are given here with a description of the applicable technologies. It is possible to define a technology where the inputs are not defined and which considers only the intermediate and output flows [27]. Different categories are given here with a description of the applicable technologies, where it is seen S waste water flows is best described by Waste to Energy Conversion.

5. Economic Aspects

Population increase and industrial expansion lead to raise a variety of urban problems. One of the significant problems that need immediate focus is solid waste in the urban areas. Waste is a major environmental problem in all countries. Inefficient management of waste causes many environmental problems. The production of waste increases by 2% each year along with the world population growth. In previous years, the waste production increase varies from place to place depending on socio-economic condition. The present initial production of municipal solid waste can be estimated at 400 g per person per day. It means the present population of 82 million in Vietnam generates just over 175 t/d of solid waste. The waste rate of Vietnam is found to be about 0.65 kg per capita per day and thus it annually generates about 13 million tonnes of solid waste. Moreover, the economic growth is directly proportional to waste production. For example, in India the municipal solid waste rate is about (0.2 - 0.6 kg/day/capita). So that the production is nearly 40% of bio-degradable waste. Better environment and technology offer public service health and welfare in the community area. Broad of urban service improvements in individual consumption and increased individual welfare. The society consumes more in transportation, parks, entertainment and housing [20]. More attention has been paid on the health lungfulness in urban area living conditions in which the rural people migrate to urban area and in the rural area urban people move into the rural area. Apart from the better service to the population provision of urban life provides people to lead a specific role for economic and social urban centric and indicate the growth of the population. Economic effects towards the invest the mechanism, function, size and age of the city in which rose consumption and waste production exhibited the average cost per unit of the sanding of urban population. Functional effect indicate the specialization of the city selectivity of the mechanism, technical change and density effect. It is the change in the consumption pattern of the personal service public service, vehicles etc. The size of the effect can be interpreted by the standard fiber diagram. Regarding the age effect it may be described by shift of the market demand curve over the time, deterioration demands at the earlier and later stage of the adult life. Shifts in the market may change the elasticity market curve.

5.1. Cost-Benefit Analysis

Growing attention has been placed on the potential of waste pyrolysis and gasification as the route to waste-to-energy (WtE) technology in order to augment energy recovery and conserve fossil resources in a sustainable manner. However, the environmental consequences have been scarcely addressed, let alone the potential benefits. In light of this, the environmental impacts and potential benefits of WtE technologies are investigated via life cycle assessment, using incineration as a reference.

Table 3 shows an up to ±665% variation in the environmental impacts, of which non-toxic impacts appear of remarkable relevance. It is discovered that the variation is primarily related to the amount of energy recovered, as it could replace the associated emissions from the burning of fossil fuels. These results confirm a crucial role of the energy recovery efficiency in determining the total sustainability of a WtE plant, from both environmental and economic perspectives. Table 4 shows that the benefit is dominantly attributed to the reduced airborne emissions from char combustion, together with a small portion of avoided emissions from fertilizer substitution and carbon sequestration. However, a non-negligible increase of the HTs and ETs loadings is observed due to the increased heavy metals to soil, which should be controlled effectively apart from the associated potential benefits of land application.

The theoretical analysis shows that using pyrolysis/gasification to supply a gas turbine or combined cycle may achieve higher energy efficiencies and lower emissions than the current incineration, owing to a more intensive and higher temperature provision of energy carriers. In recent years, the development of the pyrolysis/gasification-based WtE technologies has become a focus of attention, stimulated by the search for more efficient energy recovery and environmentally sustainable waste management. By connecting the pyrolysis or gasification unit/s with a gas turbine or a combined cycle, as an alternative to the conventional steam cycle, it is expected that energy efficiencies higher than current values are possible [7].

5.2. Funding and Investment

The capital expenses are the largest constituent cost item accounting for 58.5% of the total costs. The operating expenses and variable costs are closely related and account for 25.6–27.8% of the total costs, depending on the plant type and the parameters' values used in the cost model. The cost items associated with the environmental constraints account for rather low percentages of the total costs, at 6.8% and 1.1%, respectively. However, the younger incineration plant constructed recently is more environmentally attractive than the older one, i.e. the difference in plant costs between the most and the least environmentally friendly incineration plant is almost 10%. This economic gap may be considered as a financial advantage for pyrolysis and gasification technologies and it may stimulate their further developments in the proposed industrial application. On the other hand, in the young incineration plant it is rather difficult to distinguish the cost structure between the items linked with air pollution control and the others. Thus, the financial incentives to permit more accurate cost analysis and development of representative cost functions for the future are not equally distributed among all technologies. This conclusion also indirectly confirms the requirements not to apply the subsidies for the waste-to-energy plants.

5.3. Job Creation and Economic Growth

Energy consumption, electricity purchase, production and residual waste disposal costs, sale of bricks, bottom ashes and ferrous metals costs and creation of 1.09 job per 1,000 t/year treatment capacity are the main monetary valuations. It is very cheap from the produced WtE plants unit energy regarding gathered values from invoices. The waste treatment costs are high for all contracted WtE plants. Even the MSW ceding to the WtE plants be paid and the high sale of the produced electricity by the operator, the side shows average service costs of R$ 220 million annually. However, in some specific years the costs to treat all the supplied MSW tend to exceed R$ 300 million for a year. The job creation assessment is based on counts of the number of indirect jobs originated from inputs and services demanded by the sector.

6. Regulatory Framework

Prior to 2013, waste to energy leaked by compost and landfill gas projects activated the investment by the price adder. This price was combined with excess power purchaser under a power purchase agreements (PPA) with Provincial Electricity Authority or Metropolitan Electricity Authority. This adder price was given to these projects for 7 years. A project wishing to participate in the conversion to the feed-in tariffs system must lodge an application requesting the Energy Regulatory Commission (ERC) and apply for a new power purchase agreements (PPA) within 31 March 2015. The projects must also be operated with an installed capacity not exceeding 10 megawatts (MW) and not exceed the installed capacity associated with the electricity selling from the renewable power plants. A single fixed feed-in tariff may provide greater financial returns than the price payable under an adder rate [28]. In the consequence, all adder rates would therefore disappear from Thailand from 2020.

This system would maintain for the entire subsidised period. The subsidiary period for landfill gas projects is 10 years after the operation of a facility. The Ministry of Energy and ERC may extend this period but only if the agreements with the government of Japan securing the greenhouse gas emission reduction effect are met. The projects in this sector must also comply with the Landfill Gas Emissions Standard of 20 mg/ in accordance with the Prime Minister’s Office Announcement. For the activation of biogas projects, the biofuel standard must be applied. The adder price is also offered for 10 years after the operations in the case of biogas projects. Detailed legal framework need for the operation of this feed-in system will be specified in the notification of ERC. The projects in landfill gas and in biogas projects have legible potential to register as a CDM project activity. The registered projects can claim for selling of the annual CER, which helps the private sectors more profitable and receiving higher return of the investments. This kind of the applied policy has proven from the experience in Thailand, where currently 5 landfill gas projects were registered as a CDM project activity. The new scheme of subsidiary in terms of feed-in tariffs in purchasing electricity form the renewable energy will enhance the private sectors in long term investment feasibility in waste to electricity project sectors.

6.1. International Regulations

This sub-section reports the international regulations which may potentially influence the acceptance and the general development of a new type of Waste-to-Energy conversion technology. Internationally, the sharpest regulations for waste disposal come from the European Community, since the waste and other environmental impositions may come to a financially severe bill. On the other hand, Waste-to-Energy is an energy conversion method that fulfils two needs at once. It helps to get rid of waste and it makes the need of buying oil or coal dirtier. This is exactly what the industry of Western Europe, in particular of Germany, has been doing for the last two decades with great success [7]. Although Germany steps out from the Waste-to-Energy in places it pollutes the most, it is environmentally friendly enough to import a lot of waste for more processing. There naturally is the danger for competition from similar industry, since patents and teamwork don’t reach borders. On the other hand, since business arrangements may be attending meetings are proposed, ensuring the competitive advantage of the licensees also in the international scale. According to the experiences or suppositions presented in the following paragraphs several alternative procedures are plausible.

Waste-to-Energy is a branch of energy conversion, therefore wholesale and resale licenses or combination of the two may be imagined rather determined for a great many fields and countries. Predetermination starts from the fact that electricity is still difficult to transport, so the disposal of the energy potential in big gas- or coal-powered stations are recommendable if the leaf instead of the earth is chosen again. The aforementioned technology applied in western industrial countries of Europe is using it since 40 years. The Waste-to-Energy conversion technologies currently not yet applied industrial scale in Europe however, are rather intricate first touch comedy besides flammable semisolid products, dominating practical aspects in licensing. Intended licensees are experts in that complicatedness, therefore handling the conventional mass and energy exchange technologies when designed to biological or chemical waste conversion is preferred. There are scenarios of prior art bio- and chemical alternatives which are of no infringement concern for Waste-to-Energy, but they are of a preliminary use and help. The renewable energy sources are nationally sponsored in a number of countries.

6.2. National Policies

Special attention is given to biogasification objectives of selected national energy policies. Thousands of tons of municipal solid and liquid wastes are produced daily. Only a very small fraction of the waste material generated in urban areas is treated by recycling. Waste-to-energy (WTE) conversion technologies contribute greatly to ensure environmental compliance and sustainability in urban areas [29]. National energy policies of separate countries provide strategic vision and outline targets for implementing energy technologies. Energy policies may contain objectives on renewable energy sources (RES) such as waste, biomass, biogas, wind, and solar. Biogasification is the thermo-chemical conversion of organic materials under high temperature in the absence of oxygen. Synthesis gas is obtained as an energy product. A valuable gas mixture is similar to natural gas which can be easily combusted to produce heat and power. Biogasification releases energy in the form of solid by-products such as pyrolysis or carbonization. Biochar material is collected and industrialized due to its advantageous properties. Biochar is also considered as a soil amendment because of its porosity, low density, and surface area. Recycling of biochar back into the terrestrial system contributes to the collection of atmospheric CO2 and nutrient cycling. More than 1602 national energy policies are investigated through full-text search at the database of energy policy journal. Bio-residue and waste are scarce keywords and only one of the 1602 national energy policies includes the CSI keyword of bio-residue. Biogasification objectives of selected national energy policies are extracted in the form of a comprehensive table.

6.3. Local Guidelines

In order to promote the actions related with production of energy from urban waste, several

OECD Countries has adopted resolutions using special incentives. Some of them establish that, in the case of similar situations of technical and economic feasibility, the mechanisms of obtaining electric energy from urban waste shall receive priorities with respect to the conventional options; the Brazilian Resolution 005/92, for example. The investments in the case of concessions and permissions will not be considered global values for the Company, for the distribution of the results and division of tasks, at the opportunity of the yearly revision of the rates. Another points that should receive special attention in the case of municipal solid residues refers to adequate treatment and destination of reject residuals; the control of contamination of the atmosphere by the emissions of the loirs, flock-gas or soot, essentially constituted by noxious products such as carbon monoxide, heavy metals and organic compounds; and the control of gaseous emissions store exits by governmental establishments of the federal, state of municipal spheres, in conformity with the legislation of every sphere. It is reminded that the development process of installation and management of plants, also, the SW's incinerations to the least cultivating accepted, as well as the development of any activities like composting, pyrolysis, industrializing and any other time of thermal treatment of SW, must be subjects of hearings of the zone of installation by the entities with activities regarding protection and capable jurisdiction as was specified before. These hearings should also be made for any occasion of extension, leveraging, or modification of these plants or altered future workings. In order to apply the Commission Guidance on Community waste management. This mission guidance will help plant operators and competent regimes, review of the plant operators [7]. This guidance will consider the management of the main environmental aspects that waste-to-energy plants may have, and that should be considered in the permit granting process.

7. Case Studies

Waste-to-energy conversion technology consists of waste gasification, recovery of exergy from waste, and dust removal. These technologies have been developed economically on the threshold between waste management and energy. Exergy recovery is an indispensable step in various types of waste treatment technologies, for example, incineration, gasification, pyrolysis, wet oxidation, dry supercritical oxidation, and hydrothermal oxidation. Every conversion technology, especially waste gasification, releases a flammable waste gas with a large combustive exergy. Most waste gasification and waste pyrolysis include a waste drying process. The evaporation heat in the waste drying process can be regarded as the exergy contained in a humid waste. Therefore, the distribution and exergy in waste are keys to understanding, designing, and evaluating waste-to-energy conversion technology. The energy form of waste includes the energy of vibration, rotation, and translation of chemicals, the energy of matter that is easy to dissipate in the environment, and the energy of matter that is difficult to dissipate in the environment. [30][31][4]

7.1. Successful Implementations

WtE technologies can be divided into process categories including incineration, pyrolysis, gasification, and the intermediary strategies between these. There is no standard definition of the intermediate strategies, but usually they mean the basic concept of a two-stage processes, such as pyrolysis followed by combustion. There is a general expectation that WtE processes like pyrolysis or gasification might be more sustainable and environmentally friendly than simple incineration. Generally, they offer a higher liquid and gaseous fuel yield, of which part can replace fossil fuel combustion. Moreover, the remaining solid residue is usually char, which can be effectively mitigated in agriculture or as construction material, especially after some post-treatment. Disregarding the basic economic feasibility, a central issue seems to be the environmental performance of the waste-to-energy process. However, much published generalized claims are based on pilot plants, whilst the ability of commercial scaled technologies to treat the same waste streams is questionable [7]. Here presented case study tackles the discrepancy between pilot scale experiments and large station implementations. The aim is to find out if and under which scenario conditions smaller pilot scale plant results can be successfully transferred into large industrial scale implementations. Six economic and seven environmental indicators are used to perform an IEA of five plants in five advantageously selected locations in USA. Industry similar station has been identified based on their waste composition, legislation, and plant capacity to ensure comparability. The analysis employs site-specific data and verified tools and methods.

7.2. Lessons Learned

Besides the expected results, this study has also produced, gathered or been indirectly exposed to a number of positive and neutral side effects from the concessions made by other people / organizations connected to this project. Furthermore, during the entire lifecycle of the grant two losses occurred, one of which is well known by the Principal Investigator and, therefore, by the consortium, the more interest-based one - a big one occurred last January 1st. Given the amount of things one has been learning along this TRL5 adventure, this communique has been prepared to register some specific points to perhaps help others to avoid them.

One crucial point is the request for feedbacks about the detailed requirements for the upcoming TRL6 tests & activities. On the IMM we saw an astonishing series of technical troubles, when one single document or presentation could solve a number of issues... Unless one is a specialist in testing of devolatilization of compounds, of course. Several suggestions about simplification of the contract amendment process have also been ignored, to the point of raising absurd requests for information available in other open documents. For future development, particular care (and time) should be dedicated to create a common ground for discussion, focusing on the critical issues. [32][33]

7.3. Comparative Analysis of Technologies

The performance of modern waste-to-energy (WtE) technologies was theoretically compared on the basis of a closed-loop “from collection to utilization” approach. Results showed a variation in the predicted environmental impacts of commercial plants currently operating up to ±665%, given the toxic impacts of dioxin, furan, and toluene, and the non-toxic impacts of mercury and CO_2. In light of such results, WtE plants that use pyrolysis/bituminous coal to feed a gas turbine and a combined cycle achieved the highest levels of energy efficiency and the lowest levels of toxic emission. Snowballing concern about environmental, human health, and land constraints has placed an urgent need on policy makers to develop greener and more sustainable waste management strategies for municipal, industrial, and hazardous waste. In European countries, the disposal of waste in landfills is both economically penalized and discouraged by several regulations. Meanwhile, Eastern European countries have been increasingly adopting landfilling as a dominant method of waste disposal, thereby reducing the share of the recycled and incinerated waste. In the Czech Republic, for example, 58% of the municipal solid waste produced was landfilled in 2005, 38% was incinerated, and 4% was recycled and composted. Efforts have been made to improve recycling, and to treat biodegradable and hazardous waste before landfilling. But in the foreseeable future, it is likely that other disposal methods will be required to close landfills. So the Czech government has committed to the EU landfill ban by 2024 starting from 2004 levels. Meanwhile, the Czech Republic has joined the European Union and its existing incineration policy cannot deal with current commitments. Development in the thermal treatment of waste has therefore become a strategic focus, stimulating an increase in the number of waste incineration plants. At present, only large companies are waisting.

8. Challenges and Barriers

Waste management has become a critical issue in almost all developed countries. Nowadays, as a variety of methods are available, the energy and environmental costs of processing these wastes need to be addressed, and methods sustainable for both environment and economy have been sought. Waste-to-energy (WtE) deals with the large-scale conversion of waste into a useful energy form via thermal and/or non-thermal processes. Conventional WtE systems include incineration, pyrolysis, and gasification. Pyrolysis is an important technology for the utilization of waste as a renewable energy source. Pyrolyzing waste may produce three commercial products: char, gas/liquid fuels, and bio-oil. All of them are able to serve as energy carriers, while gas and bio-oil can also be used in various chemical applications. Gasification is another crucial WtE technology. Both pyrolyzed and gasified waste generate medium heating value gas fractions, designated in a generic way as syngas. This gas can be combusted to produce energy directly, but after cleaning and enrichment it can be further used as a H2 carrier in fuel cells or after further processing it can be linked to any gas engine used in co-generation plants. For this reason, gasification is often linked to large-scale WtE in a niche of renewable energy production. While these gas fractions can be ensured also by the selective collection and treatment of appropriate waste fractions, the most promising application concerns energy conversion. Theoretical and applied research have shown that products derived from pyrolysis and gasification bio-wastes are sustainable and economically convenient. However, there is still a problematic area of energy balance and the need for further development, as well as a need for techniques to eliminate the toxic effects of gas. The issue of this paper is an overview of the existing challenges and barriers facing the development of modern pyrolysis and solid waste gasification technology and the outlook for the future. The state-of-play of pyrolyzing and gasifying wastes is illustrated based on the example of the technologies developed to large scale. It is already shown that looseness exists in developing both of these methods and can become of higher efficiency and can complete the new trend in energy production from waste, not only in specific applications but globally. There are a number of WtE technologies available. They can be conventional, emerging, pyrolysis is conversion in the absence of air and oxygen, and gasification is partial oxidation in a low-level O2 environment, typically with air intrusion; there is a shift from pyrolysis to gasification with gradual air/oxygen intrusion. An extensive literature analysis did not indicate a comprehensive and analogous comparison of pyrolysis and gasification technologies for the conversion of solid waste. There are considered many aspects of theoretical and experimentally discovered pyrolysis and gasification in several recent works. Industrial competition and commercial development of gasification can be commenced from analysis of such technologies for a sector as complex and intricate as WtE, using too general approach and LCA principles. Given the shifting industry trend in interest to gasification, this paper focuses on technological quantitative data only. Note there are no existing experimental data of this type for low-capacity industrial plants. [34][35][36]

8.1. Public Perception

Despite the high investment costs associated with production of CO₂-free energy, Waste to Energy (WtE) is not yet considered as an efficient choice by the public on a global scale, in terms of acceptable sustainability and compatibility with the needs of future generations. Although humanity is now facing an exponential increase in the amount of industrial, domestic and agricultural waste generated, and also the price of fossil fuels is increasing day by day, and the negative community perception, and the levels of support for siting of new facilities employing waste processing technology are consistently found to be low in all jurisdictions. However, in contrast to the UK, publicised concerns over climate change rather than conventional pollution issues drive concern and have become a key factor in objections being lodged to proposals for new plants. Indeed, governmental and residents' negative concerns on such waste-to-energy plants are mainly concentrated on the dioxins and heavy mercury contents in the flue gas waste, which might pollute the environment and be dangerous for human health in the long term. From the overall perspective, the public perceptions and governmental considerations play a significant role in the development of the WtE facilities.

Landfilling still represents a common option for waste management. WtE facilities can handle the non-preventable and non-recyclable fraction of generated waste from municipal, industrial and hazardous sources, which leads to a significant reduction of its volume, odors and microorganisms. Moreover waste type and characteristics should be adapted to any WtE process to improve the energy recovery efficiency, reduce the ash formation and control the gaseous emissions and leachates as non-toxic impacts appear of remarkable relevance, and the increased associated transport should be also considered. Furthermore, the changes on their associated emissions might have large discrepancies depending on the particular treatment applied. As a second best option, land application that allows the recycling of the ash as accumulative liner in dumps or as cement additive would meet the objectives of recycling, but can raise some concerns. Overall the public opinion on waste treatment technologies also influences the decision on recycling waste ashes and could be mitigated by an environmental assessment program conducted throughout the process.

8.2. Technological Limitations

The preferential ranking favors pyrolysis TPP@GCT@CC PPU@GCT@CC GPP@CC, when char is used as soil amendment either KP or ST, PCB many management strategies make little difference, and TS larger particle size includes the enhanced landfill. On the other hand, this advantage of landfill for HP disappears when other pollutants (HCB and HPA) with different characteristics are considered. The sensitivity analysis result highlights the complex trade-offs between the potential benefits, risks, and energy recovery of the gaseous products generated by the different WtE advanced thermal-treatment plants [7]. This work focuses mainly on the comparative analysis between three types of WtE gasification process (fixed bed, fluidized bed, and rotary kiln). In addition, two different syngas purification processes are considered (cold physical cleaning and chemical cleaning), as well as two possibilities of energy recovery (gas engine combined heat and power and gas engine power production only). Landfilling appears to be the best solution for some types of polymers (LDPE, PS). However, these systems find application at very low power range. There are no large-size steam boiler/steam turbine syngas cleaning and energy recovery systems. According to the knowledge and the consulted scientific literature, at the moment, the best technology for harvesting the energy from UCG process is syngas cooling and cleaning, followed by feeding of cleaned syngas into the gas turbine combined cycle. [37][38][39]

8.3. Economic Constraints

Energy produced in waste-to-energy (WtE) plants can replace the fossil-based energy production and therefore associated emissions. The effect of pyrolysis WtE technology was systemically evaluated by considering an emerging low temperature pyrolysis for significant increase of volatile matter yields at the expense of lower quality syngas. The LCA results showed that pyrolysis could only mitigate global warming when ca. 80% of the waste input undergoes pyrolysis and recover at least 90% of energy from volatiles with respect to the feed, both of which are distant from current or foreseeable WtE practices. It is also recommendable to directly utilise syngas in a gas turbine for power generation [7]. A theoretical analysis and a case study of a commercial WtE system show more stringent economic constraints for low temperature pyrolysis-based WtE systems and similar sensitivities to waste composition between pyrolysis and incineration. Into a hot gas cleaning device, a boiler, or a gas turbine that has to be further adapted, with a significant economic burden; as it is the case for incineration, the remaining char bears a low calorific value and is expected to be used as refuse derived fuel, which can be only burnt after a pelletisation process. The application of the char could also move down the waste management hierarchy; modern incineration of well-sorted waste could have energy recovery efficiencies of 80% and higher, that is at least similar to the one predicted by the theoretical model for WtE systems consisting of drying, devolatilisation and gas turbine or, pyrolysis that supplies a gas turbine or a combined cycle boiler. Not considering the additional equipment costs, the potential energy production from the existing waste quantity should not compensate the current treatment costs for WtE plants. On the other hand, all considered technologies are promising routes for reducing the fossil fuels dependency of conventional power plants through the co-firing of treated MSW or SRF.

9. Future Trends in Waste to Energy

Given the current knowledge that applied waste composition is a key factor for the technological choice to be made, it was defined that three scenarios of feedstock composition may drive active systems development: plastic waste, food waste and a mix of both, including them with paper and cardboard. Tune into the communication to find out how earlier observations are reflected in the designed scenario-based exhibit.

In Europe, approximately 30% of post-consumer plastic waste, as well as a negligible amount of post-commercial plastic waste, is mechanically recycled. One way to increase these rates could be to prioritize investment in new, efficient mechanical recycling technologies. However, as long-lived or multi-material products still present in the regulated market phase out, and full effectiveness of the recently adopted design guidelines for its contribution to the circular economy is achieved, progressively less polymer types shall be directed to both household and commercial streams. Consequently, as they consider end-of-life management, packaging technology evolves towards a more mono-polymeric setup. Given their hydrophobic nature, separated plastic waste streams can also be accumulated, awaiting treatment or its transformation into marketable powders, fluff or pyrolysis feedstock. Therefore, it was assumed that an inexpensive alternative choice would be to burn post-consumer packaging, that may arise as losses or overflows from separate sorted waste biological treatment in a more centralized system scenario.

Food sharing initiatives, which represent over a third of post-consumer waste, may reduce the negative impacts from its management by limiting the waste rise, particularly of the organic fraction. Nevertheless, they are not highly effective in reducing the streams contaminant load due to non-resource waste disposable activities. Burning such mixed waste shall also be possible in the planned first generation of so-called shared waste bins, equipped with a smaller incineration reactor. This waste-to-energy (WtE) conversion technology is being developed by [7] and has not yet reached maturity in the majority of EU member states.

10. Conclusion

Waste is a by-product of human activities that indicates growing and diverse waste production. Rapid production and accumulation of waste in Indonesia has caused several problems, including environmental degradation, health disturbances, and ecological imbalance. A sustainable waste management framework is needed, including the 3R principle (reduce, reuse, and recycle), sustainable lifestyle, and technology-based waste management. However, the current waste management process has not minimized the waste problem, but in some cases has exacerbated it. Therefore, innovation is needed to utilize waste as an energy source. A promising technology is the conversion of waste to energy, which can be achieved through several technologies such as incineration, pyrolysis, gasification, and bio-digestion. This technology is waste processing, and transforming it into a more valuable energy form, which can be electricity, biofuel, diesel, or other needable energy. Furthermore, alternative mechanisms are being developed to boost Agro-Industrial production, as a vehicle to boost Kazakhstan's economic growth. The likely mechanism involves the successful incorporation of energy generation to Agro-Industrial Rack. This concept is sustained on the conceit of 'the internet of things'. Structurally designed energy-related innovations incorporated to strategic equipment will constitute a scheme capable of energy generation, energy supply, and equipment monitoring at adjustable levels.

It can be analyzed that designing a chain for energy supply to sensor reads, exhibits several promising potential collection points, enumerated: metalworking heat treating racks, scopolamine gas treating apparatuses, dairy pasteurization tundishes, medicinal water tank loading units, cloth drying racks, and metal bending furnaces (all projected fields must be equipped with one of the following types of mechanization: metal furnaces, gas treating units, oil immersion tanks, gas burners, electrical burners, combined fuel systems, air-blast ventilations, cyclone separators, installations for cooling in various mediums, switchboards, an electric cabling). Assumed improvements will primarily concern the replacement of existing stock with energy-efficient devices, the introduction of modifications to reduce energy losses, and a commercial-scale implementation of advanced control systems. An approach will be employed that combines a top-down analysis for the choice of a strategic segment with a bottom-up analysis for the actual engineering of the new energy-friendly devices. Estimations reveal the achievability, over time, of substantial savings in electricity and gas consumption, beyond 1.000 GJ/year.

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