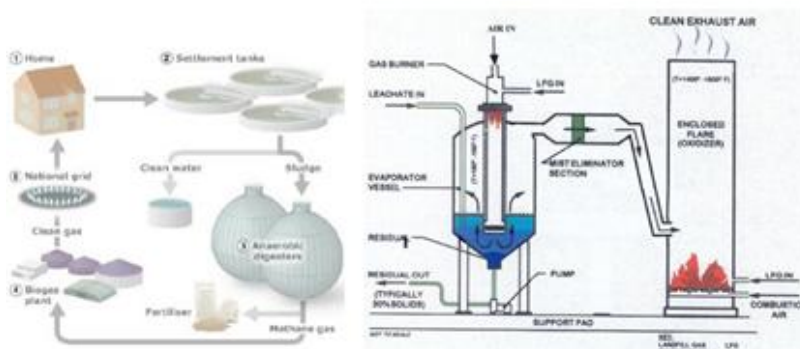
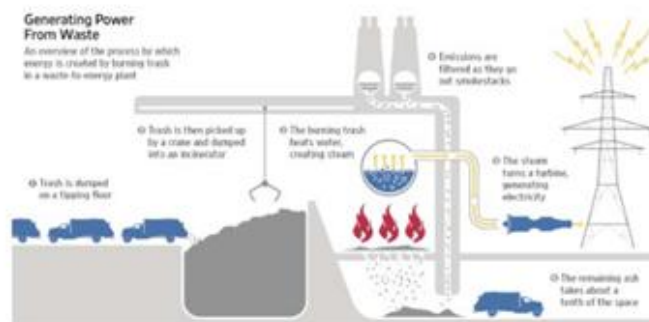
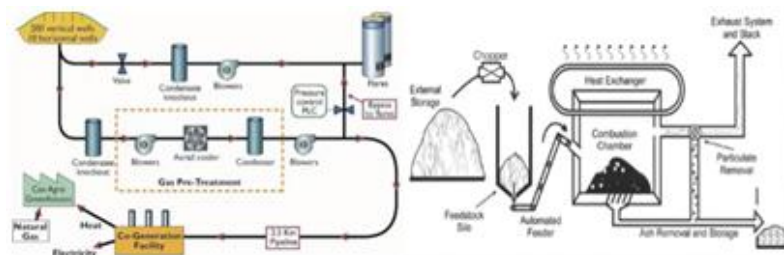




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# Fiji Renewable Energy Power Project (FREPP)

## Report on Recommendations from Technology Research on Waste-to-Energy in Fiji



## Waste to Energy Resource Assessment in Fiji

September - 2014

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## Abbreviations & Acronyms

<b>AD</b>	Anaerobic Digestion
<b>CAPEX</b>	Capital Expenditure
<b>CH<sub>4</sub></b>	Methane
<b>CHP</b>	Combined Heat and Power
<b>CO</b>	Carbon Monoxide
<b>CO<sub>2</sub></b>	Carbon Di-oxide
<b>EPA</b>	Environment Protection Agency
<b>EU</b>	European Union
<b>GHG</b>	Greenhouse Gases
<b>GW</b>	Gigawatt
<b>GWh</b>	Gigawatt hours
<b>H</b>	Hydrogen
<b>H<sub>2</sub>S</b>	Hydrogen Sulphide
<b>FEA</b>	Fiji Electricity Authority
<b>FREPP</b>	Fiji Renewable Energy Power Project
<b>FSC</b>	Fiji Sugar Corporation
<b>HCL</b>	Hydrochloric Acid
<b>IPPs</b>	Independent Power Producers
<b>IRENA</b>	International Renewable Energy Agency
<b>Kg</b>	Kilograms
<b>KWh</b>	kilowatt hour
<b>MJ</b>	Mega joule
<b>MSW</b>	Municipal Solid Waste
<b>MT</b>	Metric Ton
<b>MW</b>	Megawatt
<b>MWh</b>	Megawatt-hours
<b>N</b>	Nitrogen
<b>NH<sub>3</sub></b>	Ammonia
<b>NO<sub>x</sub></b>	Oxides of Nitrogen
<b>NGO</b>	Non –governmental Organization
<b>O&amp;M</b>	Operation and Maintenance
<b>STP</b>	Sewage Treatment Plant
<b>SO<sub>x</sub></b>	Oxides of Sulphur
<b>TWIL</b>	Tropik Wood Industries Limited
<b>UNDP</b>	United Nations Development Programme

## Contents

<b>1. Background</b> .....	<b>5</b>
1.1 Report on “Quantification and Assessment of Waste to Energy Resources in Fiji” ....	5
1.2 Report on “Feasibility of Resources and Sites for Waste-to-Energy Power Generations Facilities” .....	6
<b>2. Approach &amp; Methodology</b> .....	<b>6</b>
<b>3. Waste to Energy (Power) Generation Technologies</b> .....	<b>7</b>
3.1 Thermo-chemical Processes.....	8
3.1.1 Combustion or Incineration .....	8
3.1.1.1 Grate combustion .....	9
3.1.1.2 Fluidized bed Combustion .....	9
3.1.2 Pyrolysis .....	10
3.1.3 Gasification.....	10
3.1.3.1 Fixed bed Gasifiers.....	11
3.1.3.2 Fluidised (circulating or bubbling) bed Gasifiers.....	11
3.1.4 Plasma Gasification .....	12
3.2 Bio-Chemical Process.....	12
3.2.1 Anaerobic Digestion.....	12
3.2.2 Landfill Gas Recovery.....	13
<b>4. Overview of Global Waste to Energy Trends</b> .....	<b>15</b>
<b>5. Cost Implications of Waste to Energy Projects</b> .....	<b>17</b>
<b>6. Evaluation and Recommendation of Waste to Energy Technology Options</b> .....	<b>20</b>
<b>7. Conclusion &amp; Next Step</b> .....	<b>22</b>
References .....	23

## List of Figures

<b>Figure 1:</b> Waste to Energy (Power) Generation Technologies .....	7
<b>Figure 2:</b> Technology Status of Waste to Energy Generation (Source: IRENA, 2012) .....	7
<b>Figure 3:</b> Overview of Alternative Thermo-chemical Conversion Processes.....	8
<b>Figure 4:</b> Schematic of a Typical Incinerator.....	9
<b>Figure 5:</b> Typical Schematic of Gasification Process.....	11
<b>Figure 6:</b> Typical Schematic of Anaerobic Digestion Process .....	13
<b>Figure 7:</b> Landfill Gas Recovery and Utilization .....	14
<b>Figure 8:</b> Global Grid Connected Waste to Energy Installed Capacities .....	15
<b>Figure 9:</b> Global Share of Waste to Energy Installed Capacities by Feedstock and Region.....	16
<b>Figure 10:</b> Capital Costs Range for Waste to Energy Projects by Technology .....	18
<b>Figure 11:</b> Break Down of Capital Costs for Waste to Energy Technologies .....	18

## List of Tables

<b>Table 1:</b> O & M Costs for Waste to Energy Technologies.....	19
<b>Table 2:</b> Estimated Electricity Generation Potential in Fiji from Waste Resources .....	20
<b>Table 3:</b> Technology Evaluation and Recommendation Matrix for Waste to Energy Projects in Fiji ...	21

## **1. Background**

The “Resource Assessment Study for Waste-to-Energy Resources in Fiji” under the “Fiji Renewable Energy Power Project (FREPP) intends to quantify and assess the amount of waste resources available in Fiji for power generation and identify technology options for feasible implementation of waste to energy projects. The study aims to:

- Quantify and Assess the Amount and Types of Resources available for Waste-to-Energy (Power generation) in Fiji;
- Assess the Feasibility of Resources and Sites for Waste-to-Energy (Power Generation) Facilities;
- Suggest Technology research and recommendation on Waste-to-Energy options; and
- Recommend Effective Implementation of potential Waste-to-Energy (Power Generation) Facilities in Fiji

The study also aims to develop four reports under the assignment mainly focusing on the above listed objectives. A brief background of the study reports submitted under this study is provided below.

### **1.1 Report on “Quantification and Assessment of Waste to Energy Resources in Fiji”**

This report focused on quantification and assessment of the amount and types of waste resources available in Fiji for waste-to-energy power generation. The methodology adopted for development of this report involved identification, collection, research and review of relevant national and regional data and reports, national policy and regulatory documents, consultation with relevant stakeholders including line ministries, development partners, electricity utilities, academic institutions, private power producers and NGO’s.

The report included the quantitative and qualitative assessment of various potential wastes resource generated and main characteristics of waste resources from each identified waste streams in Fiji. The key waste stream includes Municipal Solid Waste (MSW); Sewage and Sludge (Waste Water); Livestock Waste; Biomass Waste; Non Hazardous Industrial Organic Waste and Agricultural Crop Residues.

Based on the assessment of waste resources, it appeared that some (MSW, biomass, livestock) of the waste streams identified in Fiji have reasonable potential for power generation. It is envisaged that some of these potential projects could play a valuable role in stand-alone electricity applications and be particularly effective for rural electrification in remote rural areas with no or very limited grid connectivity. On the other hand, waste residues and resources, resulting mainly from medium and large sources and enterprises could provide opportunities for large-scale centralized power generation.

Further, the use of waste resources as substitute for fossil-based fuels might offer many attractive benefits for Fiji. The key socio-economic benefits include private sector investment opportunities, employment generation, rural electrification and overall poverty alleviation. There are additional benefits to the environment in terms of offsetting the GHG emissions associated with burning fossil fuels and anaerobic digestion of biogenic waste and waste utilization.

## **1.2 Report on “Feasibility of Resources and Sites for Waste-to-Energy Power Generations Facilities”**

This report (Second under the study) was a macro assessment focusing on estimating the theoretical potential for power generation from the identified waste streams and assessing the feasibility of the available resources for energy generation. The report also discussed on the identified potential waste to energy projects in Fiji including their estimated potential for power generation based on the site survey carried out. The scope of this study did not involve carrying out a detailed techno-economic feasibility assessment for the identified waste streams or the potential projects.

Based on the detailed assessment, in terms of theoretical potential for electricity generation, it appears that biomass waste stream (bagasse & logging and forestry industry residues) has the highest potential followed by MSW and livestock waste.

The two IPPs, Fiji Sugar Corporation (FSC) and Tropik Wood Industries Ltd (TWIL) are currently involved in biomass based waste to energy generation (bagasse & wood residues) and are consuming most of the economically available biomass waste generated by using them as fuel at the existing power plants. Currently there is no excess or surplus biomass waste is available which could be economically collected and transported to the existing project sites. As discussed in the report, collection, handling and transportation costs are the key challenges for utilizing the available biomass resource effectively in Fiji.

Under the MSW stream, Naboro landfill and Vunato Dump in Lautoka seems to have a reasonably good potential to generate electricity. The appropriate technology and approach needs to be adopted based on the detailed techno-economic feasibility studies. Also as discussed in the report, for the Vunato dump in Lautoka, the sensitivities and issues related to location of the dump site and available area for waste processing needs to be considered whilst deciding on the appropriate waste to energy technology.

All the potential projects identified for the piggery and the poultry waste under the livestock stream have good potential to generate electricity. The power generated from these potential projects could be used for captive consumption and the excess power can be fed to the grid. The manure from cattle although has the highest potential to generate electricity, due to the grazing pattern adopted in Fijian cattle farms, it is difficult to collect the cattle manure and transport it to a centralized location for processing.

This is the third report under the study focusing on research and identification of relevant technologies available globally (particularly in developing country context) for waste to energy power generation. The report also intends to recommend appropriate technology options for waste to energy power generation in Fiji considering similar experiences in other developing countries.

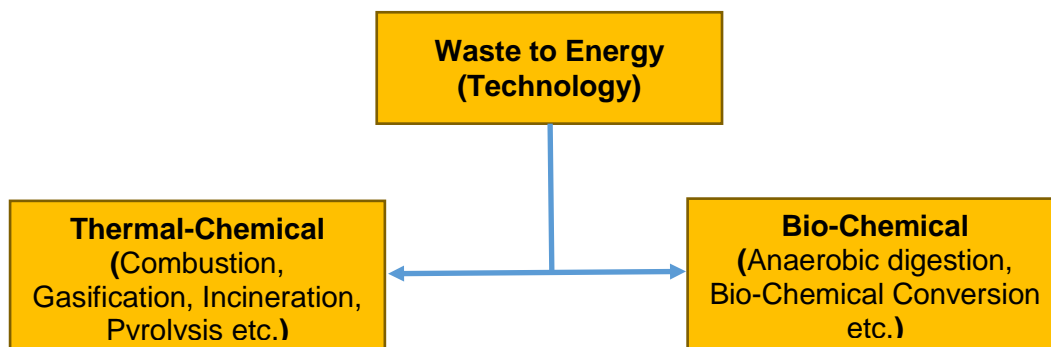
## **2. Approach & Methodology**

The approach and methodology adopted for research included desktop research with collection and assessment of available global studies, reports and strategic documents relevant to waste to energy generation. The key aspects for the research were to assess the: current status of waste to energy technologies and their possible optimization; most used waste to energy treatment methods including recommendation of appropriate technology options for waste to energy power generation in Fiji considering similar experiences in other developing countries across the globe.

### 3. Waste to Energy (Power) Generation Technologies<sup>1</sup>

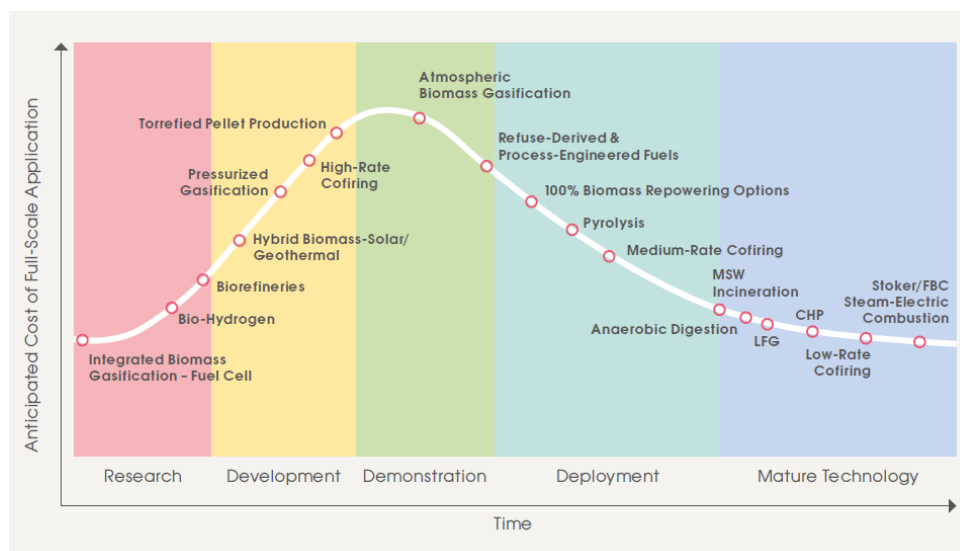
Globally there are two main technology options available to convert the available waste to energy i.e. Thermal-Chemical, Bio-Chemical or combination of both the conversion of waste to energy process. Waste resources can be converted into power through thermal-chemical processes (i.e. combustion, gasification, incineration and pyrolysis) or bio-chemical processes like anaerobic digestion. Power generation from waste resources can be achieved with a wide range of feed stocks and power generation technologies that may or may not include an intermediate conversion process (e.g. gasification). In each case, the technologies available range from commercially proven solutions with a wide range of technology suppliers (e.g. solid fuel combustion) through to those that are only just being deployed at commercial scale (e.g. gasification).

**Figure 1: Waste to Energy (Power) Generation Technologies**



There are other waste to energy (power) generation technologies that are at an early stage of development; these are not considered in this analysis. The status of technology i.e. research, development, demonstration, deployment and mature stage, that are available for waste to energy generation are depicted in Figure 2. In addition, different waste resources as feed stocks and conversion technologies are limited or more suited to different scales of application, further complicating the scenario.

**Figure 2: Technology Status of Waste to Energy Generation (Source: IRENA, 2012)**



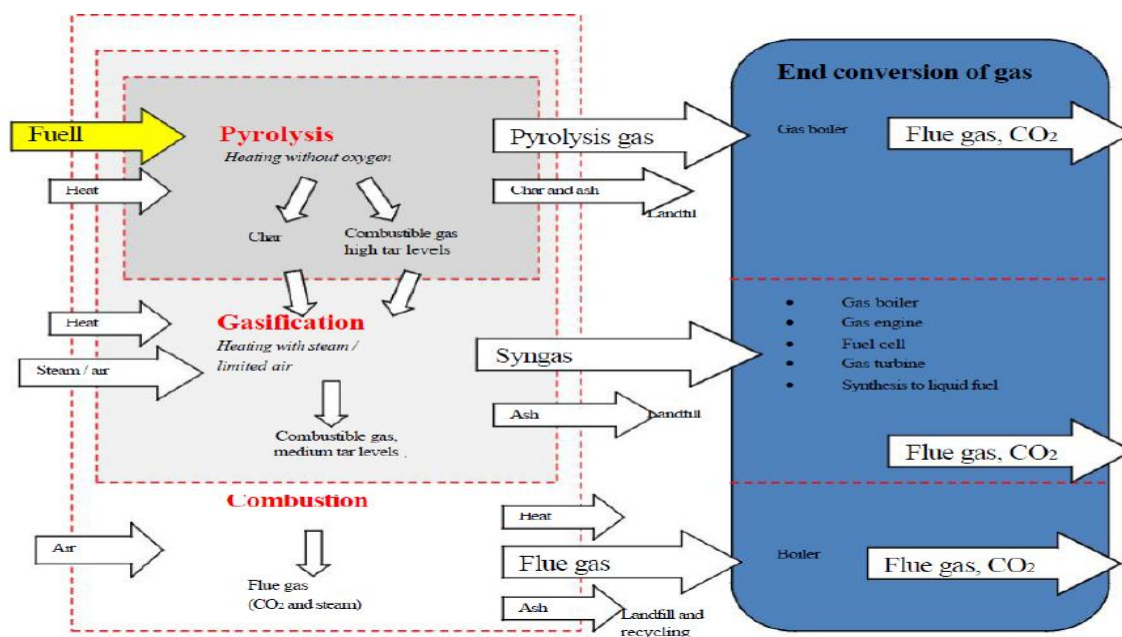
<sup>1</sup> Extracted and Adopted from: EU Report on Global Analysis of Waste to Energy Field, 2014; THULE Institute, Finland, 2011 and Some Additional Sources Cited in the Reference with Integrations



### 3.1 Thermo-chemical Processes

The key differences between direct combustion of waste (i.e. incineration) and other alternative thermal treatment are summarized in the below figure. Basically, the main difference is related to the oxygen content inside the thermal functional unit of the facility. Plasma arc technologies can be used both in pure pyrolysis and gasification mode.

**Figure 3:** Overview of Alternative Thermo-chemical Conversion Processes

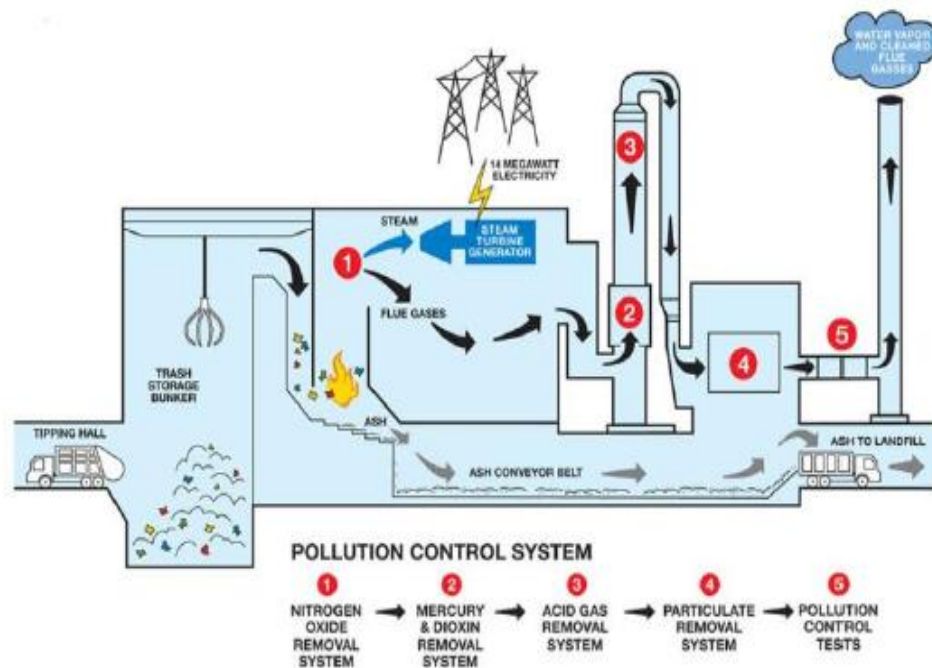


(Source: Alternative Waste Conversion Technologies (White Paper) – International Solid Waste Association, 2012)

#### 3.1.1 Combustion or Incineration

Combustion is one of the oldest ways to convert fuel to useful energy. Combustion of waste is a process in which oxygen reacts with carbon in the fuel and produces carbon dioxide, water and heat. Conventional thermo-chemical conversion of waste to energy provides direct combustion or incineration of combustible non-hazardous waste, thus combining in one stage, pyrolysis, gasification and combustion. The combustion gases typically are treated in either a dry, semi-dry or wet flue gas treatment system to abate emission levels of HCl, NO<sub>x</sub>, SO<sub>x</sub>, dioxins and furans, heavy metals, in order to meet the prescribed emission levels. Depending on heat supply possibilities, the energy that is generated in an incinerator is either primarily converted into heat or into heat and electrical power (CHP) or electricity only if there is no demand for the heat.

Figure 4: Schematic of a Typical Incinerator



(Source: EU Report on Global Analysis of Waste to Energy Field, 2014)

Incinerators are usually provided in two main types of processes:

### 3.1.1.1 Grate combustion

Grate combustion (also called: stoker combustion) consists of waste being introduced onto a moving grate, where it is burned. The unburned material - bottom ash - is typically collected and removed in a wet discharger. Flue gases pass through the steam boiler where steam with typical parameters of around 400°C and 40 bar (there are installations that use considerably higher steam parameters, up to 490°C and up to 135 bar) is generated and converted into electricity and heat through a steam turbine. Flue gases are subsequently cleaned from fly ashes and pollutants through ash collection and dry or wet flue gas treatment.

### 3.1.1.2 Fluidized bed Combustion

Fluidized bed combustion technology consists of particle size reduced waste being introduced in an air stream with a floating sand bed. In view of efficient heat transfer fluidized bed combustion may work at lower combustion temperatures. Flue gases loaded with ash pass the steam boiler section and a dry ash collection / ash cleaning section. Typically waste must be pre-treated by particle size reduction and a stable waste quality (limited variation in heating value) is required. Fluidized bed combustion technology is very suitable for homogeneous waste streams and biomass streams

Incinerator installations claim that waste with a heating value between roughly 7.5 and 15 MJ / kg (depending on the chosen technology) can be efficiently converted into heat and electrical power. Waste with lower and higher heating value can also be treated, with the design of the plant adapted to these conditions. Complete burnout of the waste and flue gases occurs, at net electricity output of 18 - 27% (depending on chosen technology). If heat is supplied for district heating or industrial heating, this will replace part of the electricity output. Installations prove an operational life time of > 20 years and a high average availability of 8,000 h for grate based installations and 7,500 h for fluidized bed.

Key impacts and risks involved with incineration plants include: require large capital investment and show little economic return; do not complement recycling programmes because they require materials with high calorific value (such as paper, cardboard & plastics); requirement of Landfills to dispose of the bottom ash and fly ash which are deemed to be highly toxic; incineration of mixed solid waste leads to emissions of heavy metals, dioxins and other volatile organic compounds that are released into the atmosphere.

### 3.1.2 Pyrolysis

Pyrolysis is the thermal breakdown of waste in the absence of air. Waste is heated to high temperatures (>300°C) by an external energy source, without adding steam or oxygen. In pyrolysis, large hydrocarbon molecules (cellulose, hemicelluloses and part of the lignin) break down into smaller and lighter molecules. The intermediate products that will be created are char, pyrolysis oil and syngas. An example of pyrolysis is the conversion of wood into charcoal.

The initial steps of conventional pyrolysis are usually drying and milling. From milling, raw material enters the pyrolysis chamber, where temperature is high. Condensable volatile gases (heavy hydrocarbons) are recovered and condensed after separation step. Solid products (charcoal) and liquid tar are separated for further treatment and utilization.

Typically two types of pyrolysis processes are used, namely 'slow pyrolysis' in a drum or stationary kiln, generating syngas and char and so called 'flash pyrolysis'; generating primarily pyrolysis oils through condensation of gases into liquids. Condensable pyrolysis gases can be condensed into bio-oil, which can be utilized for vehicles or in CHP-units. Other lighter gases (CO<sub>2</sub>, CO, CH<sub>4</sub>) can be combusted and thus heat can be produced. Slow pyrolysis of waste (often in a drum) is followed by incineration of the gases and chars with subsequent electricity generation in a boiler and a steam turbine; flue gas cleaning is carried out via conventional processes.

For pyrolysis external energy has to be added (gas/oil). In a number of pyrolysis concepts the chars are incinerated at high temperatures. This will decrease operational efficiencies. If syn-gases cannot be incinerated in a gas turbine or a gas engine, electrical efficiencies will be substantially lower for conventional waste to energy combustion.

The key issues with pyrolysis are associated with the quality of the intermediate products such as: High requirement for pre-treatment for the waste input, leading to extra costs; Claims of high quality carbon black production (the char) cannot be met in many cases, lowering income streams; Pyrolysis gases contain high amounts of tars, that lead to malfunction of the power generation cycle behind the pyrolysis installation, reducing income and maintenance requirements and cost of the systems is high.

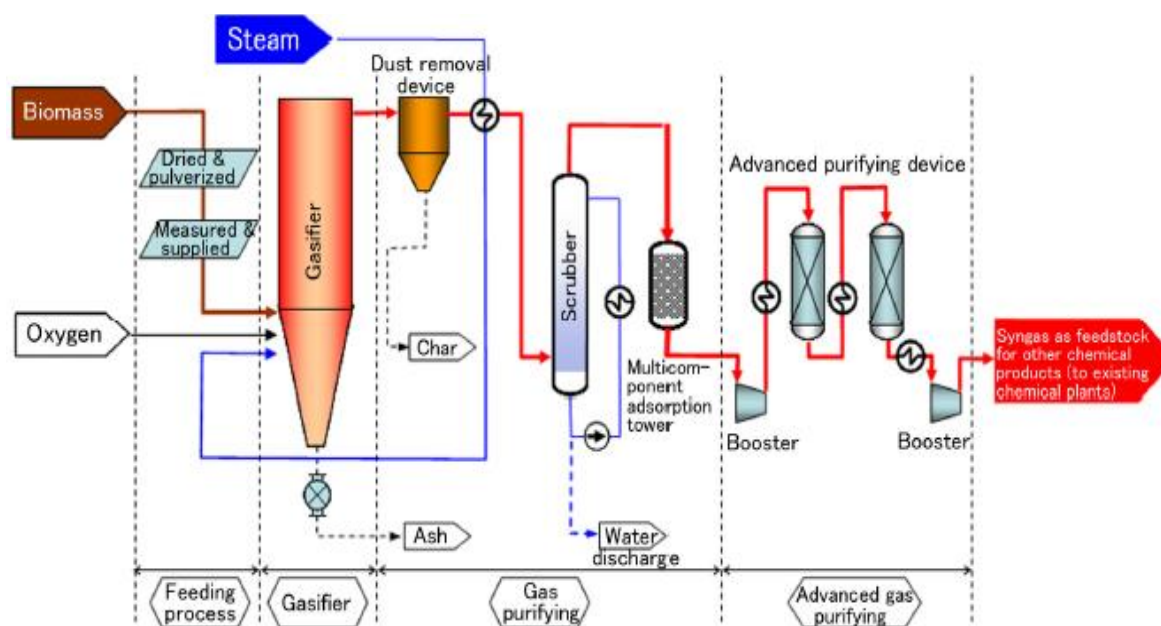
### 3.1.3 Gasification

Gasification is a thermochemical process, which uses biomass as a feedstock in order to produce syngas and other outputs. Gasification is the thermal breakdown of waste under a controlled (lower than necessary for combustion) oxygen atmosphere, thus creating as an intermediate product syngas instead of direct combustion of the waste. The waste (having passed pyrolysis) is allowed to react chemically with steam or limited amounts of air at high temperatures exceeding ~750°C. This consumes the carbon in the waste and produces combustible gases. The tar levels from the syn-gases are lower than in pyrolysis gas. The resulting amount of tar in the syngas differs however between gasification technologies.

The final product, syngas (a mixture of hydrogen and carbon monoxide) can be utilized as a fuel in the internal combustion engine or to run a gas turbine. Ash from the process can be utilized as a fertilizer or as an additive in construction materials. Possible feedstock for gasification includes wood, wood residues, bark, shrubs, sawdust, energy crops and other

wood-based raw materials. Wastes, such as agricultural wastes and crop residues, are also suitable raw materials.

**Figure 5:** Typical Schematic of Gasification Process



(Source: IRENA 2012)

There are two main types of gasification technology:

### 3.1.3.1 Fixed bed Gasifiers

Fixed bed gasifiers typically have a grate to support the gasifying biomass and maintain a stationary reaction bed. They are relatively easy to design and operate and generally experience minimum erosion of the reactor body. Fixed bed gasifiers are the preferred solution for small- to medium-scale applications with thermal requirements up to 1 MW.

### 3.1.3.2 Fluidised (circulating or bubbling) bed Gasifiers

The gasification process occurs in a bed of hot inert materials (usually sand or alumina) suspended by an upward motion of oxygen-deprived gas. As the flow increases, the bed of these materials will rise and become 'fluidised'. The use of inert materials in the bed increases the rate of reaction of the biomass with the fluidised bed compared to fixed bed reactors, thereby improving performance. In addition to improved performance over fixed bed systems, they can accept a wider range of feedstock, achieve larger scales and potentially yield a production gas with a higher energy content. However, fluidised bed systems cost more and are significantly more complex.

The main risks within gasification are associated with the quantity and quality of the intermediate product syngas. This includes:

- High requirement for pre-treatment of the waste input, leading to extra costs
- Syngases contain high amounts of tars, that lead to malfunction of the power generation cycle behind the gasification installation, reducing income
- Calorific value and quantity of produced gases may be lower than designed, thus lowering income streams
- For two stage gasification / combustion processes the efficiency of the process is in all cases lower than for "once through" processes

- Equipment suppliers are not always financially sound and bid at too low prices, reducing project success chances in view of inferior interfaces
- Maintenance requirements and cost of the systems is high.

### **3.1.4 Plasma Gasification**

A plasma Gasification Process is a waste treatment technology that uses electrical energy and the high temperatures (> 2,000°C) created by an electric arc grafiier. This arc breaks down the organic parts of the waste primarily into elemental gas. Plasma is used most efficiently either in a pyrolysis mode or a pure oxygen gasification mode. The plasma arc has very high electrical energy consumption. If oxygen is used for the plasma gasification, also the oxygen use for the gasification will contribute towards internal energy use.

A clear advantage of plasma is that the plasma will effectively clean the syngases from any remaining tar, so that a clean syngas is created, which can be fully utilized. If no oxygen is used for gasification, however “cold gas efficiency” may be low so that it remains the question what will be the ultimate total efficiency. The use of a plasma as the single conversion step for waste is extremely energy intensive.

Therefore a number of plasma suppliers have opted to use the plasma only for gas cleaning after a conventional low temperature gasifier. In that way energy use is far less and still syngases are created that meet with the requirements for highest quality use (in a gas motor or gas turbine); differences between plasma treatment suppliers are mainly in the pre-gasification unit and the plasma configuration.

The main risks within plasma technology/systems are associated with the total energy use and with the safety risks of working within an ultrahigh temperature environment. High requirement for pre-treatment of the input waste, leads to extra costs. A number of risks that are relevant for gasification basically also count for plasma gasification:

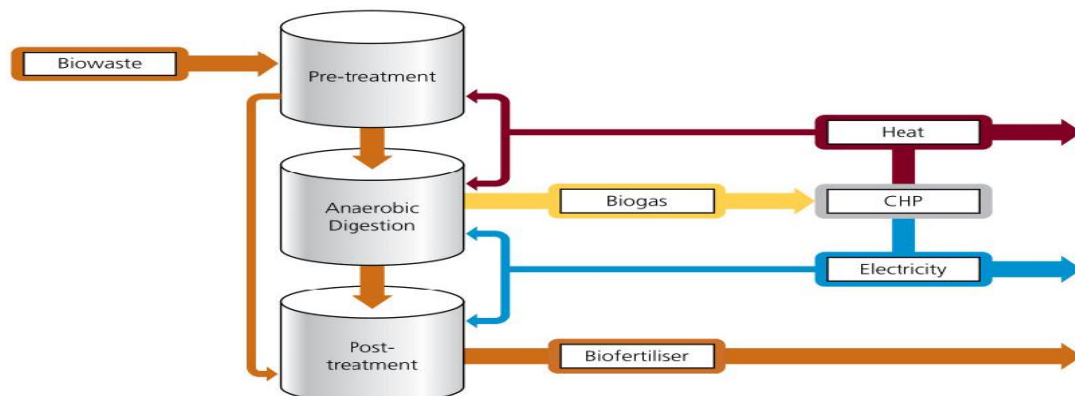
- High requirement for pre-treatment of the waste input, leading to extra costs
- Gross electrical output of the plasma through a gas motor or gas engine
- Energy requirement within the plasma cycle and the cleaning cycle is unclear and may be higher than considered (for instance in view of the production of oxygen that is needed for the process)
- Calorific value, quality and quantity of produced gases may be lower than designed, thus lowering income streams
- Equipment suppliers are not always financially sound and bid at too low prices, reducing project success chances in view of inferior interfaces
- Maintenance requirements and cost of the systems is high

## **3.2 Bio-Chemical Process**

### **3.2.1 Anaerobic Digestion**

Anaerobic digestion (AD) is a biochemical process in which biogas and a solid fraction called digestate is produced from organic matter by micro-organisms in the absence of oxygen. The biogas can be produced from bio-waste, waste waters, energy crops and organic by-products from industry and agriculture.

Biogas is a mixture essentially comprising mostly methane (CH<sub>4</sub>, around 65-70%) but also contains carbon dioxide (CO<sub>2</sub>), around 25-30%), varying quantities of water (H<sub>2</sub>O) and hydrogen sulphide (H<sub>2</sub>S). Other compounds can also be found, especially in waste dump biogas: ammonia (NH<sub>3</sub>), hydrogen (H<sub>2</sub>), nitrogen (N<sub>2</sub>) and carbon monoxide (CO).

**Figure 6: Typical Schematic of Anaerobic Digestion Process**

(Source: EU Report on Global Analysis of Waste to Energy Field, 2014)

Anaerobic digestion occurs in a bioreactor, which can be classified as wet and dry reactors. Municipal organic waste and vegetable waste are used in dry reactors, while wet reactors are more commonly used for manure and sludge waste. The operating temperatures are also divided to mesophilic (35 °C) and thermophilic (55 °C) temperatures. The advantage of thermophilic reactors is shorter retention time, but maintaining a higher temperature requires higher energy input.

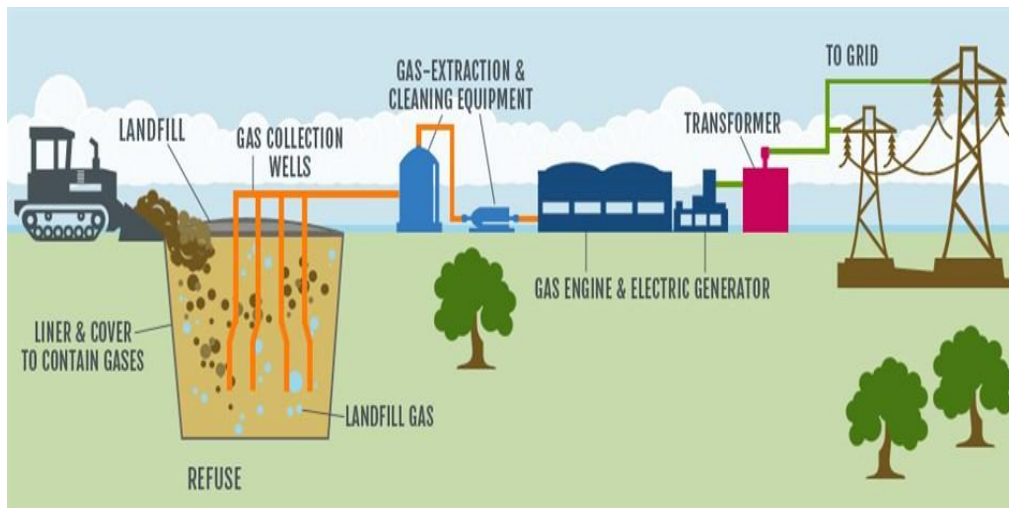
The anaerobic digestion process occurs mainly in four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. In hydrolysis insoluble organic matter is converted to soluble form. The main idea of acidogenesis is to produce acetate, volatile fatty acids, carbon dioxide and hydrogen. Volatile acids are degraded to acetate and hydrogen by acetogenesis. In the final step, acetate and hydrogen are converted to methane and carbon dioxide by methanogenesis.

The final product (biogas) can be used for combined heat and power production. The biogas can be also purified to methane and used as a fuel for vehicles. The residues from the anaerobic digestion can provide further benefits as a fertilizer. Methane is the valuable component under the aspect of using biogas fuel. The (thermal) energy available from the methane contained in biogas is about 6 to 8 kWh/m<sup>3</sup>. This corresponds to half a liter of diesel oil and 5.5 kg of firewood.

### 3.2.2 Landfill Gas Recovery

When waste is deposited in landfills, an anaerobic decomposition takes place, and landfill gas will be produced. The gas contains approximately 50% methane, which can be used for energy purposes. The landfill gas can be captured through a network of gas collection pipes and used to generate electricity. Some of the key factors that influence the generation and collection of landfill gas from a MSW landfill site include the amount, type, and age of waste; moisture content; temperature; pH; and site conditions.

Figure 7: Landfill Gas Recovery and Utilization



(Source: Advanced Disposal)

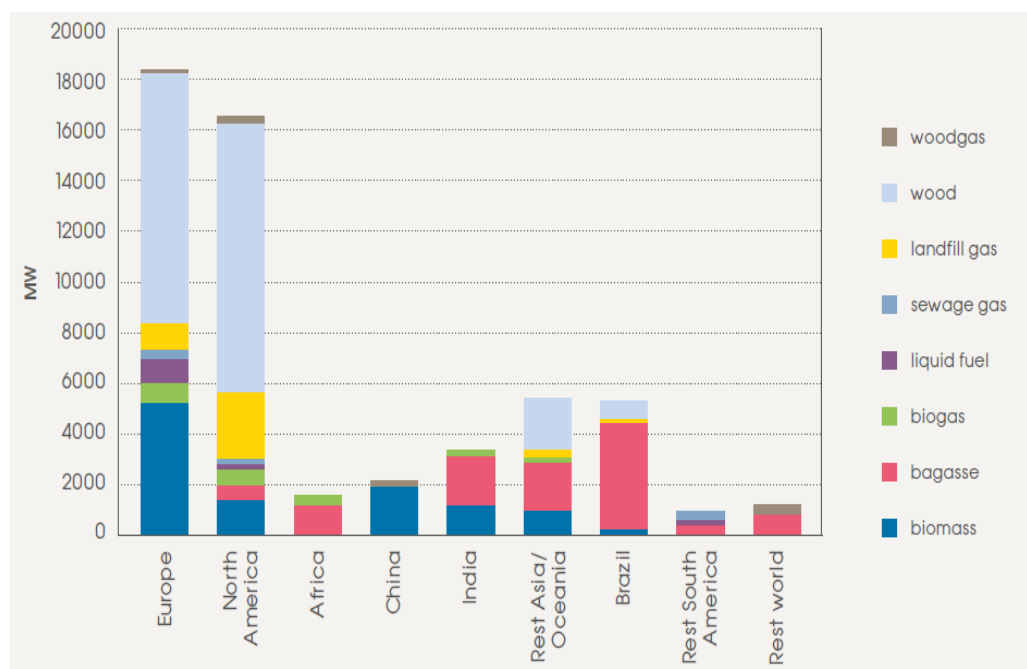
Based on the experiences with landfill gas recovery projects that are generating electricity in other developing countries, on an average, it is observed that around  $6\text{m}^3$  of landfill gas can be produced for a ton of MSW. This rate of generation is estimated to sustain for around 10 to 15 years with a collection efficiency of 75% and methane content of 50%.

Extraction of gas reduces the emission of methane into the atmosphere minimizing in that way the greenhouse effect. Furthermore, landfill gas substitute fossil fuels such as oil, coal and gas that are all contributing to the greenhouse effect. The risk of explosion is also more or less eliminated. Significant barriers to increased diffusion of landfill gas utilization, especially where it has not been previously implemented, can be local reluctance from electrical utilities to include small power producers and from gas utilities/pipeline companies to transport small percentages of upgraded landfill gas in natural gas pipelines.

## 4. Overview of Global Waste to Energy Trends<sup>2</sup>

According to Renewables 2011 Global Status Report, in 2010 the global installed capacity of biomass power generation plants was between 54 GW and 62 GW. This suggests that power generation from biomass represents 1.2% of total global power generation capacity and provides around 1.4% to 1.5% of global electricity production. Europe, North America and South America account for around 85% of total installed capacity globally.

**Figure 8:** Global Grid Connected Waste to Energy Installed Capacities



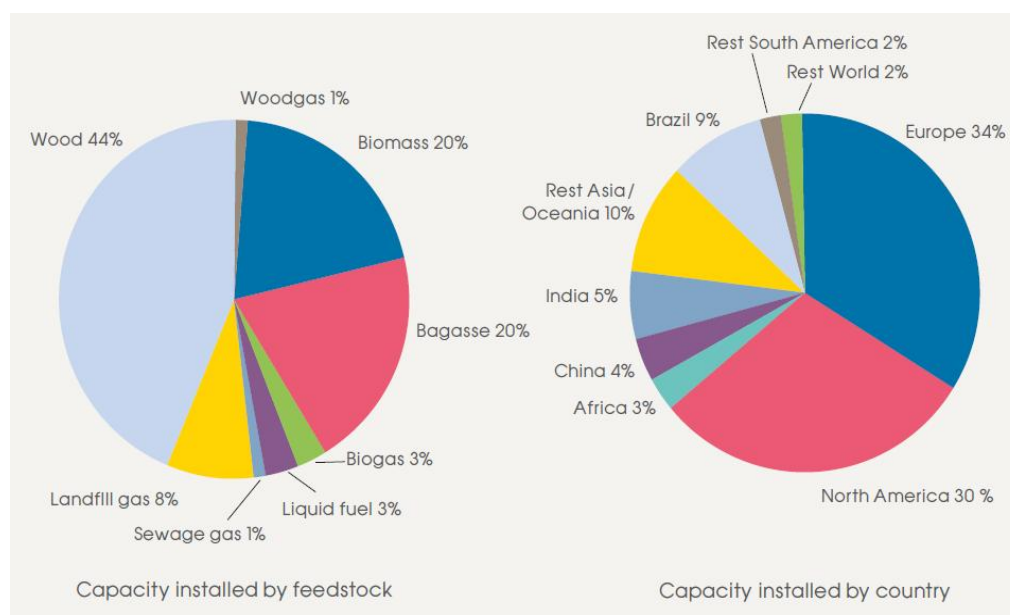
(Source: IRENA 2012)

The combustion of bagasse is the dominant source of electricity from bioenergy in non-OECD countries. Around 84% of total installed waste to energy power generation today is based on combustion with steam turbines for power generation, with around half of this capacity also producing heat (combined heat and power) for industry or the residential and service sectors.

<sup>2</sup> Extracted and Adopted from: IRENA Report on Biomass for Power Generation, 2012, EU Report on Global Analysis of Waste to Energy Field, 2014 and Some Additional Sources Cited in the Reference with Integrations



**Figure 9:** Global Share of Waste to Energy Installed Capacities by Feedstock and Region



(Source: IRENA 2012)

Waste resources currently accounts for a significant, but declining share of total renewable power generation capacity installed worldwide, but significant growth is expected in the next few years due to support policies for renewable energy in Europe and North America. In addition to the environmental and energy security benefits all renewables share, waste to energy has the additional advantage that is a schedulable renewable power generation source and can complement the growth in other variable renewables. Another important synergy for waste to power generation is with the biofuels industry, as the residues from biofuels feedstock (e.g. bagasse, corn stover and straw) and biofuels process residues can be used as raw material for co-generation systems.

According to Bloomberg New Energy Finance (2011), it is estimated that in the longer term, biomass and waste power generation could grow from 62 GW in 2010 to 270 GW in 2030. The expected annual investment to meet this growth would be between USD 21 billion and USD 35 billion. This would represent around 10% of new renewables capacity and investment until 2030.

## 5. Cost Implications of Waste to Energy Projects

Unlike wind, solar and hydro, waste to energy electricity generation requires a feedstock that must be produced, collected, transported and stored. The economics of waste to energy power generation are critically dependent upon the availability of a secure, long term supply of an appropriate feedstock at a competitive cost. Feedstock costs can represent 40% to 50% of the total cost of electricity produced. The lowest cost feedstock is typically agricultural residues like straw and bagasse from sugar cane, as these can be collected at harvest.

The low energy density of biomass feed stocks tends to limit the transport distance from a biomass power plant that it is economical to transport the feedstock. This can place a limit on the scale of the biomass power plant, meaning that biomass struggles to take advantage of economies of scale in the generating plant because large quantities of low-cost feedstock are not available. Prices for feed stocks in developing countries are available but relatively limited. In the case of Brazil, the price of bagasse varies significantly, depending on the harvest period. It can range from zero to USD 27/tonne with the average price being around USD 11/tonne, where a market exists. These low bagasse prices make the economics of waste to energy power plants with other feed stocks extremely challenging, except where a captive feedstock exists.

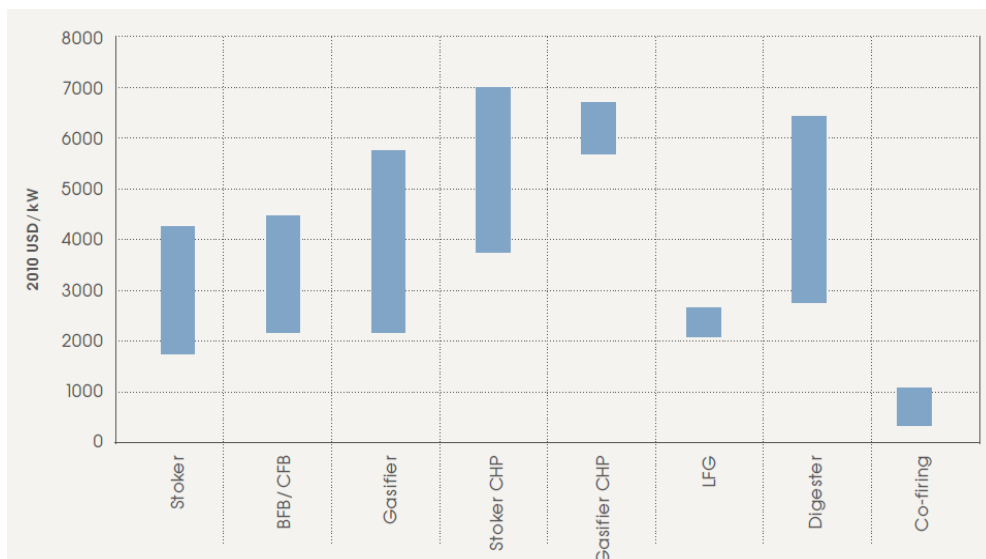
In India, the price for bagasse is around USD 12 to USD 14/tonne, and the price of rice husks is around USD 22/tonne. The biomass resources are multiple including rice straw, rice husks, bagasse, wood waste, wood, wild bushes and paper mill waste. In India, small-scale gasifier systems for off-grid, mini-grid and grid-connected applications are relatively successful and as much as 28 MW were installed by mid-2008 in industry and up to 80 MW in rural systems.

Anaerobic digestion biogas systems typically take advantage of existing waste streams, such as sewage and animal effluent, but it is possible to supplement this with energy crops. They are therefore well-suited to rural electrification programmes. In developed countries, costs tend to be higher and significant economies of scale are required compared to developing countries to make biogas systems economic.

For landfill gas, the cost of the feedstock is simply the amortised cost of the investment in the gas collection system. As per the United States Environmental Protection Agency (EPA) economic assessment for 3 MW landfill gas electricity project using an internal combustion engine (ICE) the costs related to gas collection and flare are around USD 0.9 to USD 2.8/GJ. Biogas has relatively low energy content (from 18–29 MJ/m<sup>3</sup>) and hence significant volumes are required to produce a useful biogas output.

The cost and efficiency of waste to power generation equipment varies significantly by technology. Equipment costs for an individual technology type can also vary, depending on the region but also depending on the nature of the feedstock and how much feedstock preparation and handling is done onsite.

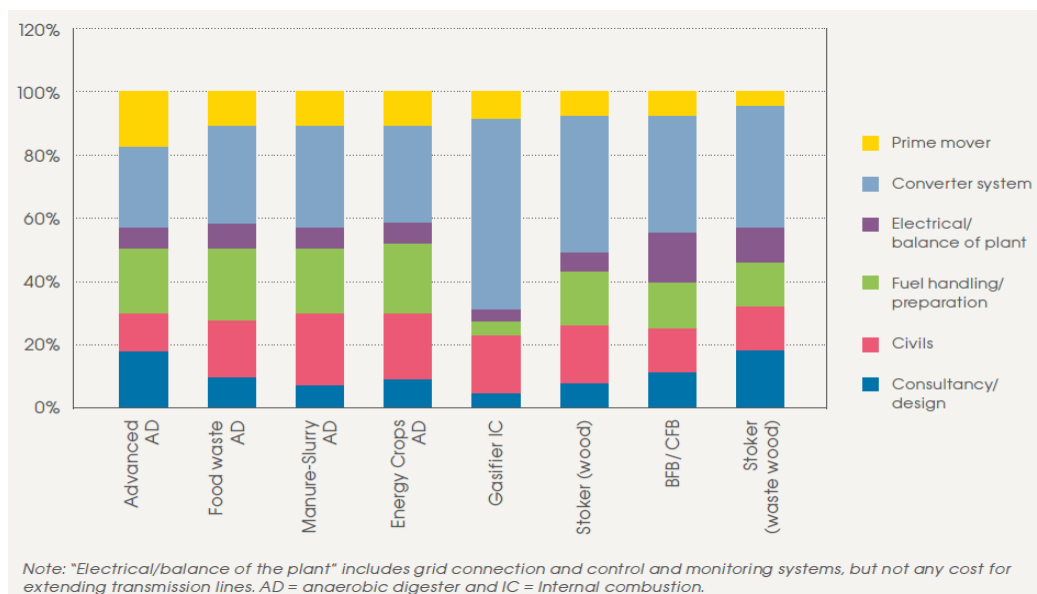
**Figure 10: Capital Costs Range for Waste to Energy Projects by Technology**



(Source: IRENA 2012)

The total investment cost – capital expenditure (CAPEX) – consists of the equipment (prime mover and fuel conversion system), fuel handling and preparation machinery, engineering and construction costs, and planning (Figure 9). It can also include grid connection, roads and any kind of new infrastructure or improvements to existing infrastructure required for the project. Different projects will have different requirements for each of these components with infrastructure requirements/ improvements in particular being very project sensitive. Figure 11 presents a breakdown of the typical cost structure of different waste to energy generation technologies.

**Figure 11: Break Down of Capital Costs for Waste to Energy Technologies**



(Source: IRENA 2012)

Operation and maintenance (O&M) refers to the fixed and variable costs associated with the operation of biomass-fired power generation plants. Fixed O&M costs can be expressed as a percentage of capital costs. For waste to energy power plants, they typically range from 1% to 6% of the initial CAPEX per year (Table 1).

**Table 1: O & M Costs for Waste to Energy Technologies**

Technology	Fixed O&M (% of installed cost)	Variable O&M (USD /MWh)
Stokers / BFB / CFC boilers	3.2 - 4.2 3 - 6	3.8 - 4.7
Gasifier	3 6	3.7
AD systems	2.1 - 3.2 2.3 - 7	4.2
LFG	11 - 20	n.a.

(Source: IRENA 2012)

## 6. Evaluation and Recommendation of Waste to Energy Technology Options

The quantification and assessment of the amount and types of waste resources available in Fiji for waste-to-energy power generation under the study carried out the quantitative and qualitative assessment of various potential wastes to energy resource generated and characteristics of waste resources for each identified waste streams in Fiji. The key waste streams identified were Municipal Solid Waste (MSW); Sewage and Sludge (Waste Water); Livestock Waste; Biomass Waste; Non Hazardous Industrial Organic Waste and Agricultural Crop Residues.

A macro assessment was carried out focusing on estimating the theoretical potential for power generation from the identified waste streams and assessing the feasibility of the available resources for energy generation. The assessment identified that the biomass waste stream (bagasse & logging and forestry industry residues) has the highest theoretical potential for electricity generation followed by MSW and livestock waste. However, as discussed in the earlier reports, collection, handling and transportation costs are the key challenges for utilizing the available biomass and agricultural residues effectively in Fiji.

**Table 2:** Estimated Electricity Generation Potential in Fiji from Waste Resources

Waste Stream	Type of Waste Resource	Technology Considered	Estimated Electricity Generation Potential ( GWh/Year)
Municipal Solid Waste (MSW)	Solid wastes dumped at landfills & dumps	Thermo-chemical conversion	38.1
		Landfill Gas Recovery	1.3
Sewerage Sludge	Sewage or domestic wastewater	Anaerobic Digestion	12.33
Livestock Waste	Waste from Cattle, Goats, Sheep, Poultry & Pigs	Anaerobic Digestion	183.9
Biomass Waste	Bagasse + Logging & forestry industry waste	Thermo-chemical conversion	399.9 (Bagasse -45.4 & Logging & Forestry Industry Wastes - 354.5)
Non-hazardous Industrial Waste Water	Organic waste from Abattoirs, distilleries & Breweries	Anaerobic Digestion	14
Agricultural Crop Residues	Organic waste residues from agricultural & farming activities	Thermo-chemical conversion	268.6

Based on the assessment for identification and quantification of waste resources in Fiji (Report 1 & 2 under the study), a technology evaluation and recommendation matrix (table 2) has been developed which provides an overview of the selected waste to energy conversion options. The matrix represents the full range of available technologies that can transform waste resources into electricity. Most of these technologies have reached a good level of commercial maturity, and their deployment in the market is common in several regions of the world. Please refer to Annex 1 for some case study examples.

Options for biogas production from organic waste are all commercially available at any scale. The main advantage of bio-chemical conversion of organic waste to biogas is that it can be applied to wet waste streams, while other technologies would require a high energy input for drying the wet biomass streams first. Under the thermo-chemical conversion here are various technologies commercially available for direct combustion of waste resources to produce power and heat. The size of production units range from 4 kW (household level) to 50 MW in the case of co-combustion or combined heat and power (CHP) installations. The

technologies under this group claim efficiency levels ranging from 75% to 90%. As discussed earlier, the O & M costs for CHP generation are higher than for boiler and co-combustion technologies.

**Table 3:** Technology Evaluation and Recommendation Matrix for Waste to Energy Projects in Fiji

Waste Resource & Sites	Estimated Potential (MWh/year)	WTE Technology	Investment Cost (USD)	Environmental Impact		Social Impact	
				On Reducing GHG Emission	On Ecosystem	Social Benefits	Acceptability
<b>Municipal Solid Waste (MSW)</b>							
Naboro Landfill	23,290	Incineration/Pyrolysis	2500 to 6000 /KW	Average	Disputed <sup>3</sup> Opinion	Low	Low
	800	Landfill Gas	1500 to 2200/KW	High	Neutral due to Leachate issue	Medium	High
Lautoka (Vanutu) Dump	8,921	Incineration or Pyrolysis	2500 to 6000 /KW	Average	Disputed Opinion	Low	Low
	306	Landfill Gas	1500 to 2200/KW	High	Neutral due to Leachate issue	Medium	High
Suva Market Waste	1,000	Biogas (Anaerobic digestion)	2200 to 4000/KW	High	Positive	High	High
<b>Sewerage Sludge</b>							
Kinoya STP	8,450	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
<b>Livestock Waste</b>							
Naboro Piggery	140	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
Vuda Piggery	639	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
Leyland Piggery	320	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
Ramsami Poultry	1095	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
<b>Biomass Waste</b>							
Logging & Forest Residues	39,990	Combustion/CHP/Gasification	2500 to 6000 /KW	Average	Neutral to positive	Average	Average
<b>Non-hazardous Industrial Waste Water</b>							
Fiji Meat Industries	12,464	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
South Pacific Distilleries	1,500	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
Paradise Beverages	138	Biogas (Anaerobic digestion)	3000 to 8000/KW	High	Positive	High	High
<b>Agricultural Crop Residues</b>							
Across Fiji	268,600	Combustion/CHP/Gasification	2500 to 6000 /KW	Average	Neutral	Low	Low

<sup>3</sup> Mainly due to the emissions of heavy metals, dioxins and other volatile organic compounds that are released into the atmosphere

## **7. Conclusion & Next Step**

The report provides an up-to-date assessment of the state of the art in waste to energy conversion technologies. Further, the most suitable conversion options has been assessed and recommended for the most relevant waste streams including identified potential projects. An overview of the level of maturity of waste to energy technologies including the associated costs and the required technical skills for operation and maintenance has also been provided.

Biogas production from anaerobic digestion of organic waste generated from market waste, sewage sludge, piggeries, poultry farms, distilleries and breweries and slaughterhouse waste appears to be the most promising waste to energy conversion option for Fiji due to the lack of alternative treatment technologies for these waste streams. Conversion technologies such as combustion, CHP and gasification for the production of power and/or heat could be an interesting option for biomass waste stream including logging and forestry industries wastes. As discussed in the earlier reports, The two IPPs, Fiji Sugar Corporation (FSC) and Tropik Wood Industries Ltd (TWIL) are already involved in biomass waste to energy generation (bagasse & wood residues)in Fiji and are consuming most of the economically available biomass waste generated by using them as fuel at the existing power plants. Collection, handling and transportation costs are the key barriers in utilizing the available biomass resource effectively.

Although the conversion potential for agricultural residues are significant in Fiji, similar to the biomass, collection and transportation costs of agricultural residues to a centralized location for electricity generation waste are key barriers due to small land holdings and dispersed nature of the agricultural residues. Given the issues and constraints with using agricultural residues as feed stock for electricity generation, it is suggested that briquetting or pelleting of agricultural residues could be a potential option to make use of large unused quantities of residues.

It is envisaged that this assessment will assist and support in terms of decision- making regarding future investments in the development waste to energy projects and business in Fiji. The identified potential projects could be of value to decision-making regarding the selection of pilot scale demonstration projects. It is to be noted that the information provided in the report is explorative and is by no means intended to replace dedicated feasibility studies. As discussed in the report, a variety of technology options exist for conversion of waste resources to energy. These options can serve many different energy needs (such as power, heat etc.), from large-scale industrial applications to small-scale rural end-uses.

The next and the final report under the study will look at providing appropriate recommendations on how to effectively implement waste-to-energy power generation facilities in Fiji.

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## **Annex 1: Case Studies of Waste to Energy Initiatives**

### **Municipal Solid Waste Incineration for Power Generation, Suzhou, China**

#### **Project Background**

Municipal Solid Waste Incineration for Power Generation Project developed by Ever bright Environmental Energy (Suzhou) Limited is located in Mudu town, Wuzhong district, Suzhou city, Jiangsu Province, China. The Project has been established for the purpose of treating MSW with energy recovery for electricity generation.

#### **Main Features**

The project is designed to deal with a daily average capacity of 1500 tonnes of MSW through three incineration systems, each with the treatment capacity of 500 tonnes per day. Two steam turbine-generator units with total installed capacity of 30MW (2\*15MW) are installed for generating electricity to utilize the MSW combustion heat. On an average, about 500,000 tonnes of MSW is treated per year. The project generates around 190,000MWh of electricity annually and supplies 156,000 MWh of electricity to the East China Power Grid (ECPG).

The key technical aspects for the project include: mechanical grate incinerator for MSW; condensing steam turbine generator; pollution control equipment and measures; flue gas cleaning and other waste treatment. The total capital costs for the project was 745.9991Million Yuan.

#### **Impact**

Prior to implementation of the project activity, the MSW collected from Suzhou city was mainly transported to the Suzhou landfill approximately 13.5 km away from the city centre. There was no gas capturing or flaring system installed at the landfill site and the methane and other toxins were released into the atmosphere directly without recovery and utilization. Further, prior to commissioning of the project, the local electricity demand was met by the East China Power Grid dominated by fossil fuel based generation.

The project has significant environmental and social benefits and will contribute to the local sustainable development as below:

- Generate clean and sustainable electricity
- The project will dispose of MSW by incineration technology to avoid CH<sub>4</sub> emission from the disposal of the waste in landfill site.
- Reduce GHG emissions and mitigate emissions of other pollutants caused from local coal-fired power plants by displacing part of fossil fuel based electricity;
- Stimulate economic development and improve the environment of local area.
- Create more employment opportunities over the project construction and operation period.

## **Biomass Gasification for Renewable Power, Tamilnadu, India**

### **Project Background**

Arashi Hi-Tech Bio-Power Private Limited (AHBPPL) established a 1.25 MW biomass gasification power project located in Coimbatore district, Tamilnadu. This is the first grid connected biomass gasification power project in India. Coconut residues are the major fuel for this project activity which is available abundant in this region.

### **Main Features**

The system consists of two gasification reactor of each 500 kW capacity. The producer gas generated from the gasifier is passed through the hot cyclone where the particulate are stripped off from the gas due to centrifugal separation. The gas beyond this goes to cooling and scrubbing systems, where tar and particulate matter are removed. For further removal of tar the gas will be passed through the chilled water scrubber and bag filters. The biomass supplied to the gasifier is converted into producer gas, then the generated producer gas is supplied to the five numbers of 250 kW producer gas engine. The generated electricity is exported to Tamilnadu Electricity Board (TNEB) grid and consumed by its sister company by wheeling.

### **Impact**

The project contributes to the sustainable development through the effective utilization of surplus biomass residues available in the project region for power generation, thereby enhancing additional income through rural employment opportunities in the region. In addition, generation of eco- friendly power and reduce the dependence on fossil fuel based conventional power contributes to climate change mitigation.

The project also assists in generating enhanced income for the local populace involved in growing, harvesting, handling and selling of biomass. It also improves the availability of power in the region leading to enhanced and appreciable development in agricultural and industrial activities.

Since the project is located in a village it will assist in alleviation of poverty to certain extent by generating both direct and indirect employment in the area of skilled/unskilled jobs for regular operation and maintenance of the power plant. The possibility of using the gasifier for internal combustion engine makes it a potential competitor for decentralized power generation. The advantage of decentralised power generation is reduction in transmission and distribution losses and the prospect of rural electrification- a major concern for India.

## **Sewage Biogas Electricity Generation Project, Makati, Philippines**

### **Project Background**

The Makati South Sewage Treatment Plant with on-Site power generation has been developed by Magallanes Bio-Energy Corporation. This is an anaerobic digestion sludge treatment project at the sewage treatment plant located in Magallanes Village, Makati City, Philippines.

### **Main Features**

The project approximately treats 900m<sup>3</sup> of sludge with a COD of 20,770 mg/L through anaerobic digestion on a daily basis in the sludge treatment system. The high rate biological treatment system enhances the existing sludge treatment capacity. The 'Covered in Ground Anaerobic Reactor' (CIGAR) breaks down the organic components of the sludge in the absence of oxygen in a highly efficient process. High density polyethylene (HDPE) liners and covers are used in the construction of a purpose built bioreactor to provide a 'gas seal' and to ensure the full integrity of the system.

The biogas captured by the CIGAR process is used to generate electricity for use on-site. Three units of biogas fuelled 300 kW engines produce around 1,990 MWh of electricity annually, satisfying the power requirements of the sewage treatment plant. The electricity produced which exceeds the demand of the site is being sold to Magallanes village, the immediate community.

### **Impact**

The project demonstrates that sewage can successfully be used as a source of energy generation. The use of sewage waste has a range of potential environmental benefits such as a decrease in greenhouse gas emissions. The project reinforces the business case for further sewage waste to energy deployment and reduces national fuel import needs and healthy living environment for the citizens.

## **Livestock Waste based Electricity Generation, Santa Rosillo, Peru**

### **Project Background**

Santa Rosillo is a small, isolated community (224 people) with approximately 67 head of livestock. At night, these animals stay in a pen for 12 hours, accumulating 160 kilograms (kg) of manure. Prior to this project, the manure was randomly disposed off in the village and had no productive use or disposal pathway.

### **Main Features**

The two bio-digesters (each of 93 m<sup>3</sup>, giving a total capacity of 186 m<sup>3</sup>) installed produces around 16 kW of electricity for domestic and productive uses. Cattle manure is added in daily loads of 270-360 kg. Key features of the project include:

<i>Site Name</i>	: BioSynergy, Santa Rosillo Village, Huimbayoc, San Martin, Peru
<i>Site Type</i>	: Small, communal village farm (67 animals)
<i>Digester Type</i>	: Trapezoidal lake type with a PVC-reinforced geo-membrane; 289.6 m <sup>3</sup> (two digesters total volume of liquid and gas)
<i>Biogas Generation:</i>	Between 8.74 and 11.65 m <sup>3</sup> of biogas are produced per day. The equipment used to generate electrical energy is two generators that have a total combined power of 16kW.
<i>Biogas Use</i>	: Electrical energy via combustion in electrical generators

### **Impact**

The key benefits include:

- Improved community access to sustainable energy
- Provides electricity to communal centre, school, clinic, and church; as well as public lighting for evening activities
- Utilizes fertilizer for improved crop production and cost savings

The project focuses on an innovative model for electricity generation in isolated communities, taking advantage of livestock waste that is locally available. The slurry is used as fertilizer to increase yields of crops such as cacao, coffee and others. The project also aims to contribute to a reduction in poverty levels in dispersed and isolated communities in the Peruvian Amazon, by demonstrating the technical, social, economic, and environmental feasibility of an integrated and self-sufficient renewable energy access model.

## **Landfill Gas Recovery and Utilization, San Salvador, El Salvador**

### **Project Background**

The Nejapa Landfill receives MSW from the San Salvador metropolitan area through a contractual agreement with the private operator of the landfill. From 1999 through June 2005, roughly 2.7 million tonnes of MSW was disposed at the landfill, and this tonnage is expected to increase to 12.5 million tonnes by 2024.

The project activity is to recover and utilise the landfill gas emanating from the Nejapa landfill in order to reduce greenhouse gas (GHG) emissions and to address numerous other environmental related issues.

### **Main Features**

The 6 MW power generation project was developed in two phases: Phase 1 involved design, construction, and operation of the LFG collection and flaring system; Phase 2 involved design, construction, and operation of an LFG electricity system.

The collection system is designed as simply and efficiently as possible for gas extraction: vertical wells and bentonite seal to reduce air infiltration, surface horizontal collectors for ease of inspection and repair, sole well head connection to main collector for easy balancing of the well pressure, condensate trap located at low points in the gas collection system to remove condensate to minimize clogging risk, blower station, enclosed flaring station and power plant for methane combustion.

The facility installed on site is made of multiple 1.059 MW engines. Each internal combustion engine, especially designed to run on low calorific value gas, is equipped with its own electric generator. The use of multiple engines allows for a flexible operation over the years, as landfill gas volume varies, as well as reducing installation cost and maintenance.

### **Impact**

The key project impacts and benefits include:

- Contributes to sustainable development in El Salvador.
- Mitigates odors, fire issues, and LFG migration in surrounding neighbourhood.
- Project has reduced emissions by 753,560 tonnes of carbon dioxide equivalent (CO<sub>2</sub>e) emissions from 2006 to 2010.
- Generates management, operation and maintenance opportunities associated with the project.
- Improves environmental and health-related conditions.
- Creates opportunities for socio-economic development through technological transfer and collaboration.
- Contributes to the reduction of dependency on fossil fuel.
- Promotes replication of similar projects to other landfill owners, project developers, and energy companies in El Salvador and Central America.