SUPERIOR TECHNOLOGY SOLUTION

Incineration

- The Most common technology
- Applicable only for generating power and heat
- Significant air emissions
- Low energy conversion efficiency: **600 kWh/t**
- High capital cost

BRADAM

- ✓ Oxygen purged process
- ✓ More efficient cleaning system
- ✓ Produce clean syngas
- ✓ High energy conversion efficiency: **1540 kWh/t**

Gasification

- Requires preprocessing of waste feedstocks
- Partial incineration of waste
- Low quality syngas
- Generate noxious oxides
- Low energy conversion efficiency: **1000 kWh/t**

BRADAM

- ✓ No oxygen used in the process
- ✓ Minimal waste preparation for processing
- ✓ Ratio of H2/CO>2, suitable for liquid fuel production

Plasma Gasification

- Operates at very high process temperatures
- Very high parasitic loads leading to high operating costs
- Challenging to operate
- Not efficient tar cleaning
- Produced syngas has low BTU value

BRADAM

- ✓ Simpler operations at lower temperature
- ✓ Lower parasitic load
- ✓ Lower capital cost
- ✓ Higher heating value of syngas
- ✓ Produces less emission

Pyrolysis

- Low temperature process ~550ºC
- Yields a mixture of syngas, pyrolysis oils and char
- Pyrolysis oil is very acidic and unstable
- Pyrolysis chars are contaminated
- Low energy conversion efficiency

BRADAM

- ✓ Produces mostly high quality syngas usable for a multitude of applications
- ✓ Operates at higher temperature >800ºC
- ✓ Minimizes undesirable products

Landfilling

- Most widely used form of waste disposal
- Causes odours and leachate
- methane gas and other emissions
- Challenging environmental and public health
- Growing trend toward elimination

BRADAM

- ✓ Controls odours and leachate
- ✓ Diverts waste from landfills
- ✓ Prevents harmful pollutants
- ✓ Creates valued clean energy products

Clean Energy: Steam Reformation Technology

biofuelsdigest.com/bdigest/2016/06/22/clean-energy-steam-reformation-technology/

Jim Lane

By Zoltan Kish, Ph.D., Lee Enterprises Consulting

Special to The Digest

One possible solution for clean energy production is to produce energy products from waste and biomass feedstocks by effective Biomass/Waste-to-Energy technology applications. Typically, the waste is sent to landfills and the energy in waste is essentially lost, creating mountains of trash, and emitting harmful pollutants into our air, water and soil. In a landfill the biodegradable components of waste decompose and emit methane – a greenhouse gas, which is at least 21 times more harmful than carbon dioxide and the cause of significant environmental problems [1].

In addition, landfill fires, earth movements, and groundwater flows contribute to landfill leachate, which eventually leak and contaminate nearby ecosystems. In response to global environmental challenges, there have been requirements towards Waste-to-Energy technologies to produce clean/alternative energy from waste feedstocks (e.g. Municipal Solid Waste (MSW), industrial waste, biomass waste, sewage sludge, plastics used tires, etc.) and biomass.

Both biomass and waste feedstocks contain carbonaceous materials. There are extensive biomass resources, such as forestry residues, energy crops, manufacturing wood waste, olive husks, grasses, livestock and food processing residues. Wood is the most commonly used biomass fuel. The most economic sources of wood for fuel are wood residues from manufacturers, discarded wood products diverted from landfills, and wood debris from construction and demolition activities. Fast-growing energy crops (e.g., short rotation hardwoods) show promise for the future, since they have the potential to be genetically tailored to grow fast, resist drought and be easily harvested.

The primary challenge of clean energy production is the heterogeneous nature of waste and biomass, which creates a widely varying chemical constituency of the energy products generated from these processes. Feedstocks can be converted to higher value products by the physico-chemical (including biochemical) interactions, such as thermo-chemical and/or biological processes, without or with additional reactants (e.g. water, oxygen, air, etc.) [2, 3]. The produced product type depends on the types of feedstocks and reactants, and the applied physico-chemical interaction conditions in the system. The higher value products created from waste can be transformed to various forms of clean energy correspondingly to the application/ market requirements. The steam reformation technology could successfully be used to convert biomass and waste feedstocks into clean energy products.

Steam Reformation

Steam Reformation is a thermo-chemical process and is based on carbonaceous materials reaction with steam without the participation of oxygen or air at elevated temperatures above 700°C. The main product of the reactions is a synthesis gas (syngas) containing mostly hydrogen and carbon monoxide, and a smaller amount of methane, carbon dioxide, water vapour, and other hydrocarbons. Usually, the steam reformation process is used for production of hydrogen from natural gas. Biomass/waste steam reformation is based on reactions of carbonaceous materials content of feedstocks (e.g. biomass, MSW, sewage sludge, plastics) with steam.

The steam reformation technology represents a potential alternative for the traditional waste and biomass treatments to produce higher energy content syngas, which contains no noxious oxides and higher hydrogen concentration than products produced by gasification [3]. The chemistry is different due to the high concentration of steam as a reactant and the total exclusion of air, and therefore oxygen, from the steam reformation process. The produced pollutants should be removed to produce clean energy products. Contaminates (e.g. tar, acid gases, ammonia, and particulate matter) are easier to remove from the syngas because it is not diluted by excess air or nitrogen and products of combustion.

The steam reformation technology eliminates the formation of dioxins, furans and nitrous and sulfur oxides within the conversion process. Additionally, the steam conversion method significantly reduces the volume of the original waste feedstock converting carbonaceous materials into usable energy products.

Utilizing an indirectly heated kiln, the waste steam reformation technology is a novel and unconventional Waste-to-Energy technology, which allows for robust operation of various heterogeneous feedstocks (e.g. MSW, industrial waste, sewage sludge, biomass, plastic, used tires and medical waste) with high moisture content and significantly reduces the requirements for pre-processing feedstock [4]. The developed unique conversion of carbonaceous materials and a scrubbing/cleaning system produce clean syngas and reduce water and land contamination to protect air, water, and land. The produced syngas has a high hydrogen content syngas – up to 50% by volume, an H2/CO ratio over 2, and a high heating value, which is typically higher than syngas produced by competitor technologies.

The high quality of the produced syngas and residual waste heat could be used to power combined cycle gas turbines, reciprocating gas engines or fuel cells for the generation of electricity and “green” hydrogen. In addition, because of high hydrogen to carbon monoxide ratio of the syngas, the technology can potentially be coupled with a Gas-to-Liquids technology (e.g. Fischer – Tropsch process) to produce higher value liquid synthetic fuels, such as synthetic diesel, methanol, and “green” chemicals. A combination of the waste (biomass) steam reformation as a Biomass/Waste-to-Gas technology with a Gas-to-Liquids technology could become an economic and environmentally viable method of the clean energy production.

Conclusion

The waste/biomass steam reformation technology has a number of advantages over traditional Waste-to-Energy technologies, including robust operation of various heterogeneous feedstocks, a production of high quality syngas, and reduction of the produced usable gas and residual waste volumes. The steam reformation of waste/biomass is more efficient than other thermo-chemical and bio-chemical technologies. The technology is able to convert both biodegradable and also non-biodegradable carbonaceous waste contents into higher value clean/renewable energy products. Therefore, the steam reforming can potentially be combined with anaerobic digestion to convert non-biodegradable product – digestate into fuels [3].

The Waste-to-Energy technology can be optimized by analysing interactions in material system and modifying physico-chemical interactions, chemical bonds and reactants to produce new products having clean usable energy content. Additionally, the goal is to separate the contaminations from the produced energy products to produce clean energy and segregate the toxic components (e.g. heavy metal compounds) in the smaller volume of the produced solid residue. If contaminants are not above the application specification limits, the main part of produced solid residue can be utilized (e.g. construction aggregate materials).

The physical-chemical interactions of waste and biomass feedstocks with steam, as a reactant, is one of the most promising pathways of energy production as a thermo-chemical conversion of feedstocks into clean and renewable energy. The biomass/waste steam reformation technology can convert various heterogeneous feedstocks and divert waste materials from landfills producing clean energy and significantly reduce environmental impacts versus other waste disposal and waste conversion methods. The steam reformation technology could change waste to a clean energy source, replace a portion of fossil fuels, and provide cost effective and environmentally sound supply of clean energy.

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Circular Economy and Waste Conversion

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The increasing amount of waste is one of the most demanding problems facing the world, which creates global environmental challenges. Worldwide, 2.12 billion tons of waste are generated annually, and it is expected to rise at the current trend [1]. Most of the trash ends up in landfills emitting harmful pollutants into our air, water, and soil. Therefore, waste reduction in a circular economy is vital for climate change mitigation and sustainable economic growth. The circular economy is not only based on simple recycling and reuse of the produced waste. In a circular economy, waste materials are redesigned or converted into forms retaining as high value as possible. Garbage can be converted into high-value products by mechanical/physical, thermochemical, and biochemical processes. Consequently, a circular economy should include the use of the effective waste conversion technologies based on thermochemical and biochemical processes (e.g., Waste-to-Energy, Waste-to-Gas, and Gas-to-Liquids technologies) to produce usable products. However, a circular economy should not be limited to recycling and conventional technologies, such as incineration and anaerobic digestion.

Many waste products as contaminated plastic, paper, diapers, medical waste, waste biomass, anaerobic digestion and industrial byproducts are very difficult to recycle.

Incineration is a wasteful use of resources – providing low energy conversion efficiency. In addition to thermal energy, products of the incineration process include bottom ash, fly ash, and flue gas, in which a number of regulated pollutants (e.g., mercury, lead, cadmium, etc.) are found. The produced flue gas significantly diluted and increased in volume by the nitrogen content of the excess air use. Combustion of waste is a significant source of furans and dioxins, which are highly toxic and carcinogenic pollutants. Also, the typical gaseous pollutants in the flue gas are carbon dioxide, nitrogen oxides, sulfur oxides [2].

On the other hand, anaerobic digestion has a limit in the waste conversion. It is only suitable for the treatment of the biodegradable organic portion of waste feedstock. Non-biodegradable material – digestate remains after processing waste by anaerobic digestion. The produced digestate can be contaminated with toxic heavy metal compounds from municipal solid waste (MSW) and sewage sludge. Therefore, the by-products of the anaerobic digestion often cannot be reused without environmental contamination. The produced biogas and landfill gas are contaminated by sulfur gases (e.g., hydrogen sulfide, methyl mercaptan), siloxanes, halogenated hydrocarbons, and ammonia, which can be sources of air pollution after burning [2].

The circular economy can be based on emerging waste conversion technologies, such as steam reformation, gasification, pyrolysis, and other [2, 3]. An appropriate Waste-to-Energy technology can convert both biodegradable and also non-biodegradable carbonaceous waste contents into the higher value of clean/renewable energy products, recover materials for reuse, and divert waste from landfills to prevent contamination of air, water, and land. Higher value liquid synthetic fuels can be produced from waste materials by a combination of a Waste-to-Gas technology with a Gas-to-Liquids technology. The waste feedstock can be a cost-effective and environmentally sound supply of clean energy source and replace a portion of fossil fuels. Potentially, garbage can be transformed into various forms of clean and sustainable products, such as electricity, hydrogen, liquid synthetic fuels, "green" chemicals, and food-based products. The produced product composition depends on the type of waste feedstocks and reactants, and the applied processing conditions [2, 4]. The used waste conversion technologies should be efficient and combined with a reliable scrubbing/cleaning system to remove contaminants in order to generate clean/ renewable energy and other sustainable products, and prevent pollution of the surrounding environment. In a circular economy, effective waste conversion technology applications can play a key role to find a solution for waste disposal, clean energy and sustainable product regeneration.

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About the Author

Dr. Zoltan Kish has a Ph.D. in Chemistry with over 25 years of diverse industrial and academic experience and contributed to more than 70 scientific publications. He has developed and managed complex research and development programs related to alternative/renewable energy, clean technologies, GHG, sustainability, and advanced materials applications, such as solar energy technology, ceramic engine & cutting tool components, materials processing, and electronics. Dr. Kish was the Director of Research & Development at two major Canadian alternative energy companies where he focused on R&D and commercialization of unique Waste-to-Energy technologies and reliable scrubbing/ cleaning systems to produce clean and sustainable energy products. In response to global environmental challenges and the need for scientific evaluations of new technologies and advanced materials applications, he has established a consulting company - Quasar ScienceTech (www.quasarsciencetech.com) to provide multidisciplinary science and technology consulting in the areas of Natural & Applied Sciences, Clean Technologies & Energy, Waste Conversion, Technical Due Diligence, Climate Change Mitigation, Circular Economy, Sustainability, Innovation, and Advanced Materials Applications.

Waste Accumulation Problems and Opportunities

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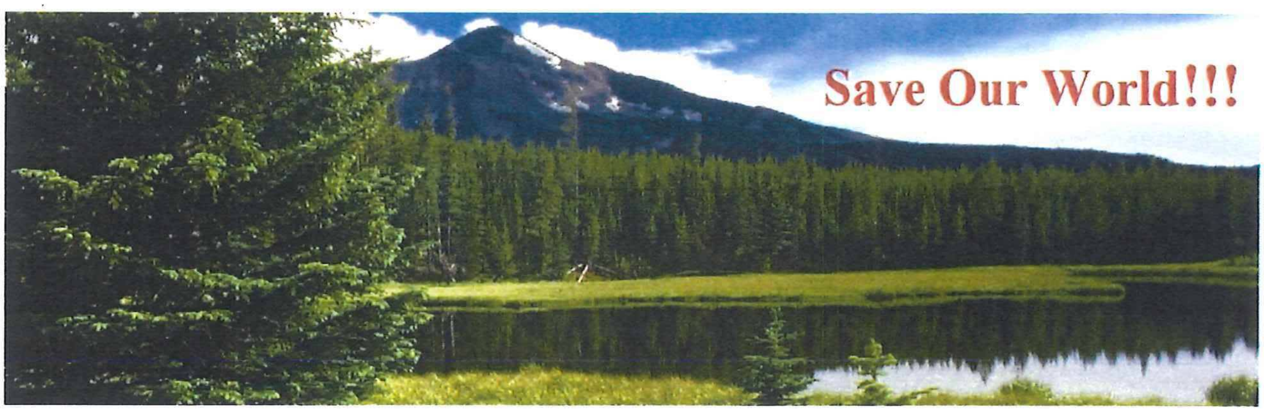
An incredible amount of waste is produced in Canada and around the world. We are killing our planet by dumping 2.12 billion tons of garbage every year and polluting the oceans, land, and air [1]. Consequently, we need sustainable and effective waste management to protect our environment and save our world. It is particularly important now after China banned foreign waste acceptance, and more garbage ends up in landfills and water resources creating enormous environmental problems.



In 2016, the Ontario government released its Strategy for a Waste-Free Ontario [2], diverting our wasteful ways towards an entirely **circular economy, but it doesn't seem to** be widely discussed. This strategy requires appropriate tools and an innovative approach to solving the tremendous waste accumulation problem. Particularly, after China stopped the import of foreign waste, the waste recycling facilities around the world cannot send recycled waste to China anymore, and municipalities are facing pileups of garbage, substantial extra costs and the risk of losing millions in revenue. The following websites reflect this problem in Canada and globally:

- https://www.washingtonpost.com/news/energy-environment/wp/2018/06/20/a-giant-wave-of-plastic-garbage-could-flood-the-u-s-in-10-years-a-study-says/?noredirect=on&utm_term=.d8f30513a28f
- https://www.theglobeandmail.com/news/national/chinese-ban-on-foreign-recyclables-leaving-some-canadian-cities-in-the-lurch/article37536117/
- https://www.thespec.com/news-story/8048791-chinese-ban-dumps-on-city-s-recycling-parade/
- https://www.canadafibersltd.com/on-point-canada-fibers/#more-1812
- https://www.express.co.uk/news/uk/980704/eu-plastic-recycling-makes-pollution-worse
- https://www.politico.eu/article/europe-recycling-china-trash-ban-forces-europe-to-confront-its-waste-problem/

Under the new circumstance, some municipal governments could get out of the recycling business altogether, and the recycled waste will end up in the landfills while the energy in waste is mostly lost, creating mountains of trash, emitting harmful pollutants into our air, water, and soil. In landfills, the biodegradable components of garbage decompose and emit greenhouse gases (e.g., methane, carbon dioxide, hydrogen sulfide, ammonia), which increase global warming. Also, the toxic content of the waste contributes to landfill leachate, which eventually leaks and contaminates nearby ecosystems.

Until January 2018, the world applied a short-sighted and self-serving strategy to deal with the waste: sending waste to China and other East Asian countries and dispose of waste into landfills and the oceans. As it was written in the **Bloomberg article, "Without bold new ideas and management strategies, current** recycling rates will no longer be met, and ambitious goals and timelines for future recycling growth will be **insurmountable"** [3].

We need more effective and sustainable ways to manage the produced waste. The government could address the demand to solve the incredible waste accumulation by developing appropriate tools for the waste **management challenges. One man's trash can be another man's treasure. For example,** depending on the waste plastic composition and level of contaminations, the plastic feedstock could be effectively converted into high-value products through pyrolysis and waste steam gasification technologies. If the plastic feedstock is clean and has an appropriate composition, pyrolysis can be applied to depolymerize plastic and convert it mostly into liquid fuel. The steam gasification reformation technology is more suitable for contaminated plastic waste conversion into high energy value syngas and hydrogen. Additionally, syngas can be converted into liquid fuels and green chemicals using Gas-to Liquid catalytic process.

The advanced and effective Waste-to-Energy technology applications in combination with a reliable scrubbing/cleaning system can provide a solution for biodegradable and non-biodegradable waste disposal, clean energy production, and sustainable product regeneration. The waste, potentially, can be converted into various forms of clean energy products, such as electricity, hydrogen, liquid synthetic fuels, and **"green" chemicals. Trash can be a cost**-effective and environmentally sound supply of clean energy source and replace a portion of fossil fuels. High quality liquid synthetic fuels without sulfur contamination can be produced from waste materials by a combination of a Waste-to-Gas technology with a Gas-to-Liquids technology based on the Fischer–Tropsch catalytic process. Perspectives on different Waste-to-Energy technologies have been presented in the following articles [4, 5, 6].

Regrettably, incineration has been often considered as a Waste-to-Energy technology to process waste for an astonishing price and producing relatively low power. For example, a new incinerator has been built for a very high price - **£1.4 billion** in York and North Yorkshire in the UK. The incinerator will divert more than 230,000 tonnes of household waste but will produce only 24 MW of power [7].

Another example of an enormous and overpriced incineration facility is being built in Hong Kong. The project will cost $4 billion by processing 3000 tonnes/day (1,050,000 tonnes/year) and produce just 489 million kWh/year of energy, which is equivalent to 57 MW of power [8]. Incineration is a very costly and inefficient way for waste conversion into electricity and generating highly toxic and carcinogenic pollutants.

In a circular economy advanced emerging waste conversion technologies (e.g., Waste-to-Energy, Waste-to-Gas, and Gas-to-Liquids technologies) can play a pivotal role in waste disposal. Efficient waste conversion technology applications can be a path to a working circular economy. Recycling is not only based on simple reusing the waste products. The purpose of recycling is to redesign and convert waste into forms retaining as high value as possible in a circular economy. Contaminated waste products are challenging to recycle and reuse. Garbage can be converted into high-value products through mechanical/physical, thermochemical, and biochemical processes. The waste can be transformed into various forms of sustainable and clean energy products utilizing effective waste conversion technologies in the circular economy [9].

Regrettably, the underlying scientific/technical basis of the business is often neglected. As a result of this, enormous and overpriced Waste-to-Energy facilities were built producing very little energy from waste. Investors (e.g., in CleanTech sectors) often make an investment decision based on shallow scientific claims, optimistic financial and psychological factors as a consequence of that the basic science of the technology is not adequately evaluated. In addition to financial data and management of the company, the underlying scientific/technology base of the business should be considered. Science is supposed to be an essential pillar of a successful and sustainable business. The success of waste conversion technology applications depend on the following main factors:

- The underlying scientific/technical basis of the waste conversion process
- Adequate preparation of the waste feedstock
- Implementation of effective cleaning/scrubbing system to remove contaminants, especially, tars
- Adequate processing and mass & energy balance modeling
- Financial data based on mass & energy balance
- Local waste availability
- Waste energy conversion efficiency
- Quantity and quality of the produced products
- Applications of the products
- Cost-effectiveness of the project

The increasing amount of waste is one of the most challenging problems facing the world, which creates global environmental challenges. Contaminated waste products (e.g., plastic, paper, diapers, medical waste, waste biomass, and industrial byproducts) are challenging to recycle and reuse in the traditional way. Therefore, we have an urgent requirement to deal with the tremendous waste accumulation. At the same time, we have a tremendous business opportunity to convert waste into usable sustainable products. The circular economy can be based on efficient waste conversion technologies, such as traditional gasification, steam gasification, pyrolysis, and anaerobic digestion. Typically, the steam gasification reformation of waste is more efficient and cost-effective than other thermo-chemical and bio-chemical technologies and able to convert both biodegradable and non-biodegradable carbonaceous waste contents into higher value clean/renewable energy products. It is essential that sustainable waste management become an integral part of urban development. With the right approach, we could have a comprehensive and cost-effective solution for waste disposal, clean energy production, and sustainable product regeneration as a combination of biodegradable and non-biodegradable waste processing.

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Perspectives on Waste-to-Energy Technologies

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March 2016

Introduction

Reducing the emission of carbon dioxide and other greenhouse gases is one of the greatest environmental challenges of our time. Growing population, increased urbanization rates and economic growth could lead to a doubling in the volume of municipal solid waste (MSW) created annually by 2025, according to new research conducted by the World Watch Institute [1]. The doubling of waste would bring the volume of MSW from today's 1.3 billion tonnes per year to 2.6 billion tonnes, challenging environmental and public health management in municipalities worldwide. Typically, the waste is sent to landfills and the energy in waste is essentially lost, creating mountains of trash, emitting harmful pollutants into our air, water and soil. In a landfill the biodegradable components of waste decompose and emit methane, which is a greenhouse gas and 21 times more harmful than carbon dioxide. In addition, landfill fires, earth movements, and groundwater flows contribute to landfill leachate, which eventually leaks and contaminate nearby ecosystems. In response to global environmental challenges, there has been a requirement towards Waste-to-Energy technologies to produce alternative/ clean energy from waste feedstocks, such as MSW, industrial waste, biomass waste, sewage sludge, used tires, etc. The primary challenge of these technologies is the heterogeneous nature of MSW, which creates a widely varying chemical constituency of the energy products generated from these processes. A solution for waste disposal and clean energy production is an effective Waste-to-Energy technology application. The global market of Waste-to-Energy has significantly increased. Waste feedstock can be converted to higher value products by the physico-chemical (including biochemical) interactions, such as thermo-chemical and/or biological processes without or with additional reactants (e.g., water, oxygen, air, etc.). The produced product type depends on the types of feedstock and reactants, and the applied physico-chemical interaction conditions in the system [2]. The higher value products created from waste can be transformed into various forms of clean energy correspondingly to the application/ market requirements.

Waste-to-Energy technologies

The Waste-to-Energy technologies can be classified in the following major types.

Conventional
- *Incineration*
- *Gasification & Plasma Enhanced Gasification*
- *Pyrolysis*
- *Anaerobic Digestion*

Unconventional
- *Steam Reformation*

Incineration

The most common technology for treating waste is incineration, which is a thermo-chemical process wherein the combustible components of a solid waste stream are oxidized to produce heat energy, which can be used to create steam to generate electrical power using a steam turbine, for industrial processes, or for district heating. Incineration is the combustion of waste using an excess of oxygen (air) to ensure complete combustion at temperature above 850°C. Therefore, the products (flue gas) of the waste combustion are significantly diluted and increased in volume by the nitrogen content of the excess air use. In addition to thermal energy, products of the incineration process include bottom ash, fly ash, and flue gas, in which are found a number of regulated pollutants (e.g., mercury, lead, cadmium, etc.). The common gaseous pollutants in the flue gas are carbon dioxide, nitrogen oxides, sulfur oxides. Combustion of waste is a major source of furans and dioxins, which are highly toxic and carcinogenic pollutants. Incineration can be identified as a baseline competitor technology. However, incineration is a wasteful use of resources – providing low energy conversion efficiency.

Gasification and Plasma Enhanced Gasification

Gasification and Plasma Enhanced Gasification are thermo-chemical processes and are based on partial oxidation of the waste to convert carbonaceous materials into syngas (synthesis gas). Usually, the gasification is performed at temperature above 700°C. Pure oxygen has limited use for the partial oxidation processes as a result of high costs. Hydrogen and carbon monoxide are predominating gas products in the syngas, along with water vapor, methane, carbon dioxide, nitrogen (if air is used), and other hydrocarbons. As a result of the oxidation/ incineration component of the gasification systems that use oxidation, they will generate noxious oxides (e.g. nitrogen oxides, sulfur oxides). In addition, produced syngas is contaminated by tar, acid gases, ammonia, and particulate matter. Plasma arc gasification is a waste treatment technology that uses an electric arc to produce high temperatures (up to 7000°C) within the reactor to convert carbonaceous materials into syngas and melt the residual inorganic materials. Plasma is the fourth state of matter containing ionized gases. The content and consistency of the waste have a direct impact on performance of the plasma enhanced gasification. The tar cleaning is not efficient as a result of the inconsistency of the heat distribution produced by the plasma arc. Large amounts of inorganic materials such as poorly sorted construction waste, metals, and glass, result in increased slag production and decreased syngas production. The heat energy that is required to melt these materials is lost since the molten slag does not contribute to syngas production. The use of the plasma arc significantly increases parasitic electricity consumption and operating and capital costs of the gasification process. In addition, gasification of waste typically requires extensive and expensive waste feedstock pre-treatment and the produced syngas will be significantly diluted by the oxidation process which includes the nitrogen content of air. Therefore, the heating value of syngas produced from the partial oxidation gasification process is significantly reduced. The lower quality syngas fuel generated from partial oxidation gasification can be run in reciprocating engines, but generally cannot be used as a fuel for cleaner burning and more efficient gas turbines, due to its relatively low heating value.

Pyrolysis

Another competing Waste-to-Energy technology is pyrolysis. Pyrolysis is a thermo-chemical conversion of waste feedstock without the participation of oxygen or air at elevated temperatures (400°C – 600°C). The main products of the pyrolysis process are char, pyrolysis oil and a mixture of gases. The products are produced in different ratios depending on the reaction types, residence time, temperature, feedstock composition and size. The pyrolysis processes can be classified as slow and fast pyrolysis. The residence time for the slow pyrolysis is in the range of hours and the product yield is approximately 35% of char, 30% of pyrolysis oil, and 35% of syngas. The fast pyrolysis process is performed during very short time (~1 second) and the main product is pyrolytic oil; the product produced ratio is in the range of 12% of char, 75% of oil and 13% of gas. The slow pyrolysis is suitable for charcoal production from biomass. However, the use of the pyrolysis oil is problematic because the produced oil is very acidic, unstable, and contains significant amount of water. For electricity generation, pyrolysis systems typically cannot cool or clean the syngas before burning these mixed products (which then must include both particulate and volatilized contaminants) in a steam boiler combustion unit; otherwise they will lose the energy benefit of the condensable oils and tars. The end result is then not a lot different from simply burning contaminated wastes as during incineration. The energy recovery is then very analogous to incineration, i.e. low energy efficiency plus the additional challenge of developing a cleaning plant which must be very similar to that for incineration, in order to meet environmental emission limits.

Anaerobic Digestion

Anaerobic Digestion is a biochemical conversion of the biodegradable organic portion of waste feedstock in the absence of oxygen into biogas and remaining non-biodegradable material - digestate. Biogas comprises mainly of methane and carbon dioxide and trace amount of hydrogen, sulfur gases (e.g. hydrogen sulfide, methyl mercaptan), siloxanes, halogenated hydrocarbons, and ammonia. Usually the mixed gas is saturated with water vapour and may contain dust particles. Digestate consists of a mix of microbial biomass and undigested material (e.g. lignin, cellulose), which contains organic matter and essential plant nutrients required for plant growth. However, digestate (especially, from sewage sludge and MSW) may also contain contaminants such as heavy metals, industrial chemicals, pharmaceuticals, nano-particles, infectious pathogens, etc. The produced product content is depending on the effectiveness of the treatment process and the contamination levels of the feedstock. Depending on the operational temperature level, anaerobic digestion processes can be classified into three main types: psychrophylic (15°C - 25°C), mesophilic (30°C - 40°C), and thermophilic (50°C - 60°C). The anaerobic process is slow in comparison with thermo-chemical processes, as a result of low temperature operation. it takes many days to convert the biodegradable content of waste feedstock into biogas. The anaerobic digestion technology is best suited to the treatment of wet organic feedstocks, such as high moisture agricultural biomass, food waste, and animal wastes including manure, domestic sewage, and biodegradable components of MSW. The biogas can be used as a source of renewable energy, as a fuel in combined heat and power gas engines. During combustion, siloxanes are converted to silicon dioxide, which is a solid compound and will remain in the engine and cause considerable damage. The produced digestate can be used as a fertilizer if contaminants are not above the application specification limits. Land application of biologically treated waste is regulated in most countries to protect human health, the environment and soil functionality from detrimental impacts associated with potential contaminants.

Steam Reformation

Steam Reformation is a thermo-chemical process and is based on carbonaceous materials reaction with steam without the participation of oxygen or air at elevated temperatures above 700°C. The waste steam reformation is the waste feedstock gasification. The main product of the reactions is a syngas containing mostly hydrogen and carbon monoxide, and a smaller amount of methane, carbon dioxide, water vapour, and other hydrocarbons. Usually, the steam reformation process is used for production of hydrogen from natural gas. The steam reformation technology represents a potential alternative for the traditional waste treatments to produce higher heating content syngas, which contains no noxious oxides and higher hydrogen concentration than products produced by gasification. The chemistry is different due to the high concentration of steam as a reactant and the total exclusion of air and, therefore, oxygen from the steam reformation process. Contaminates (e.g., tar, acid gases, ammonia, and particulate matter) are easier to remove from the syngas because its is not diluted by excess air or nitrogen and products of combustion. Utilizing an indirectly heated kiln, the waste steam reformation technology is a novel and unconventional Waste-to-Energy technology, which allows for robust operation of various heterogeneous feedstocks (e.g., MSW, industrial waste, sewage sludge, waste biomass, used tires and medical waste) with high moisture content and significantly reduces the requirements for pre-processing feedstock [3]. The high quality of the produced syngas and residual waste heat can be used to power combined cycle gas turbines, reciprocating gas engines or potentially fuel cells for the generation of electricity and "green" hydrogen. In addition, because of high hydrogen to carbon monoxide ratio of the syngas, the technology can be coupled with a Gas-to-Liquids technology (e.g., Fischer - Tropsch process) to produce higher value liquid synthetic fuels, such as synthetic diesel, methanol, and "green" chemicals. A combination of the Waste Steam reformation as a Waste-to-Gas technology with a Gas-to-Liquids technology can, potentially, become an economic and environmentally viable method of the clean energy production.

Conclusion

The Waste-to-Energy technologies produce pollutants and, therefore, appropriate and effective scrubbing/ cleaning systems should be applied to remove contaminants from the usable fuel products in order to produce clean renewable energy and protect land, water and air. Depending on the applied processes and processed waste feedstocks, in addition to inorganic materials, the produced solid residue may contain carbonaceous materials (e.g., carbon, tar, digestate). Despite that, all conversion methods, especially, thermo-chemical processes significantly reduce the volume of the original waste feedstock converting carbonaceous materials into usable energy products. The steam gasification reformation technology eliminates the formation of dioxins, furans and nitrous and sulfur oxides within the conversion process. In addition, the waste steam reformation technology has a number of advantages over traditional Waste-to-Energy technologies, including a significant increase of the produced syngas quality, and reduction of the process gas and residual waste volumes. The steam reformation of waste is more efficient than other thermo-chemical and bio-chemical technologies and able to convert both biodegradable and also non-biodegradable carbonaceous waste contents into higher value clean/renewable energy products. Therefore, the steam reforming can be combined with anaerobic digestion to convert digestate into fuels. The Waste-to-Energy technologies can be optimized by analyzing interactions in material systems and modifying physico-chemical (including biochemical) interactions, chemical bonds and reactants to produce new products having clean usable energy content. The goal is to separate the contaminations from the produced energy products to produce clean energy and segregate the toxic components (e.g., heavy metal compounds) in the smaller volume of the produced solid residue. If contaminants are not above the application specification limits, the main part of produced solid residue can be utilized. For examples, the residual inorganic materials can potentially be used as a construction aggregate material and digestate can be used as a fertilizer. The physical-chemical interactions of waste feedstock with steam as a reactant is one of the most promising pathways of energy production as a thermo-chemical conversion of waste feedstock into clean and renewable energy. The waste steam reformation technology can convert various heterogeneous feedstocks and divert waste materials from landfills producing clean energy and significantly reduce environmental impacts versus other waste disposal and waste conversion methods.

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