CROSS-SECTORIAL

TECHNOLOGY CATALOGUE

FOR SOLID WASTE MANAGEMENT AND WASTE TO ENERGY

Lombok & Batam/Kepri

EMBASSY OF DENMARK
Jakarta I Indonesia

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DEVELOPMENT OF A CROSS-SECTORIAL TECHNOLOGY CATALOGUE FOR SWM AND ENERGY

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1 Foreword

The world enjoys a vast amount of technologies and solutions for the many challenges of our everyday lives. The aim of this technology catalogue is to help provincial energy planners get an overview of existing and developing technological solutions related to solid waste management and waste to energy. Planning for solid waste management is a difficult task with a wide range of considerations related to feedstock and choice of technology. Residual waste from agriculture can provide valuable feedstock for bio-based waste to energy projects. This report presents a range of technologies with attributes able to mitigate the waste streams in Lombok and Batam/Kepri. Choosing a given technology for a project will depend upon a variety of factors, but none the least the economic and technical performances of a given technology are vital parts of defining the best fit for a waste to energy project. The intention behind this catalogue is to provide the reader with such information.

The technology catalogue is the first of its kind created as a product of the Indonesian-Danish Energy Partnership Programme. A broad set of actors, including local Dinas ESDM, local governments and PLN, from both Lombok and Batam/Kepri have contributed to the final product. The vision is to provide comparable aspects of relevant technologies to improve the sustainability of solid waste management. The methodology behind this report is closely tied to the approach used in the Danish technology catalogues.

The authors of this report hope to see this catalogue become useful in the coming years as Lombok and Batam/Kepri will continue to develop pathways mitigating environmental concerns from the waste sector.

2 List of abbreviations

Abbreviation	**Meaning**
ATEX	Atmosphères explosibles
BAT	Best Available Technology
BFB	Bubbling Fluidised Bed
CSTR	Continuously Stirred Tank Reactor
DCS	Distributed Control System
CAPEX	Capital Expenditures
CEMS	Control Emission Monitoring System
CFB	Circulating Fluidised Bed
C&DW	Construction & Demolition Waste
GDP	Gross Domestic Product
GHG	Green House Gasses
ha	Hectare – 10.000 m^2
Kg/d/capita	Kilo per day per person
ktpa	Kilo Tonne Per Anno
LFG	Landfill Gas
LNG	Liquified Natural Gas
LPG	Liquefied Petroleum Gas
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditures
ORC	Organic Rankine Cycle
MBT	Mechanical Biological Treatment
MJ	Mega Joule
MSW	Municipal Solid Waste
NDT	Non Destructive Testing
RDF	Refuse Derived Fuel
RFB	Revolving Fluidized Bed
SRF	Solid recovered Fuel
SWM	Solid Waste Management
tpa	Tonne Per Anno
tonne/h	Tonne per hour
tpd	Tonne per day
USD	United States Dollar
WtE	Waste to Energy

3 Introduction

This technology catalogue for Solid Waste Management (SWM) and Energy describes technologies for handling waste in Lombok and Batam/Riau Islands, with a focus on electrical production. For determination of the relevant technologies the catalogue starts with descriptions of the available waste amounts in Lombok respectively Batam/Riau Islands.

The Waste to Energy (WtE) technologies described in this catalogue cover both mature technologies and technologies which are still under development. Some of the technologies still under development have been used in relation to handling waste (in most cases sorted waste) but the operation of the plants has in general not been acceptable, and therefore implementation of the technology is limited.

This catalogue covers many different technologies for handling solid waste and biomass, which have only been implemented in Japan. Japan has a unique legislation in relation to handling waste and requirements to the by-products from handling waste, and therefore some of the technologies have been implemented on several plants in Japan, but not outside Japan.

For the mature technologies the price level and performance are in general well known and therefore these can be stated with a relative high level of certainty. Though, with the reservation that the prices in for example Europe are in general not the same as in islands in Indonesia. For the technologies with fewer (and in some cases very few) references both cost and performance today as well as in the future have a high level of uncertainty.

All technologies have been grouped within one of four categories: 1. Incineration Technologies, 2. Other Thermal Technologies, 3. Biological Treatment and 4. utilization.

The boundary for both cost and performance data are the generation assets but not the infrastructure required to deliver the energy to the main grid. The figures given for electrical power is the gross generation minus the auxiliary electricity consumed at the plant. This also means the electrical efficiencies are net efficiencies.

Unless otherwise stated, the thermal technologies in the catalogue are assumed to be designed for and operating for approx. 6,000 full-load hours of generation annually (capacity factor of 70%). Some of the exceptions are grate-fired incineration, which are designed for continuous operation, i.e. approximately 8,000 full-load hours annually (capacity factor of 90%).

When biomass is mentioned in this catalogue, it is meant as biomass which otherwise would have been waste for landfill, if not utilized for energy production. This biomass is a by-product from agriculture, waste wood (from demolition etc.), food waste or garden/forest waste. (Manure can be utilized in agriculture but also in production of biogas).

Where relevant and where the data is available the section for the technology has a data sheet included, following the format explained below. These have been filled into the extent possible based on the available data.

Below Figure 1 gives an overview of the technologies included in the catalogue and the outputs from each technology.

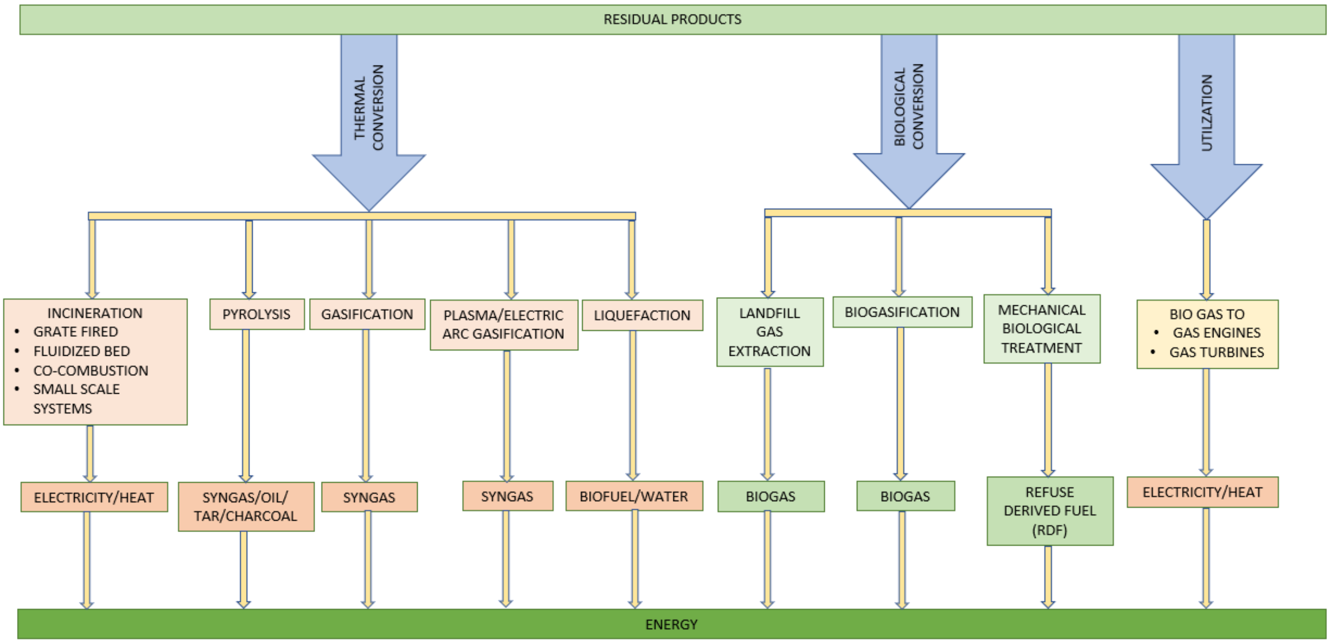

Figure 1. Overview of technologies included in the catalogue and the outputs.

4 Methodology

4.1 Structure of Technology section

4.1.1 Brief technology description

Brief description of how the technology works and for which purpose.

4.1.2 Inputs

The main raw materials, primarily fuels, consumed by the technology.

4.1.3 Outputs

The output of the technologies in the catalogue is electricity. Other output such as process heat are mentioned here.

4.1.4 Capacities

The stated capacities are for the total power plant consisting of a multitude of ‘engines’, e.g. spark gas engines. The total power plant capacity should be that of a typical installation for the two islands in question.

4.1.5 Ramping configuration

Brief description of ramping configurations for electricity generating technologies, i.e. what are the part-load characteristics, how fast can they start up, and how quickly are they able to respond to demand changes (ramping).

4.1.6 Advantages/disadvantages

Specific advantages and disadvantages relative to equivalent technologies. Generic advantages are ignored; for example, that renewable energy technologies mitigate climate risk and enhance security of supply.

4.1.7 Environment

Particular environmental characteristics are mentioned, e.g. special emissions or the main ecological footprints.

4.1.8 Employment

Description of the employment requirements of the technology in the manufacturing and installation process as well as during operation. This will be done both by examples and by listing the requirements in the legal regulation for local content (from Minister Decree or Order No. 54/M-IND/PER/3/2012 and No. 05/M-IND/PER/2/2017). It is compulsory for projects owned or funded by the government or government-owned companies to follow these regulations. The table below summarizes the regulation. By local content requirement is meant the amount of work and/or resources that must be applied in Indonesia.

4.1.9 Research and development

The section lists the most important challenges from a research and development perspective. Particularly Indonesian research and development perspectives is highlighted if relevant.

The section also describes how mature the technology is.

The first year of the projection is 2020 (base year). In this catalogue, it is expected that cost reductions and improvements of performance are realized in the future.

This section accounts for the assumptions underlying the improvements assumed in the data sheet for the years 2030 and 2050.

The potential for improving technologies is linked to the level of technological maturity. Therefore, this section also includes a description of the commercial and technological progress of the technology. The technologies are categorized within one of the following four levels of technological maturity.

Category 1. Technologies that are still in the *research and development phase*. The uncertainty related to price and performance today and in the future, is very significant.

Category 2. Technologies in the *pioneer phase*. Through demonstration facilities or semi-commercial plants, it has been proven that the technology works. Due to the limited application, the price and performance is still attached with high uncertainty, since development and customization is still needed (e.g. gasification of biomass).

Category 3. *Commercial technologies with moderate deployment* so far. Price and performance of the technology today is well known. These technologies are deemed to have a significant development potential and therefore there is a considerable level of uncertainty related to future price and performance (e.g. offshore wind turbines).

Category 4. *Commercial technologies, with large deployment* so far. Price and performance of the technology today is well known, and normally only incremental improvements would be expected. Therefore, the future price and performance may also be projected with a fairly high level of certainty (e.g. coal power, gas turbine).

4.1.10 Capital Expenditures (CAPEX)

In this section investment cost projections from different sources are compared, when relevant. If available, local projects are included along with international projections from accredited sources (e.g. IRENA). On top of the table, the recommended cost figures are highlighted. Local investment cost figures are reported directly when available, otherwise they are derived from the result of PPAs, auctions and/or support mechanisms.

Cost projections based on the learning curve approach is added at the bottom of the table to show cost trends derived from the application of the learning curve approach (see the

Appendix for a more detailed discussion). Technological learning is based on a certain learning rate and on a capacity deployment defined as the average of the IEA's Stated Policies and Sustainable Development. The single technology is given a normalized cost of 100% in 2020 (base year); values smaller than 100% for 2030 and 2050 represent the technological learning, thus the relative cost reduction against the base year. An example of the table is shown below.

As for the uncertainty of investment cost data, the following approach was followed: for 2020 the lower and upper bound of uncertainty are derived from the cost span in the various sources analysed. For 2050, the central estimate is based on a learning rate of 12.5% and an average capacity deployment from the STEPS and SDS scenarios of the World Energy Outlook 2019 (see Appendix: forecasting the cost of electricity production technologies). The 2050 uncertainty range combines cost spans of 2020 with the uncertainty related to the technology deployment and learning: a learning rate range of 10-15% and the capacity deployment pathways proper of STEPS and SDS scenarios are considered to evaluate the additional uncertainty. The upper bound of investment cost, for example, will therefore be calculated as the upper bound for 2020 plus a cost development based on the scenario with a learning rate of 10% combined with the scenario with the lowest deployment towards 2050.

4.1.11 Examples

Recent technological innovations in full-scale commercial operation should be mentioned, preferably with references and links to further information. This is not necessarily a Best Available Technology (BAT), but more on an indication of the standard that is currently being commissioned.

4.1.12 References

All descriptions shall have a reference, which is listed and emphasized in the qualitative description.

4.1.13 Data sheet

(See separate sheet)

Technology	Name of technology								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)									
Generating capacity for total power plant (MWe)									
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average									
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)									
Construction time (years)									
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (g per GJ fuel)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)									
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)									
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1

2

Notes:

A

B

5 Summary

Lomboks feedstock

For the whole of Lombok, the estimated generated amounts of Municipal Solid Waste (MSW) for final disposal in 2025 is 752 tonne per day (tpd) (equal to 31 tonne per hour). The amounts for the district are shown in below Table 1. As shown in the table the generated waste amounts in northern Lombok is relatively small compared to the other districts.

	MSW for final disposal (tpd)
West Lombok	140
Central Lombok	175
East Lombok	221
North Lombok	33
Mataram City	183
Total	752

Table 1. MSW for final disposal in 2025 for the 5 districts.

The lower calorific value of the waste has been estimated to 5.8 MJ/kg. For European countries the lower calorific value is in average 10 MJ/kg, so the calorific value is relatively low. The relative lower calorific value is nevertheless high enough for example grate incineration where in general the lower limit is 5.5 MJ/kg.

Batams feedstock

For Batam the total municipal solid waste amount for disposal is 876 tonne per day. The estimated lower calorific value is 8.7 MJ/kg.

Technologies for handling municipal solid waste

The technologies described in this catalogue for handling municipal solid waste have a wide span in relation to technological development; some are very mature and some of them are very new and research and development is still ongoing for improving the technologies. Also, some of the technologies requires large investments as for example grate incineration and some smaller investments as for example landfill gas extraction.

Based on the descriptions of the technologies for handling municipal solid waste and the description of utilizing biogas as well as Solid Recovered Fuel/Refuse Derived Fuel (SRF/RDF) further work must be done for developing and maintaining this Technical Catalogue, so that it will be a used to the widest extent possible within the Indonesian energy sector.

Further work must be done in relation to determining which technologies are best feasible in relation to among other the available feedstocks in the different provinces, the calorific values of the waste, the income from gate fees, electricity sale, investments, required land etc.

6 Feed stock inventory for Lombok and Batam

This chapter outlines the available feed stock for the two selected areas, Lombok and Batam. The Catalogue describes technologies relevant to this feed stock.

6.1 Lombok

Lombok (with several islets (Gili) surrounding it) is an island in West Nusa Tenggara province, Indonesia, part of the Lesser Sunda Islands. The Lombok Strait separates it from Bali to the west and the Alas Strait separates it from Sumbawa to the east. The island is about 70 kilometres across and has a total area of about 4,514 km². The provincial capital and largest city on the island is Mataram. The 2020 population for the entire island is estimated at 3.6 million. The main livelihood in Lombok is subsistence farming and tourism.

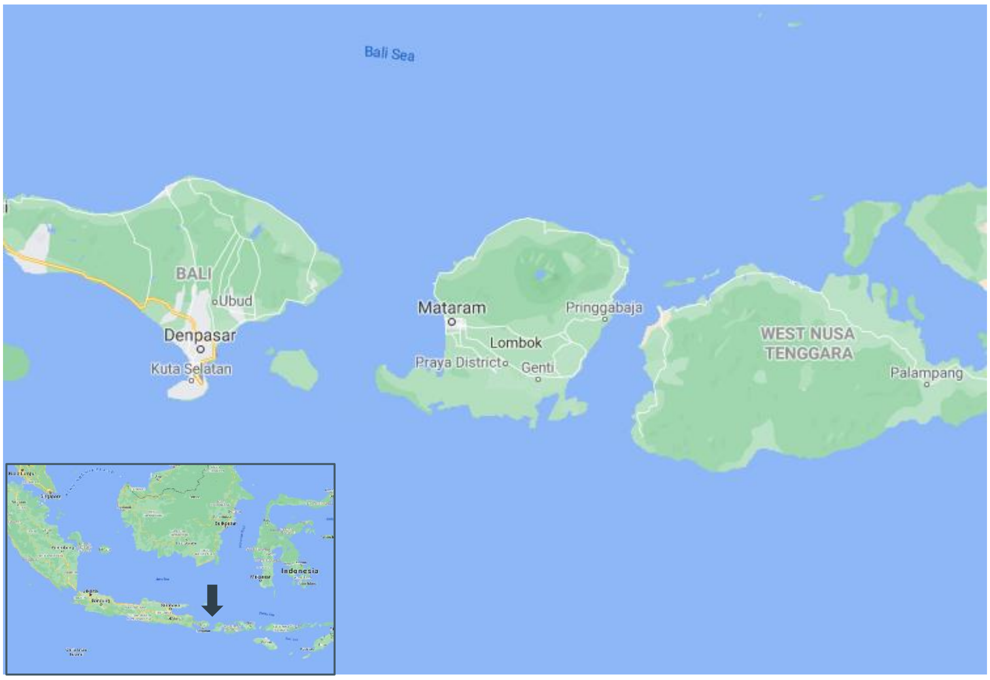

Figure 2 Map showing Lombok (West Nusa Tenggara) and Bali

Lombok is divided into four districts (Kabupaten) and one City (Kota): North, East, Central, and West Lombok, and Mataram City.

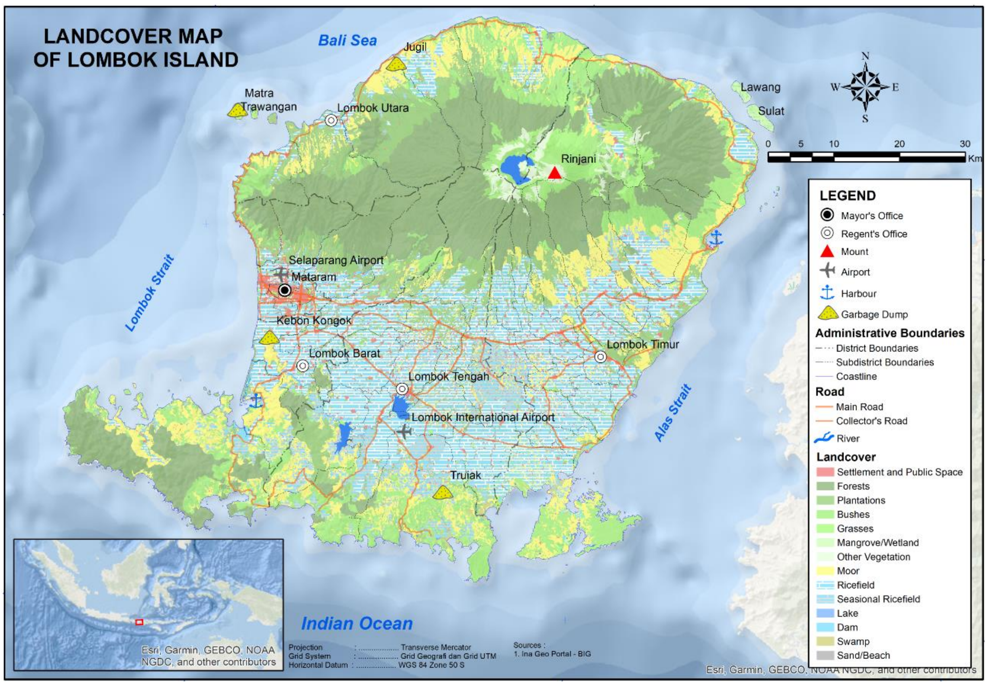

Figure 3 Landcover map of Lombok

The highlands of Lombok (mainly North Lombok) are forest-clad and mostly undeveloped. The lowlands (including parts of East, Central and West Lombok) are highly cultivated. Rice, soybeans, coffee, tobacco, cotton, cinnamon, cacao, cloves, cassava, corn, coconuts, copra, bananas, and vanilla are the major crops grown in the fertile soils of the island. The southern part of the island is fertile but drier, especially toward the southern coastline.

The majority of the population lives in the central plain stretching east-west and including the city of Mataram (on the west coast). North Lombok is scarcely populated as is the southern part of the island.

6.1.1 MSW generation

According to the Environmental and Forestry Ministry Regulation No P.10/Menlhk/setjen/PLB.0/4/2018 about Technical Guidance to Develop the Policy and Strategy of Solid Waste Management in the Regency (Article 6), the waste quantity should be estimated by population and waste generation per person per day at around 0.7 kg/person/day or based on local estimation. This number is higher than the waste generation rate of Indonesia by World Bank which estimates a generation around 0.52 kg/capita/day equal with Indonesia National Standard. The waste generation in kg/capita/day from previous research work is presented in the following table.

Table 2 MSW generation, selected cities, Indonesia.

Regencies	**Waste generation (kg/capita/day)**	**Source**
Cilacap	0.48	Jakstrada of Central Java, 2018
Pekalongan City	0.47	Jakstrada of Central Java, 2018
Semarang City	0.63	COWI, 2018
DKI Jakarta	0.52	EP&T DIM, 2018
Pasar Kemis, Tangerang	0.62	Ecoasia, 2018
Bogor Barat, Bogor	0.58	Ecoasia, 2018
Ampenan, Mataram, Lombok	0.49	Ecoasia, 2018
North Lombok	0.48	Danida, 2019
Pekanbaru, Riau	0.19	Jaspi et.al, 2015
Batam	0.63	Ministry of Public Works, 2017

Source: Survey results (indicated years); Jakstrada of Central Java, 2018; Danida, 2018; modified by WKK, 2018.

For Lombok Island including West Lombok, North Lombok, Central Lombok, East Lombok, and Mataram City, the Environmental Agency of West Nusa Tenggara has published waste generation data in each district. The following table shows the calculated waste generation in kg/person/day.

Table 3 Waste generation in Lombok Island, 2018.

Generation	**litre/person/day**	**kg/capita/day**	**waste density**	**source**
North Lombok	1.2	0.30	0.25	Dinas LHK Website (https://dis-lhk.ntbprov.go.id)
Mataram City	1.9	0.48	0.25	FIeld Survey by WKK for Ecoasia Report 2018
West Lombok	1.2	0.30	0.25	Dinas LHK Website (https://dis-lhk.ntbprov.go.id)
Central Lombok	1.2	0.30	0.25	Dinas LHK Website (https://dis-lhk.ntbprov.go.id)
East Lombok	1.2	0.30	0.25	Dinas LHK Website (https://dis-lhk.ntbprov.go.id)

The assumed generation of MSW in Lombok is presented below, based on the assumed population development.

Table 4 Estimated annual MSW generation for Lombok 2020 – 2040.

Year	**Lombok Island**		
	Population	**tons/day**	**Lombok tons/year**
2020	3,589,814	1201	438,449
2025	3,795,354	1372	500,795
2030	4,014,095	1568	572,250
2035	4,246,985	1792	654,183
2040	4,495,045	2050	748,175

It should be underlined that the above waste quantities are generated amounts, not actually collected. In general, collection rate is low in rural districts, and higher in city areas. However, the official policy is to have all waste collected by 2023, and also to divert waste from landfilling/treatment for recycling at a rate of about 30% of the annually generated/collected waste. Nevertheless, it has been assumed that not all waste will be collected in the future, due to difficulties in reaching the rural population, financial constraints, etc.

Broken down per district, the forecasted population, unit waste generation rate, generated waste and assumed waste collected is presented in the following table. It also estimates the quantities of waste that will be collected separately for recycling or by any other means diverted from final disposal, according to the official policy of Indonesia, and the remaining amount of waste to be disposed of by treatment and/or disposal.

Table 5 Estimated MSW generation, collection and quantities for final disposal. Lombok 2020 – 2040, per district. Consultant's estimate.

	Population	Unit rate kg/d/capita	Generated (tpd)	Collection (tpd)	30% reduction (tpd)	MSW for final disposal (tpd)
Year	**West Lombok**					
2020	705,003	0.307	216	173	52	121
2025	757,299	0.331	250	200	60	140
2030	813,475	0.356	290	232	70	162
2035	873,817	0.384	335	268	80	188
2040	938,636	0.413	388	310	93	217
Year	**Central Lombok**					
2020	956,372	0.309	296	207	62	145
2025	1,002,058	0.333	334	250	75	175
2030	1,049,927	0.359	377	301	90	211
2035	1,100,083	0.386	425	340	102	238
2040	1,152,634	0.416	480	384	115	269
Year	**East Lombok**					
2020	1,210,152	0.310	375	263	79	184
2025	1,259,001	0.334	421	315	95	221
2030	1,309,821	0.360	471	377	113	264
2035	1,362,693	0.388	528	423	127	296
2040	1,417,699	0.418	592	474	142	332
Year	**North Lombok**					
2020	222,483	0.309	69	41	12	29
2025	233,136	0.333	78	47	14	33
2030	244,298	0.359	88	57	17	40
2035	255,995	0.386	99	69	21	48
2040	268,252	0.416	112	84	25	59
Year	**Mataram City**					
2020	495,804	0.495	245	196	59	137
2025	543,860	0.533	290	261	78	183
2030	596,574	0.574	342	308	92	216
2035	654,397	0.618	405	364	109	255
2040	717,824	0.666	478	430	129	301

6.1.2 MSW composition

Waste characteristics and composition in Lombok has been subject to several studies, including the 2019 Waste Management Masterplan for North Lombok. Moreover, the waste composition in West Sumbawa has been reported by the Public Works Office in 2016. The condition of West Sumbawa is similar to East Lombok as both are dominated by rural areas. The baseline data of waste composition for urban areas is represented by Mataram City that collected information in 2018.

Table 6 MSW composition in Lombok and Sumbawa.

Component	North Lombok (Danida,2019)	West Sumbawa (PWO West Sumbawa, 2016)	Mataram (Ecoasia, 2018)
Bio waste	59.90%	67.48%	72.00%
Cardboard/ papers	17.40%	10.77%	9.10%
Plastic	17.60%	11.62%	13.90%
Glass	3.00%	1.67%	2.41%
Metals	1.40%	1.00%	1.13%
Other	0.80%	7.46%	1.06%

The composition of MSW is dominated by organic waste which constitutes around 60%. Inorganics waste are dominated by plastics and papers. In 2018, Ecoasia reported the composition especially for marketable waste in Mataram City (non-biowaste) as presented in the following table.

Table 7 Composition of non-biowaste – Mataram 2018.

Categories	Types	%
Plastics	LDPE	3.63%
	PET	12.29%
	HDPE	15.39%
	PP	11.84%
	PS (polystyrene foam)	1.47%
	PVC	2.49%
	other plastics	13.46%
Glass	Glass	6.71%
Papers	Papers	9.55%
	cardboard	13.64%
Metal	Soda can (aluminium)	4.47%
	Ferro	3.43%
	cooper	0.34%
	other metal	0.51%
Other	other	0.77%

Source: Ecoasia, 2018

Applying the assumed waste composition, an estimation of the calorific value of the waste was made and can be seen in the following Table 8.

6.1.3 Calorific value

Based on the estimated composition of the MSW in Lombok, Table 8 shows a calculation of the expected calorific value of MSW for Lombok.

Table 8 Calorific value of MSW (estimate), Lombok

	Compo-sition	**Mois-ture**	**Solids**	**Ash**	**Com-bustible**	**High KJ/kg**	**Low KJ/kg**
Food	59.9%	66%	34%	13%	21%	17000	1905
Plastics	17.6%	29%	71%	8%	63%	33000	20147
Textiles	0.0%	33%	67%	4%	63%	20000	0
Paper & Card	17.4%	47%	53%	6%	47%	16000	6435
Leather & Rubber	0.0%	11%	89%	26%	63%	23000	0
Wood	0.0%	35%	65%	5%	60%	17000	0
Metals	1.4%	6%	94%	94%	0%	0	-147
Glass	3.0%	3%	97%	97%	0%	0	-73
Inert	1.0%	10%	90%	90%	0%	0	-245
Fines	0.0%	32%	68%	46%	0%	15000	0
Weighted average	1.000	53%	47%			MJ/kg	5.8

As can be seen, the estimated calorific value is around 5.8 MJ/kg due to the relatively high contents of plastics. The estimated value is lower than the typical value for municipal solid waste in high-income countries with developed waste management practices (9 –10 MJ/kg). In the future, when more waste is collected for recycling, it must be expected that the contents of plastics will decrease. On the other hand, generally speaking, the contents of packaging waste is expected to increase. It may therefore be assumed that the resulting calorific value of the waste will not change much in the near future.

6.1.4 Agricultural waste feedstock

Rice production

Rice is a dominant produce of Lombok. Rice husks (hulls) are the hard-protecting coverings of grains of rice. The milling process removes the husks from the raw grain to reveal whole brown rice which upon further milling to remove the bran layer will yield white rice.

Rice grains are composed of ~20% rice husk, 11% rice bran, and 69% kernel[1]. Therefore, about 31% of the rice kernel becomes waste by-products[2]. However, data from the actual rice production in Lombok suggests higher contents of husk and bran (see Table 9 below).

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[1] Dhankhar, P. (2014). Rice milling. IOSR J. Eng. 4, 34–42. doi: 10.9790/3021-04543442

[2] Current Trends of Rice Milling Byproducts for Agricultural Applications and Alternative Food Production Systems, Aaron R. Bodie1, Andrew C. Micciche1, Griffiths G. Atungulu1, Michael J. Rothrock Jr.2 and Steven C. Ricke1*

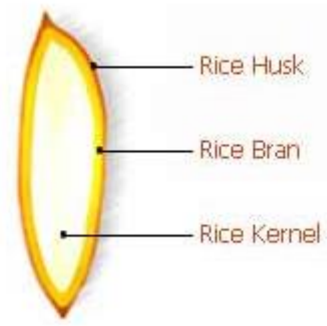

Figure 4. Composition of rice grain

Rice husk composition is as follows: cellulose (50%), lignin (25%–30%), silica (15%–20%), and moisture (10%–15%). Bulk density of rice husk is low and lies in the range 90–150 kg/m3[3]. The husk has a heating value of 13 GJ/tonne.

Rice straw is produced as a by-product of rice production at harvest. Rice straw is removed with the rice grains during harvest and it ends up being piled or spread out in the field depending if it was harvested manually or using machines. Ratio of straw to paddy ranges from 0.7-1.4 depending on the variety and growth.

Table 9 Quantities of rice production and waste from rice production, Lombok 2019[4].

Districts	Rice (paddy) production (tons/year)	Rice equivalent production (tons/year)	Rice husk and bran (tons/year)[5]	Rice straw (tons/year)[6]
West Lombok	116,410	65,960	50,450	282,121
Central Lombok	354,915	201,101	153,815	697,402
East Lombok	260,367	147,528	112,839	582,751
North Lombok	27,170	15,395	11,775	79,260
Mataram City	15,658	8,872	6,786	48,356
Total	774,521	438,856	335,665	1,689,890

Table 10 Calorific value, moisture and ash contents of husk and straw from rice production[7].

	MJ/Kg	Moisture %	Ash %
Rice husks	13	9	19
Straw	12	10	4

[3] Bhupinder Singh, in Waste and Supplementary Cementitious Materials in Concrete, 2018.
[4] Provinsi Nusa Tenggara Barat Dalam Angka 2020.
[5] Difference between paddy production and products.
[6] Estimated at 140% of paddy production.
[7] NEC; Danish Energy Agency; Danish Embassy in Indonesia, "Technology Data for the Indonesian Power Sector Catalogue for Generation and Storage of Electricity," 2017.

Availability of waste products

The rice production in Indonesia is to a low degree mechanized, and fields are in general very small, and mostly worked manually. The rice grain is removed from the straw in the fields and brought to centralized facilities – rice hellers – for processing, where husk and bran is removed. If these residual products are centralized, they can be collected and utilized. Currently some of the by-products are used for secondary purposes, for example as fuel for tile and brick production, additives for cement products and others. Therefore, the amounts indicated in the above table may not be available for other purposes.

As opposed to the grain, the straw is left in the fields, and the predominant disposal methodology is open burning. Collection of the straw for centralized utilization seems unrealistic because of the very low degree of mechanization of the agriculture sector in the target area, and because of the very small individual fields with very limited access for mechanical devices such as straw press machines. In addition, the road network is not developed for large/heavy transports of straw.

Therefore, despite a great energy potential in straw, this waste material is not considered a potential feed stock for WtE power generation in Lombok.

Other agricultural products

The waste of maize agriculture includes corncob, stem-leaf, and corn husk. The production of those materials per ha crop land is around 0.6 tonne of corncob/year, 2.6 tonne of stem-leaf/year, and 0.7 tonne/year of cornhusk[8]. Similar to rice production, corn producers will typically leave stem-leaf in the field, whereas the corn cob and husk will be brought to the farm or centralized facilities for processing/drying. In the following, only the corn cob is considered (potentially) available as a feed stuff for WtE facilities under the current conditions.

The below tables indicate the theoretical amounts of waste products from corn production in Lombok.

Table 11 Estimated annual waste from corn production - Lombok 2019[9].

Corn	Production Ha area	Steam leaf (2.6 t/ha) tons	Corncob (0.6 t/ha) tons	Cornhusk (0.7 t/ha) tons
West Lombok	39,041	101,507	23,425	27,329
Central Lombok	13,654	35,500	8,192	9,558
East Lombok	118,630	308,438	71,178	83,041
North Lombok	32,130	83,538	19,278	22,491
Mataram City	13	34	8	9
Total per year	203,468	529,017	122,081	142,428

The waste of coconut agriculture activity includes coconut shells and coconut husk. Per one tonne of produced raw coconut, an assumed amount of 360 kg husk and 165 kg of shells

[8] Lembaga Penelitian Hasiul Hutan, 1978.
[9] Nusa Tenggara Barat Province in Figures 2020.

appears[10]. The below table indicate the theoretical amounts of waste products from coconut production in Lombok.

Table 12 Estimated annual waste from coconut production - Lombok 2019[11].

Coconut tons/year	Total production Tons	36% coconut husk Tons	17% coconut shells Tons
West Lombok	12,132	4,367	2,062
Central Lombok	11,745	4,228	1,997
East Lombok	11,664	4,199	1,983
North Lombok	11,409	4,107	1,940
Mataram City	41	15	7
Total per year	46,990	16,916	7,988

For both types of agricultural waste (corn cobs/husk and coconut shells/husk), it applies that production is typically secondary to other productions (usually rice), it is not mechanized, and the waste appears in a large number of small farms. This makes it very difficult to collect the waste, and moreover, some waste is already being utilized. Nevertheless, not all waste that is not utilized finds its way to a proper disposal facility, and the waste is frequently seen scattered in the countryside as well as in towns/cities.

Livestock

Livestock in Lombok is represented in the below table.

Table 13 Estimated number of livestock - Lombok 2019[12].

Livestock	Cow	Buffalo	Goat	Swine
West Lombok	11,985	4,801	43,989	41,576
Central Lombok	176,983	21,545	116,465	1,648
East Lombok	139,063	102,315	89,026	8
North Lombok	93,675	272	31,292	4,428
Mataram City	2,152	0	22	661
Total	423,858	128,933	280,794	48,321
Unit waste generation[13]	20 kg/day	20 kg/day	1.13 kg/day	7 kg/day
Waste generation tons/year	3,867,704	1,176,514	115,813	123,460

Again, availability of this waste is considered poor: Small family farming is still the predominant structure of Lombok agriculture sector, and with the livestock distributed over a vast number of farms, it seems logistically difficult or impossible under the current conditions to collect waste for centralized use.

However, if not suited for centralized utilization, livestock waste products (manure) is better suited for utilization in decentralized, local facilities. Already today, more than 6,000 biogas

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[10] Lembaga Penelitian Hasiul Hutan, 1978.
[11] Nusa Tenggara Barat Province in Figures 2020.
[12] Nusa Tenggara Barat Province in Figures 2020.
[13] Ministry of Agriculture, 2008.

facilities exist in the Province exploiting the gas potential in manure. This may expand in the future, and larger facilities may be introduced.

6.1.5 Landfills

The landfill called Kebon Kongok is located in West Lombok and it receives each day 300-350 tons of waste from Mataram and West Lombok[14]. It has been in operation since the end of the 90s.

Other, small landfills are (see Figure 5):

- Truiak, located in Central Lombok receiving about 60 tons of waste/day[15].
- Landfill in North Lombok.
- Matra Landfill in Gili Trawangan.
- Ijo Balit Landfill in East Lombok.

Data on the Kebon Kongok landfill is indicated below (Table 14).

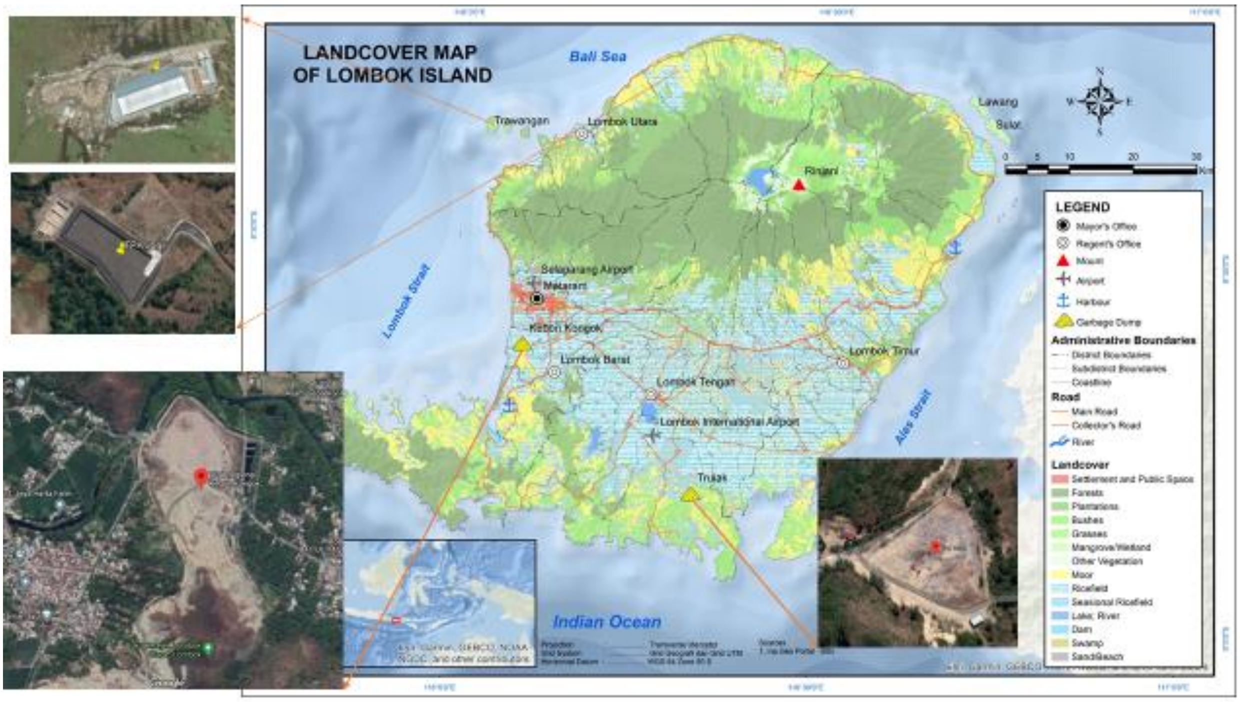


Figure 5. Landfills in Lombok Island.

[14] Provincial Government website.
[15] BPS, 2020.

Table 14 Total Waste volume in the Kebon Kongok Landfill.

Kebon Kongok Landfill	
Start operation	1993
Active landfill	5.3 ha
Transported waste to the landfill everyday	350 tonne
Maximum capacity (DLH)	951,860 m^3

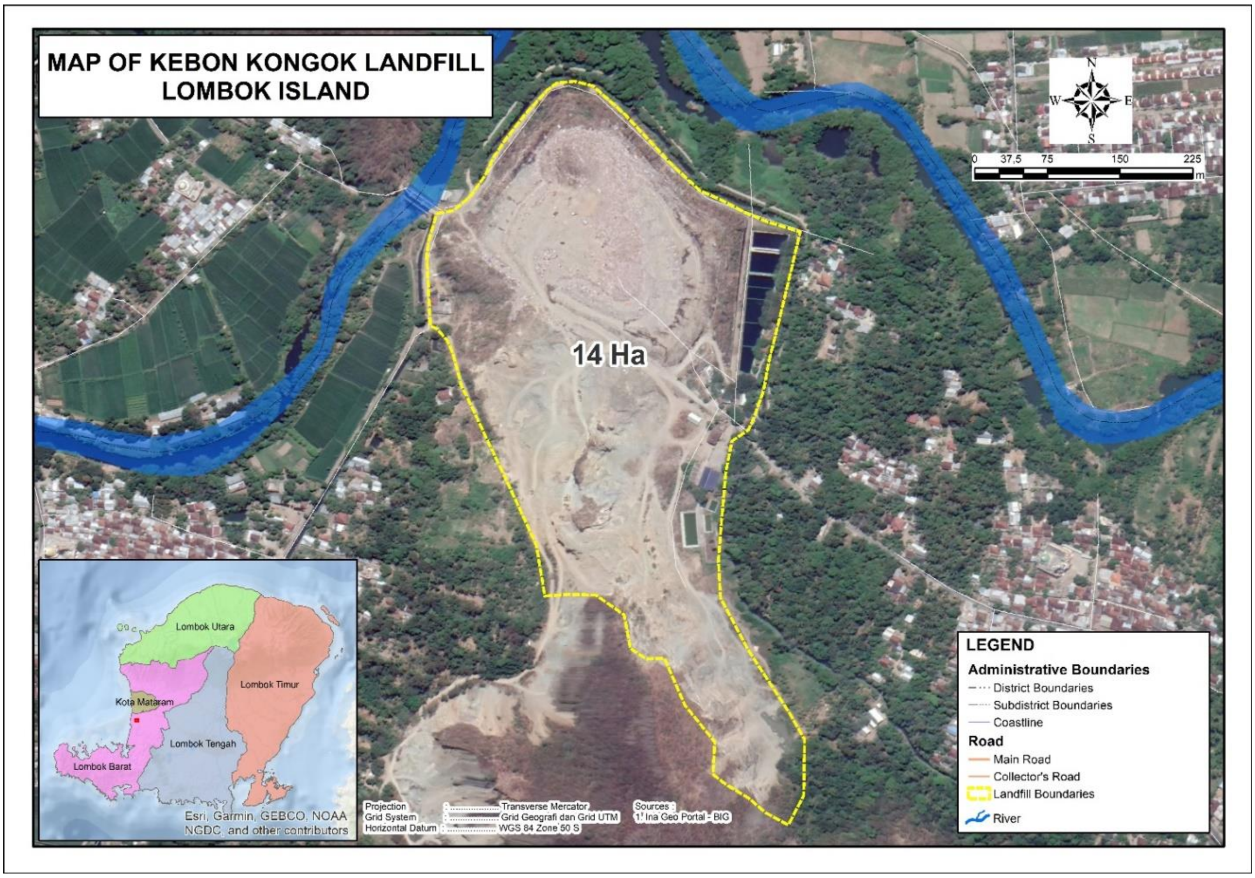


Figure 6. Kebon Kongok Landfill Map.

6.2 Batam

Batam is the biggest city in Riau Archipelago province (Riau Islands) situated some 20 km southeast of Singapore. In Indonesian the Riau Islands is called Kepulauan Riau, abbreviated to Kepri. There are around 3,200 Islands in total in Riau Islands and in 2020 the total population of Riau Islands were 2.2 million. The city administrative area covers three main islands of Batam, Rempang, and Galang (collectively called Barelang), as well as several islets. Batam Island is the core urban and industrial zone, whereas both Rempang Island and Galang Island maintain their rural character and are connected to Batam Island by short bridges.

The government established this island as an industrial zone for heavy industry. Pertamina, the Indonesian state oil company, shipbuilding and electronics manufacturing are important industries on the island. Important industries are also transport/shipping and tourism.

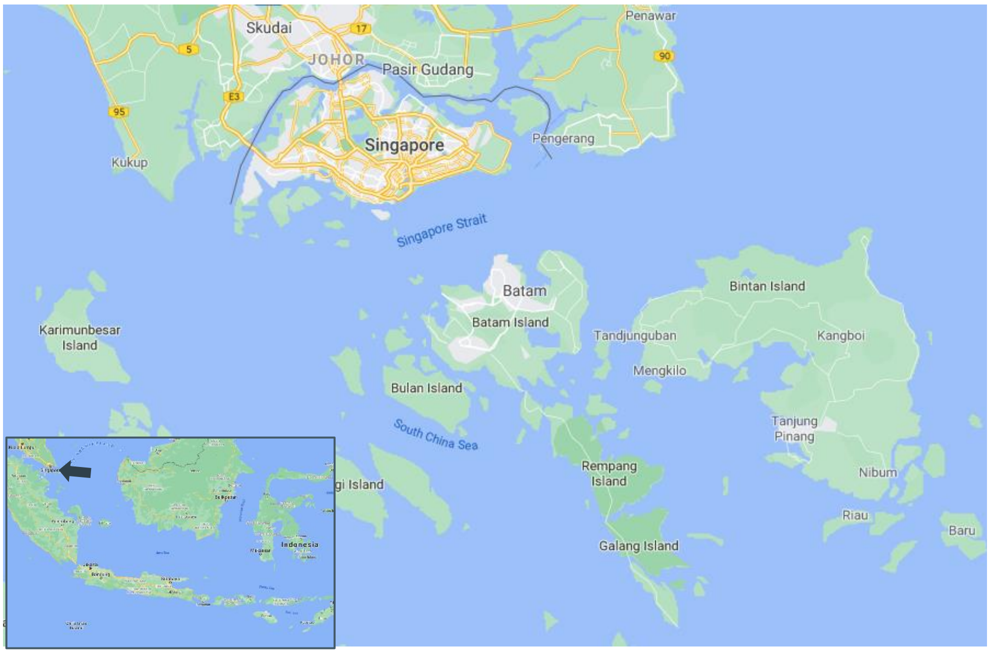


Figure 7. Map showing Batam and neighbouring islands.

The city administrative area covers three main islands of Batam, Rempang, and Galang (collectively called Barelang), as well as several small islands and covers 3,990 km², of which 1,040 km² is land but Batam island itself covers only about 410 km² out of the total.

Batam City (Kotamadya Batam) is divided into twelve districts (kecamatan) – which include several adjacent islands such as Bulan, Rempang and Galang, as well as Batam Island itself.

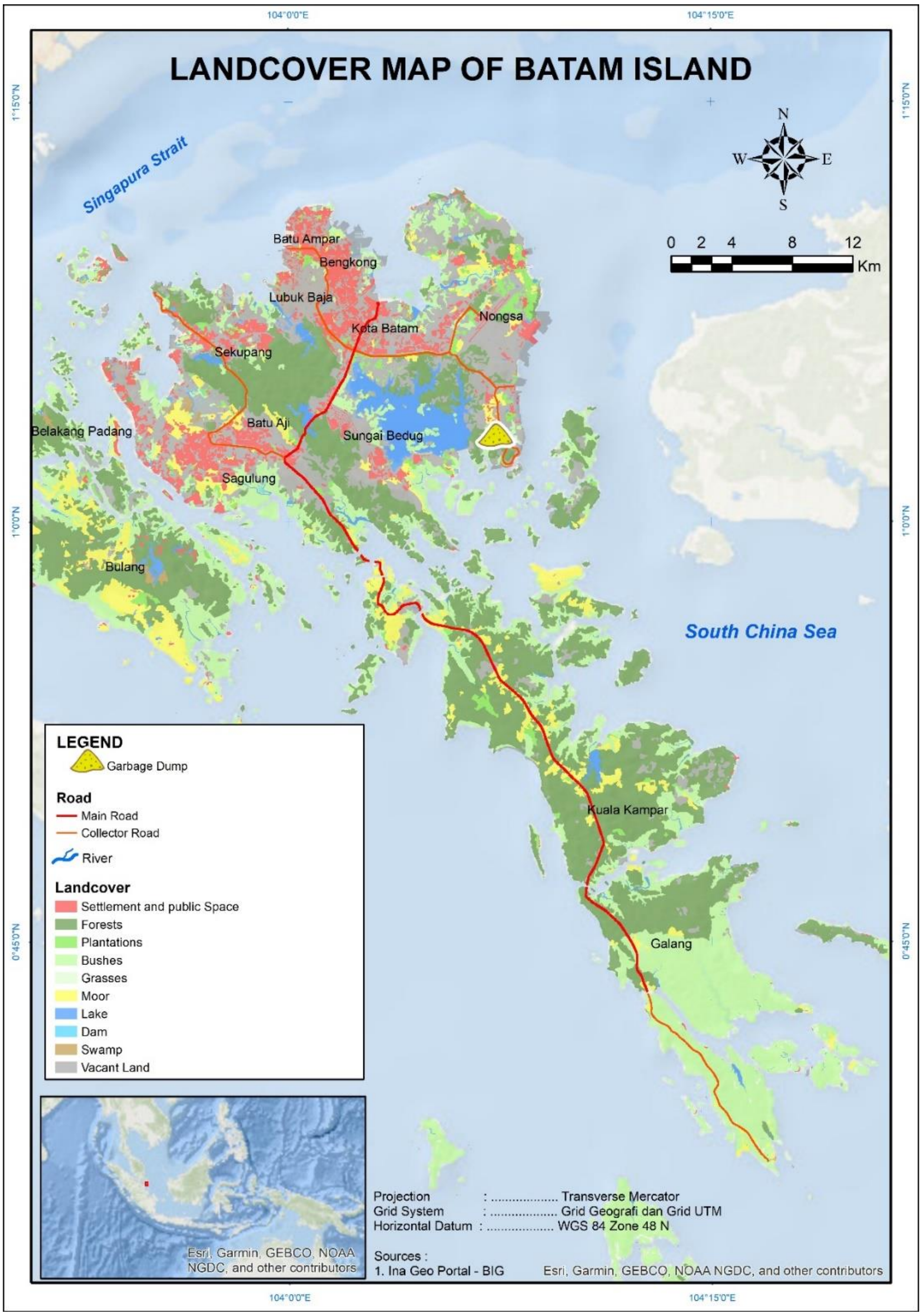


Figure 8 Map of Batam, Rempang, and Galang Islands (Barelang).

Batam Island is the core urban and industrial zone, while both Rempang Island and Galang Island maintain their rural character and are connected to Batam Island by short bridges. Pertamina, the Indonesian state oil company, shipbuilding and electronics manufacturing are important industries on the island. Important industries are also transport/shipping and tourism. The economy relies mainly (56% of Gross Domestic Product (GDP)) on industries, whereas 26% of GDP origins in tertiary activities, hence only 18% in primary activities.

Barelang population is for 2020 estimated at 1.4 million. In addition, about 1.7 million foreign and 4 million domestic tourists visit the area every year. Batam is the third-busiest entry port to Indonesia next to Bali and Jakarta.

Approximately 96% of the municipal population resides on Batam island, and only 3% of the population lives in rural environment. Batam's 2021 population is now estimated at 1,617,168[16]. Since 2015 the city has experienced an annual population growth of 4.6%. The growth is expected to decline towards 2035.

6.2.1 MSW generation

For Batam, the Batam City Sanitation Working Group, 2017 has estimated the waste generation in kg/person/day for the city, as showed in the below Table 15.

Table 15 Waste generation in Batam, 2017.

Generation	**litre/person/ day**	**kg/capita/ day**	**waste density**	**source**
Batam	2.5	0.625	0.25	Pokja Sanitasi Batam City,2017

The assumed generation of MSW in Batam is presented below, based on the assumed population development and assumed development in waste generation rates.

Table 16 Estimated annual MSW generation for Batam 2020 – 2040.

Year	**Batam City**		
	Population	**tons/day**	**Batam tons/year**
2020	1,546,064	966	352,696
2025	1,858,907	1,252	456,836
2030	2,065,114	1,498	546,736
2035	2,229,753	1,742	635,946
2040	2,393,011	1,496	545,906

For Batam, it may be expected that most waste is collected. The official policy is to divert waste from landfilling/treatment for recycling at a rate of about 30% of the annually generated/collected waste. Therefore, it has been assumed that all generated waste will be collected in the future, and the goal of 30% reduction achieved.

The forecasted population, unit waste generation rate, generated waste and assumed waste collected is presented in the following table. It also estimates the quantities of waste that will be collected separately for recycling or by any other means diverted from final disposal, according to the official policy of Indonesia, and the remaining amount of waste to be disposed of by treatment and/or disposal.

[16] World Urbanization Prospects - United Nations population estimates and projections of major Urban Agglomerations.

Table 17 Estimated MSW generation, collection and quantities for final disposal. Batam 2020 – 2040. Consultant's estimate.

	Population	Unit rate kg/d/capita	Generated (tpd)	Collection (tpd)	30% reduction (tpd)	MSW for final disposal (tpd)
Year	**Batam**					
2020	1,546,064	0.63	966	966	290	676
2025	1,858,907	0.67	1,252	1,252	375	876
2030	2,065,114	0.73	1,498	1,498	449	1,049
2035	2,229,753	0.78	1,742	1,742	523	1,220
2040	2,393,011	0.84	2,014	2,014	604	1,410

In addition to municipal waste, industrial waste is taken to the dumpsite/landfill in a quantity of up to 300 t/day. The composition of this waste is not known to the consultant.

6.2.2 MSW composition

Waste characteristics and composition in Batam has been reported in Batam City Waste Management Plan of 2016 and is shown in the below table.

Table 18 Composition of MSW, Batam 2016.

	Domestic %	Non-domestic %
Organic	48.4	40.3
Plastic	18.6	32.5
Paper	9.2	25.2
Glass	1.2	0.4
Wood	2.2	0.0
Rubber	0.1	0.1
Metal	1.3	0.9
Textile	1.8	0.4
Leaves/green	7.7	0.2
Tetra pack (composite)	0.6	0.9
Styrofoam	0.2	1.3
Diapers	6.2	1.1
Haz waste	0.1	0.0
Others	2.5	2.0

6.2.3 Chemical composition

Table 19 shows the estimated chemical composition of MSW from Batam[17].

Table 19 Calorific value of MSW (estimate), Batam.

Parameter	Unit	Value
Water content	% wet weight	50.1
Volatile Content	% dry weight	73.7
Ash content	% dry weight	1.5
Fixed Carbon	% dry weight	3.5
Calorific value	MJ/Kg (High)	16.2
	MJ/kg (Low)	8.7

As can be seen, the estimated calorific value is around 8.7 MJ/kg due to the high contents of plastics, paper, diapers, and leaves. The estimated calorific value is similar to typical values for municipal solid waste in high-income countries. As a highly urbanized area, it may be assumed that the calorific value of the waste will not change much in the near future.

6.2.4 Agricultural waste feedstock

Only 3-4 % of the landmass of Batam Island is occupied by plantations, with no significant production of commodities like rice and other agricultural products. There is a limited production of chilli, ginger, galangal, and turmeric.

There is a large population of poultry and a notable stock of swine.

Table 20 Estimated number of livestock - Batam 2019.

Livestock	Poultry	Buffalo	Goat	Swine
Batam	16,267,700	959	2,045	369,817
Unit waste generation[18]	kg/day	20 kg/day	1.13 kg/day	7 kg/day
Waste generation tons/year		7,000	843	944,882

[17] Batam City Waste Management Plan of 2016.

[18] Ministry of Agriculture, 2008.

6.2.5 Landfill

The bulk of the municipal solid waste of Batam City is disposed of in Telaga Punggur Nongsa that has been in operation since 1997[19]. The landfill area covers a total of about 47 hectares. The active area (about 9.6 ha) is currently receiving in the vicinity of 1,100 tons/day domestic, non-domestic, and industrial waste. A sanitary landfill cell has been constructed (2.6 ha), but it is currently out of operation due to technical difficulties. There is sufficient space for additional landfill capacity (and other treatment facilities) in the area.

Figure 9 The sanitary landfill of Telaga Punggur, Bantam (NB: observe the operational standard).

[19] Information from Technical Service Unit (UPT) of Telaga Punggur.

7 Incineration technologies

7.1 Grate-incineration

7.1.1 Brief technology description

Worldwide around 2,500 conventional grate-fired Waste to Energy (WtE) plants have been built. The majority of these incineration plants are based on grate–fired incineration. In overall for these plants they have an average availability of 7,500 - 8,000 h and net electrical efficiencies of 18 - 27%.

The household waste is collected directly from the households by waste trucks and delivered at the WtE plants. The waste is dumped into the tipping area. The tipping areas are enclosed to prevent odours and litter from escaping the plant. Combustion air is sucked from the tipping area to create an under pressure to control the odours from leaving the building.

The tipping area is part of the waste silo, which typically will have capacity for four days. This means that the silo will have capacity, without new waste is added, from Friday afternoon to Monday noon, plus one extra day. The waste is taken from the silo by a waste grab and dumped into a hopper. The waste slides down the chute by gravity. In the bottom of the chute the waste is pushed by waste pushers to the grate. There are different types of grates for transporting the fuel through the combustion area.

Type	Working Principle
Reciprocating grate (Forward feed grate)	This type of grate uses a step action with alternating stationary and moving grate. The type most used.
Reverse reciprocating grate (Reverse feed grate)	Reverse acting reciprocating grate. Alternating stationary and moving grates sloped downwards. The grate pushes the waste upward and causing the waste to flip over the grate and tumble downwards. This causes a good burnout.
Roller grate	The grate consists of 6 cylinders on a 30-degree downward angle that transport the waste through the furnace.

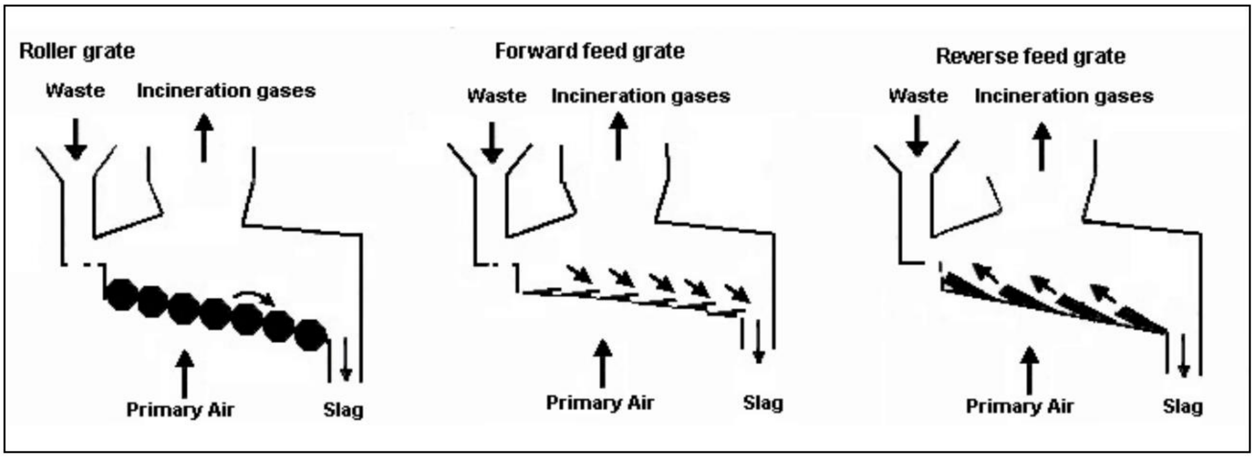
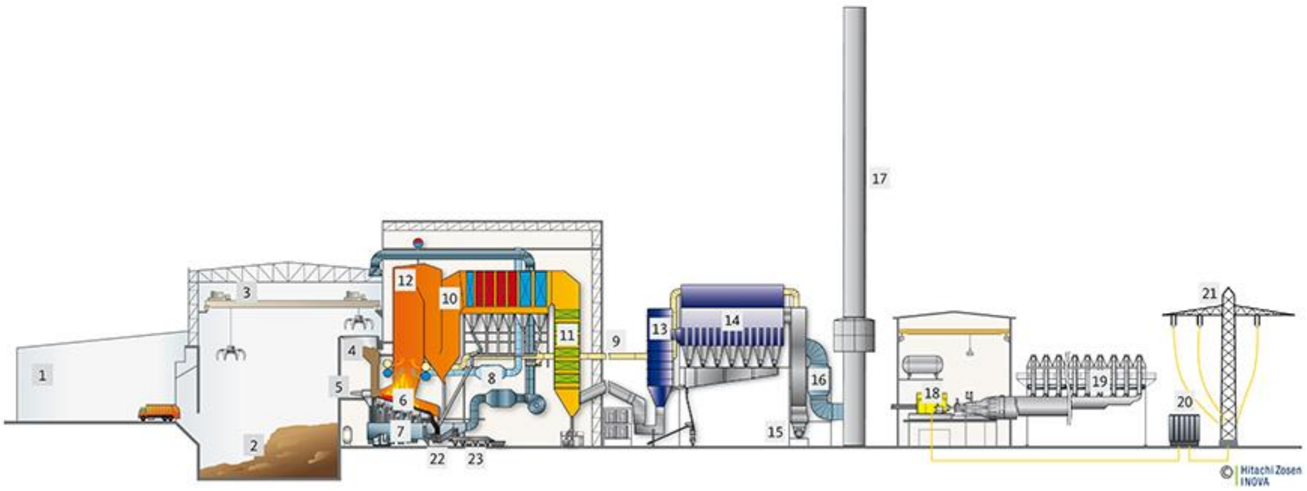


Figure 10. Working principles of grates.



Waste Receiving and Storage
1 Delivery hall
2 Waste bunker
3 Waste crane

Combustion and Boiler
4 Feed hopper
5 Ram feeder
6 HZI grate
7 Primary air system
8 Secondary air system
9 Flue gas recirculation
10 Five-pass boiler
11 Economiser

Flue Gas Treatment
12 Ammonia injection
13 HZI SemiDry reactor
14 Fabric filter
15 Induced draught fan
16 LP preheater
17 Stack

Energy Recovery
18 Turbine
19 Air cooled condenser
20 Transformer
21 Electricity export

Residue Handling and Treatment
22 Bottom ash extractor
23 Bottom ash conveying

Figure 11. Typical waste to energy plant with air cooled condenser (Hitachi Zosen Innova).

In a grate -fired boiler the waste is typically burned unprocessed. Combustion occurs in the furnace and the flue gas passes through the internal of the boiler with water-cooled walls, passes the superheater and further to the economizer. Steam is produced and can be led to a turbine for producing steam. The low-pressure steam from the turbine is cooled in an air-cooled condenser and the condensate is recycled to the feed water pumps for the boiler.

When the flue gas leaves the boiler, it is led to a dry or a wet flue gas treatment system. A wet system consists typically of an electrostatic precipitator followed by a spay drier, a fabric filter and a wet scrubbing system. A dry system consists typically of an electrostatic precipitator followed by a spray dryer and a fabric filter.

7.1.2 Inputs

Treated or untreated municipally solid waste (MSW). Can be combined with biomass if this fulfils the requirements for the fuel.

Waste, which have been stored in a landfill for shorter time (a few years, depending on the waste, the weather etc.), can be incinerated in a grate fired incinerator. The longer the waste has been in the landfill the more formulation will have taken place. If the waste is not too formulated, dug-up waste can be mixed with new waste and incinerated.

7.1.3 Outputs

Electricity and heat. Bottom Ash to be utilised as construction or landfill material.

7.1.4 Capacities

Capacity for single line for grate incineration can be from around 2 tonne/h up to 45 tonne/h. An incineration plant can consist of several incineration lines, often 2 or 3.

Based on the feedstocks and calorific values for Lombok respectively Batam the generated outputs are the stated in the following table based on boiler efficiency of 87% and electrical gross efficiency of 22%:

	Lombok	**Batam**
Feedstock	752 tonne per day = 31.3 tonne per hour	876 tonne per day = 36.5 tonne per hour
Calorific value	5.8 MJ/kg	8.7 MJ/kg
Nominal thermal load	50.1 MW	88.2 MW
Heat output	31.1 MW	54.7 MW
Electrical power gross	11.0 MW	19.4 MW
Electrical power net	8.9 MW	16.9 MW
Electrical production net	284 KWh/tonne	462 KWh/tonne
Bottom ash	6.2 tonne/hour	7.3 tonne/hour

Table 21. Generated outputs for grate incineration based on available feedstocks.

7.1.5 Ramping configuration

It takes about 24 hours for an incineration line to get from cold condition to steady operation with the turbine connected to the grid. Ramping up is typically about 5% load per hour. When going from steady operation at 100% load to stop of plant, it typically takes 12 hours. Ramping down is typically about 10% load per hour.

7.1.6 Advantages/disadvantages

Advantages:

- Relatively minor fuel preparation requirement.
- High process availability (normally more than 8,000 hours per year).
- Simple operation.
- Low auxiliary power consumption.
- Mature technology.
- Capacity of a plant can be high.
- No odours from plant.

- Bottom ash can be utilized as construction material.

Disadvantages:

- Relatively high CAPEX and Operating Expenditures (OPEX).
- High combustion losses of 2-4% unburnt carbon.
- Fly ash shall be stored in landfills or similar.

7.1.7 Environment

An incineration plant must follow legal requirements for emissions to air and emissions to wastewater. These would normally be stated in the Environmental Permit issued by the Environmental Agency in the country.

Air pollution control systems are very developed and relatively well functioning, so normally the emissions will be below the maximum permitted emission levels. It is a requirement to have a Control and Emission Monitoring System (CEMS) installed with measurement instruments in the stack to constantly monitoring the emissions. Should the actual emission levels be above the requirement, the plant must shut down, until the operating problem is solved.

7.1.8 Employment

Manning is depending on

- Capacity of the plant, especially the number of lines.
- Complexity of the plant, especially the configuration of the flue gas cleaning system.
- Whether the boiler walls are covered with Inconel (hard face) or refractory.
- The level of the distributed control system (DCS) for the plant, constantly monitoring the plant and giving alarms when something is not operating correct.
- Typical manning will be 4 – 6 persons for plant management and in the plant administration staff. In plants with an advanced distributed control system, there will typically be 2 persons on night shift for operation and 4 persons on day shift for operation and maintenance.
- For major overhauls the manning must be higher, and this is typically done by having contractors to do the work.

7.1.9 Research and development

Grate incineration is a very well-known and mature technology – i.e. category 4.

Research and development have been ongoing for many years, especially in relation to choice of steel materials for the boiler as well as improvements in relation to the grate, among other in the last decades development in waster cooled grates have been ongoing.

Also, research and development for the DCS have been ongoing and these systems are today getting more stable and functioning with less problems due to constant improvements.

There have in the last 2-3 decades been a severe research and development in relation the flue gas cleaning system, both dry and especially wet causing the emissions to decline. In the same time for example the European Union has lowered the acceptable emission levels from the incineration plants. In overall the technology for flue gas treatment has now reached a level where there are not any larger improvements to be expected.

7.1.10 CAPEX

The ultimate level of investment for a grate-fired incineration plant will depend on the final detail of the Employers Requirements and the Technical Requirements specified at the time of tendering the project, plus market forces and vendor appetite at that time. In addition, CAPEX values can sometimes be affected by the nature of the final contract based on offer. For example, offering the opportunity of a long-term O&M contract will create a higher degree of competitive tension.

The capital costs are excluded any allowance for:

- Bulk excavation, e.g. to reduce visual impact or to create the plant development platform.
- Special architectural features.
- Modifications to the existing site infrastructure, e.g. construction of feedstock vehicle traffic access roads.
- Pre-treatment of WtE plant feedstocks, e.g. bulky waste, street sweepings and/or waste wood.
- Feedstock Buffer storage / RDF laydown area.
- Heat offtake infrastructure, e.g. for chilling and/or desalination.
- Cost of financing.

Cost and throughput data have been gathered on wide range of WtE facilities in both UK and Europe. Data was collected when the project was in operation, commissioning, construction or planning phases and as such includes varying levels of confidence. Other data is from budget estimates gathered through past projects and information available in the public domain.

The estimate is 'cleaned' for complex architecture and geotechnical challenges. Further no enclosure for the facility is included and no logistics are included.

Based on these data a cost estimate for grate incineration is:

For Lombok with a potential capacity of 275 kilo tonne per anno (ktpa) in 2025 a Capex range is estimated to be 450-770 USD/tonne per anno (TPA).

For Batam with a potential capacity of 320 ktpa in 2025 a Capex range is estimated to be 420-710 USD/tpa.

Generally, the upper range represents high specified facilities established in complex areas. Building in Batam or Lombok is considered to be complex areas, most or all equipment must be imported and the majority of staffing for construction must be supplied from other areas.

Keeping the specification in a low to medium level technology investments for Lombok around 160-170.000.000 USD should be expected.

With a similar assumption a technology investment for Batam of around 175-190.000.000 USD should be expected.

Further to this 10-40% should be added for civil structure and logistics depending on the complexity of the construction site.

7.1.11 Examples

Examples of incineration plants based on grates are numerous. In Europe alone around 2,000 plants are in operation. See statistics report from ISWA – the International Solid Waste Association, "Waste-to-Energy State-of-the-Art-Report" 6^{th} edition, 2012.

The Hartlebury thermal waste treatment plant in UK. 200,000 tpa. Steam parameters of 60 bar and 415°C, the single line plant achieves net efficiency of around 25%. 68 MW thermal. Fuel: municipal solid waste with calorific value: 9.4 MJ/kg.

Istanbul TUR. Turkey’s first WtE plant will also be the largest in Europe with 1,000,000 tpa. 70 MW of electricity. Fuel: municipal solid waste with calorific value: 6.0-9.0 MJ/kg. Maximum throughput per line: 46 t/h.

Figure 12. Indaver. Ireland's first WtE plant. Delivers electricity to 20,000 households through the city's grid. Capacity to process approximately 200,000 tons of waste per year[20].

7.1.12 References

1 Martin F. Lehmann, *Waste Management*, 2008.

2 Walter R. Nissen, *Combustion and Incineration Processes*, 2010.

3 Naomi B. Klinghoffer, *Waste to Energy Conversion Technology*, 2013.

4 H. Spliethoff, *Power Generation from Solid Fuels*, 2010.

5 Thomas H. Christiansen, *Affaldsteknologi (Waste Technology),* 2001.

[20] www.babcock.com/en/industry/waste-to-energy

7.1.13 Data sheet

Technology

Technology	Grate Fired Incineration Power Plant - Municipal Solid Waste								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	22	22	23						
Generating capacity for total power plant (MWe)	22	22	23						
Electricity efficiency, net (%), name plate	29%	30%	31%	28%	32%	30%	33%	A	1
Electricity efficiency, net (%), annual average	28%	29%	29%	26%	30%	28%	31%		1
Forced outage (%)	1%	1%	1%						1
Planned outage (weeks per year)	2,9	2,6	2,1						1
Technical lifetime (years)	25	25	25						1
Construction time (years)	2,5	2,5	2,5						1
Space requirement (1000 m^2/MWe)	1,5	1,5	1,5						1
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	10	10	10	7,5	12,5	7,5	12,5	C	1
Minimum load (% of full load)	20	20	20	15,0	25,0	15,0	25,0	C	1
Warm start-up time (hours)	0,5	0,5	0,5	0,4	0,6	0,4	0,6	C	1
Cold start-up time (hours)	2	2	2	1,5	2,5	1,5	2,5	C	1
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (million $/MWe)	6,8	6,3	5,6	5,1	7,0	4,2	7,0	C	1
- of which equipment	4,0	3,4	2,8	3,0	3,5	2,1	3,5		1
- of which installation	2,8	2,9	2,8	2,1	3,5	2,1	3,5		1
Fixed O&M ($/MWe/year)	243.700	224.800	193.500	195.000	304.600	154.800	241.900	C	1
Variable O&M ($/MWh)	24,1	23,4	22,6	18,1	30,2	16,9	28,2	C	1
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	27,7	27,7	27,7					B	

References:

1 Danish Technology Catalogue “Technology Data for Energy Plants, Danish Energy Agency 2107"

Notes:

A Based on experience from the Netherlands where 30 % electric efficiency is achieve. 1 %-point efficiency subtracted to take into account higher temperature of cooling water in Indonesia (approx. +20 C).

B The investment cost is based on waste to energy CHP plant in Denmark, according to Ref 1. A waste treatment capacity of 27,7 tonnes/h is assumed and an energy content of 10,4 GJ/ton. The specific finalcial data is adjusted to reflect that the plant in Indonesia runs in condensing mode and hence the electric capacity (MWe) is higher than for a combined heat and power, backpressure plant with the same treatment capacity.

C Uncertainty (Upper/Lower) is estimated as +/- 25%.

D Calculated from size, fuel efficiency and an average calory value for waste of 9.7 GJ/ton.

7.2 Fluidized bed

7.2.1 Brief technology description

A fluidised bed consists of fuel particles above a mesh suspended in a hot fluidized bed of ash and another particulate material such as sand or limestone. Air is blown from beneath through the bed to provide the oxygen required for combustion or gasification.

Depending on the velocity of the air the bed will have one of three distinct stages of fluidisation:

- Fixed bed.
- Bubbling fluidised bed (BFB).
- Circulating fluidised bed (CFB).

In addition, there is the revolving fluidized bed (RFB), which is described below.

The bubbling fluidized bed is mainly used for burning biological wastewater sludge and the circulating fluid bed is used in hazardous waste incineration applications and for pre-treated waste.

At low gas velocities there is no significant distributing of the layer on the bed and the bed acts as a porous media. This is the fixed bed.

When the velocity is increased the velocity is just high enough (up to 2,5 m/s) to let the gas through the bed as bubbles. This is called the Bubbling Fluidised Bed.

When the velocity is increased further (up to 8 m/s) most particles are carried up by the gas flow. The particles which is carried over are separated in a cyclone and circulated back into the bed, as otherwise it would run out of particulate material; this is called Circulating Fluidized Bed. In CFB-plants the emission levels for NO_x will be lower than compared with BFB. The costs for a CFB plant are significant more expensive than compared with BFB plant.

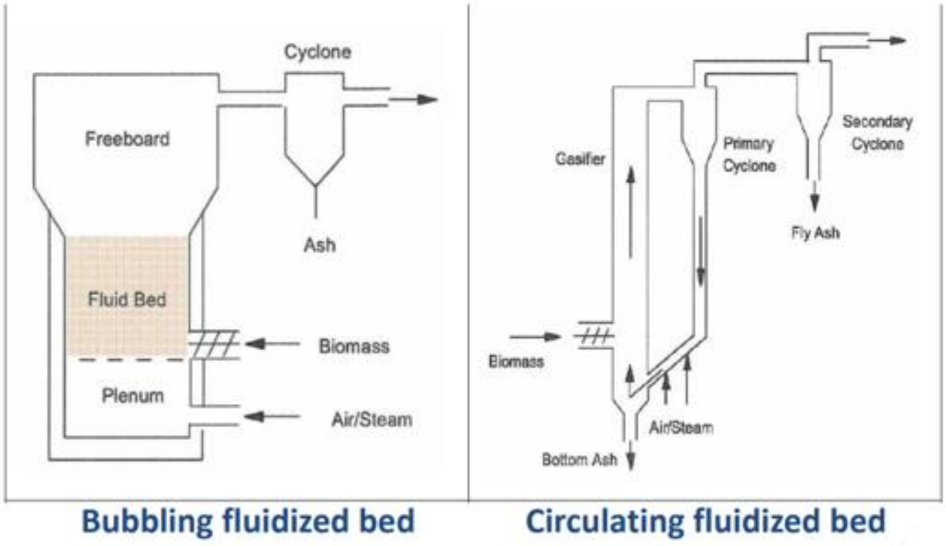


Figure 13. Bubbling and circulating fluidised bed.

In Japan the fluidized bed technology has been utilised in a rather high number of waste-to-energy plants that, in a sense, is halfway between grate systems and CFB: the Revolving Fuidized Bed (RFB). The technology favours smaller units (from 60 to 130 tonne per day). The waste can be incinerated without fine pre-shredding. Only rough tearing in shredder is required.

The reason for the relatively high number of fluidised bed plants in Japan is because there is a governmental guideline that the ash from WtE plants, in principle, should be melted. It is because hazardous heavy metals contained in the ash may be dissoluble in water. In Europe, bottom ash, the residue from grate incineration WtE plants, is traditionally utilized as construction or landfill material. The process of the fluidized bed plants causes the slag to be melted.

Steam is produced in the boiler and can be led to a turbine for producing electrical power. The low-pressure steam from the turbine is cooled in an air-cooled condenser and the condensate is recycled to the feed water tank and pumps for returning to the boiler.

When the flue gas leaves the boiler, it is led to a dry or a wet flue gas treatment system. A wet system consists typically of an electrostatic precipitator followed by a spray drier, a fabric filter and a wet scrubbing system. A dry system consists typically of an electrostatic precipitator followed by a spay drier and a fabric filter.

In Europe and US there are also a number of waste-to-energy plants based on the fluidized bed technology, but the number of plants is significantly smaller than the number of waste to energy plants based on the grate incineration technology. A fluid bed incinerator requires the feed stock is homogeneous and reduced to a size normally not greater than 2-10 cm. Therefore, fluid bed incinerators are normally not applied for mixed residual waste, which have not been reduced in size.

Less than 100 waste to energy plants based on fluidized bed have been built worldwide. Experiences are that these installations function well, provided the waste particle size distribution and waste calorific values are carefully managed. The efficiency of the fluidized plants is lower compared with conventional grate incineration waste-to-energy plants. Gasification with oxygen and integrated melting has led to net electrical efficiencies well below 10%.

7.2.2 Inputs

Treated municipally solid waste (MSW). Can be combined with biomass if this fulfils the requirements for the fuel.

7.2.3 Outputs

Electricity and heat.

In Japan melted ash (around 2% of the fuel) is utilized for soil material or concrete secondary product. For plants with other technologies than utilized in Japan the ash (not melted) content is around 10%.

7.2.4 Capacities

Capacity for single line for fluidized bed incineration can be from around 2 tonne/h up to 35 tonne/h. An incineration plant can consist of several incineration lines, often 2 or 3.

7.2.5 Advantages/disadvantages

Disadvantages of fluidized bed:

- Higher requirements pre-treatment of waste and close monitoring compared with crate incineration.
- Lower net electrical efficiency.
- High limestone demand for sulphur capture.

Advantages of Circulating Fluid Bed against Bubbling Fluidized Bed:

- Better burnout.
- Lower limestone demand for sulphur capture.
- Lower emission values.
- Better power control.

7.2.6 Environment

An incineration plant must follow legal requirements for emission to air and emission to waste water. These would normally be stated in the Environmental Permit issued by the Environmental Agency.

Air pollution control systems are very developed and the relatively well functionally so normally the emissions will be below the maximum permitted emission levels. It is a requirement to have a Control Emission Monitoring System (CEMS) installed with measurement instruments in the stack to constantly monitoring the emissions. Should the actual emission levels be above the requirement the plant must shut down until the operating problem is solved.

7.2.7 Employment

Manning is depending on

- Capacity of the plant, especially the number of lines.
- Complexity of the plant especially the configuration of the flue gas cleaning system.
- The level of the distributed control system (DCS) for the plant, constantly monitoring the plant and giving alarms when anything is not operating correct.
- Typical manning will be 4 – 6 persons for plant management and in the plant administration staff. In plants with a advanced distributed control system there will typically be 2 persons on night shift for operation and 4 persons on day shift for operation and maintenance.

For major overhauls the manning must be higher, and this is typically done by having contractors to do the work.

7.2.8 Research and development

Fluidized bed for solid waste is category 3 technology since the deployment has been moderate so far.

Research and development are ongoing in improvement of fluidized bed technology. There is a relatively large number of companies designing and selling design and/or fluidized bed boilers based on biomass and some of these types are for solid waste also.

7.2.9 CAPEX

The ultimate level of investment for a fluidized bed incineration plant will depend on the final detail of the Employers Requirements and the Technical Requirements specified at the time of tendering the project, plus market forces and vendor appetite at that time. In addition, CAPEX values can sometimes be affected by the nature of the final contract based on offer. For example, offering the opportunity of a long-term O&M contract too will create a higher degree of competitive tension.

The capital costs are excluded any allowance for:

- Bulk excavation, e.g. to reduce visual impact or to create the plant development platform.
- Special architectural features.

- Modifications to the existing site infrastructure, e.g. construction of feedstock vehicle traffic access roads.
- Pre-treatment of WtE plant feedstocks, e.g. bulky waste, street sweepings and/or waste wood.
- Feedstock Buffer storage / RDF laydown area.
- Heat offtake infrastructure, e.g. for chilling and/or desalination.
- Cost of financing.

Cost and throughput data have been gathered on wide range of WtE facilities in both UK and Europe. Data was collected when the project was in operation, commissioning, construction or planning phases and as such includes varying levels of confidence. Other data is from budget estimates gathered through past projects and information available in the public domain.

The estimate is 'cleaned' for complex architecture and geotechnical challenges. Further no enclosure for the facility is included and no logistics are included.

Based on these data a cost estimate for fluidized bed is:

For Lombok with a potential capacity of 275 kilo tonne per anno (ktpa) a CAPEX range is estimated to be 450-620 USD/tonne per anno (TPA).

For Batam with a potential capacity of 320 ktpa a CAPEX range is estimated to be 420-560 USD/tpa.

Generally, the upper part of the range represents high specified facilities established in complex areas. Building in Batam or Lombok is considered to be complex areas, most or all equipment must be imported and the majority of staffing for construction must be supplied from other areas.

Further to this 10-40% should be added for civil structure and logistics depending on the complexity of the construction site.

Further details are given in the data sheet in section 7.2.12.

7.2.10 Examples

It is estimated there are around 40 plants in Europe for treated waste, as for example refuse derived fuel (RDF).

7.2.11 References

1 Dipl.-Ing. Shinnosuke Nagayama, *High Energy Efficiency Thermal WtE Plant for MSW Recycling.*
2 Dan Fredskov, *Presentation for Incineration Technology – Theory and practical*, 2013.
3 H. Spliethoff, *Power Generation from Solid Fuels*, 2010.

7.2.12 Data sheet

Technology

Technology	**Fluidized Bed Power Plant - Municipal Solid Waste**								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	17	17	17						
Generating capacity for total power plant (MWe)	17	17	17						
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average	14%	14%	14%						2
Forced outage (%)	4%	4%	4%						
Planned outage (weeks per year)	8,0	8,0	8,0						
Technical lifetime (years)	25	25	25						
Construction time (years)	2,5	2,5	2,5						
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (million $/MWe)	6,0	5,5	5,0	4,5	6,2	3,7	6,2		1
- of which equipment	4,5	3,0	2,5	3,4	3,1	1,9	3,1		
- of which installation	1,5	2,6	2,5	1,1	3,1	1,9	3,1		
Fixed O&M ($/MWe/year)	309.500	295.400	262.700	247.600	386.900	210.200	328.400		
Variable O&M ($/MWh)	30,7	30,7	30,7	23,0	38,3	23,0	38,3		
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	20,0	20,0	20,0						

References:

1. Krystian Leski et al "Technical Transactions, Application of Circulating Fluidized Bed Boilers in the Fuel Combustion Process" 4/2018
2. Van Caneghem et al "Fluidized bed waste incinerators: design, operational and environmental issues", 2010

7.3 Co-combusting technologies

7.3.1 Brief technology description

Co-combustion in a coalfired boiler with biomass is a proven and used technology which does not require extensive modifications of an existing coalfired boiler. The experience with co-combustion with RDF is limited. Normally, a boiler suited for the production of high-pressure steam for electricity production would be a Benson type boiler with a dust fired system. The build up in live steam pressure and drum type boilers by nature is a difficult combination. A grate fired boiler would normally be a drum type.

The type of boiler and combustion system as mentioned is important. A boiler type with a grate fired fuel feeding system would be most suited for various types of fuel. The grate would have to be able to work well in periods without co-combustion and only one type fuel according to availability.

Wood or straw pellets will normally work well in a traditional coal grinding system and through a pressurized firing fuel injection system such as normal coal fired burners. This, however, will not apply for more unprocessed solid wastes which by nature will be more suited for grate type boilers as mentioned above and fluidized bed boiler types.

If the fuel injection system is more complex various issues needs to be taken into consideration. If the boiler is fed through a grinding system and dust fired it is important to recalculate the amount of air needed and how it is injected. Often such systems will end in a scenario where one (or more) coal grinder is rebuilt and adjusted to the biomass. The transport air and mechanical filters often needs to be redesigned and commissioned. Purging air systems and probably the overall boiler trip system must be re-evaluated in order to secure safe and reliable operation. In a grate fired boiler this will be a simpler task and the fuel can be mixed prior to being fed to the boiler furnace. Overall, no further steps need to be taken in order to maintain boiler safety and purging system.

Analysis of the composition of the co-combustion biomaterial must be evaluated, since with a new fuel, new types of corrosion can be introduced to the boiler system. Fertilizers used in agriculture will be part of the biomass fuel also and can introduce new problems, mainly related to corrosion issues but also new heavy metals might be an issue to consider in systems downstream of the boiler furnace.

Fly ash systems should be evaluated as well. Depending of the percentage of cofiring the electrostatic precipitator or other type fly ash filter assumedly will need modification and maybe also the conveying system, again depending on the percentage of co-combustion. The resistivity of the fly ash will change depending on the percentage of co-combustion leaving that especially an electrostatic precipitator must be redesigned. Lastly, if the fly ash has any use, could be in concrete or asphalt manufacturing this should be taken into consideration as well since landfill should be sought to be avoided.

7.3.2 Inputs

Coal and biomass fuel. Municipality waste is possible, but in most cases the waste must go through mechanical-biological treatment to produce RDF. The requirements for the pre-treatment for RDF are high in relation to purity for taking out metal and glass. In practice the energy basis of RDF is maximum 5-10% of the fuel mix, and there are stringent particle size requirements, <2-3 mm.

An example of characteristic of RDF for a pulverized-coal unit in Fusina Power Station in Italy are the following[2].

- Moisture content: 8-18wt.%.
- Ash content: 15-20wt.%.
- Lower heating value (LHV): 17-21 MJ/kg.
- Chlorine content: 0.7-0.9wt.%.

7.3.3 Outputs

Electricity and heat.

The electrical energy naturally being utilized and desired. Heat in principal being a by-product of electricity production could be used for heating purposes or as auxiliary steam for various purposes.

Slag and ashes are normally not an output but more of a residue where a usage in order to get rid of the materials is sought. Normally fly ash with low content of unburnt coal residue can be used in concrete production with good result or else slag and low-quality fly ash can become encapsuled in asphalt.

Gypsum would be the normal product from desulphurization of coal fired boilers. This is a sought-after material and has high value in civil industries.

7.3.4 Capacities

The boiler is normally designed according to demand. The largest Danish single coalfired unit has an electrical output of 650MW.

7.3.5 Ramping configuration

Ramping configuration of loads in a coalfired boiler will depend on the design of boiler and steam turbine. If all temperatures are at nominal conditions, a 20 MW/ min up and down regulation of electrical output would normally be acceptable without any additional lifetime consumption.

7.3.6 Advantages/disadvantages

Advantages:

- Low additional investment costs.
- Relatively minor fuel preparation requirement but depending on boiler type.
- Flexibility in fuels.
- High process availability.
- Simple operation.
- Simplicity of operation.
- Low auxiliary power consumption.
- With a small proportion of waste, it is easy to keep emissions below legislation limits.

Disadvantages:

- Increased complexity of flue gas cleaning.
- Space requirements for fuel storage.
- Increased logistics handling.
- Waste and coal ashes are mixed, which may compromise ash utilization.

7.3.7 Environment

Both conventional power plants and incineration plants must follow legal requirements for emission to air and emission to wastewater. These would normally be stated in the Environmental Permit issued by the Environmental Agency.

Air pollution control systems are very developed and the relatively well functionally so normally the emissions will be below the maximum permitted emission levels. It is a requirement to have a Control and Emission Monitoring System (CEMS) installed with measurement instruments in the stack to constantly monitoring the emissions. Should the actual emission levels be above the requirement the plant must shut down until the operating problem is solved.

7.3.8 Employment

Staffing for power or incineration plants vary according the number of units and the complexity of these. Especially how many systems like flue gas cleaning, fuel handling, harbour area for unloading of fuels, process steam/ heat distribution that are in connection with the energy production. Also, the level of automation and the quality thereof. Especially in relation to the Distributed Control System (DCS) system.

However, a normal setup would be as for grate fired systems hence 4–6 persons for plant management and in the plant administration staff. In plants with an advanced distributed control system there will typically be 2 persons on night shift for operation and 4 persons on day shift for operation and maintenance but again this relies heavily on the overall complexity of the unit and plant.

For major overhauls the manning must be higher, and this is typically done by having contractors to do the work. For these type jobs normally specially, trained personnel is needed which would not be feasible to have as inhouse employees.

7.3.9 Research and development

Co-combustion of coal with solid waste is a category 2 or 3 technology depending on the type of solid wate incinerated. If the solid waste is based on biomass it is a category 3 technology. If the solid waste is RDF, it is a category 2 technology since the few plants with co-combustion of coal and RDF are more or less demonstration facilities.

Most technologies within traditional boiler setup have matured over long time and research and development have been ongoing for many years, especially in relation to choice of steel materials and alloys for boiler piping as well as improvements in high temperature resistance.

7.3.10 CAPEX

With reference to section 7.1.10, Capex for a green field plant co-combustion facility the technology cost is covered within the same capex estimate. Co-combustion is normally utilising either grate, fluidized bed or stocker technology and is expected to be established at the same Capex.

7.3.11 Examples

Most often it will be a retro fitted scenario where a coal fired unit is modified to accommodate biofuels as well but more newly built unit are able to burn various types of fuels most naturally being grate or fluid bed type boilers.

There are not many references for coal fired plants with co-combustion with RDF:

- Fusina Power Plant in Italy. 320 MWe. Co-combustion with 5% RDF.
- Rodenhuize Power Plant, Belgium. 285 MWe. The plant has been operating on 50% wood pellets.

The Waste Management Directorate Ministry of Environment and Forestry reported that the PLN (Indonesia Energy Company) through Indonesia Power conduct a pilot project of waste to energy using RDF technology. They processed the waste into RDF pellets. The RDF pellets are used as co-firing biomass in the Jeranjang Power Plant located around 3,5 km from the landfill.

Figure 14. RDF Processing in Kebon Kongok landfill

The laboratory results of the RDF pellets are presented in the following table.

Table 22. Proximate and Ultimate Analysis result of RDF Pellets from Kebon Kongok.

Analysis parameters	Sample marks		Unit	Basis	Standard methods
	Coal	Coal 95%+ RDF pellets 5%			
Proximate analysis:					
Moisture in air dried	17.13	14.44	%	adb	ASTM D.3173
Ash	5.10	7.70	%	adb	ASTM D.3174
Volatile matter	40.64	41.40	%	adb	ASTM D.3175
Fixed carbon	37.13	36.46	%	adb	ASTM D.3172
Ultimate analysis:					
Total sulphur	0.16	0.18	%	adb	ASTM D.4239
Carbon	54.34	54.03	%	adb	ASTM D.5373
Hydrogen	5.49	5.34	%	adb	ASTM D.5373
Nitrogen	0.89	0.93	%	adb	ASTM D.3176
Oxygen	34.02	31.82	%	adb	ASTM D.5374

Source: Waste Management Directorate Ministry of Environment and Forestry, 2020.

The conclusion of the pilot project includes:

1 The calorific value of pellets is lower that coal, so the fuel flow increases 4% in the same loading condition.

2 Generally, the temperature distribution on the lower part furnace do not change significantly. In contrast, the temperature distribution on the upper part of the furnace increase during the co-firing, likely caused by retarding combustion due to the residence time of pellets.

3 The differential pressure in the boiler increased that probably caused by bed material agglomeration, so the fluidization unwell processed.

7.3.12 References

1 VGB Powertech, Advantages and Limitations of Biomass Co-combustion in Fossil Fired Power Plants (2008).

2 Naomi Klighoffer, Waste to Energy Conversion Technology, 2013.

7.3.13 Data Sheet

Technology

Technology	CoCombustion - Solid Waste and Coal								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	22	22	23						
Generating capacity for total power plant (MWe)	22	22	23						
Electricity efficiency, net (%), name plate	29%	30%	31%	28%	32%	30%	33%		
Electricity efficiency, net (%), annual average	28%	29%	29%	26%	30%	28%	31%		
Forced outage (%)	1%	1%	1%						
Planned outage (weeks per year)	2,9	2,6	2,1						
Technical lifetime (years)	25	25	25						
Construction time (years)	2,5	2,5	2,5						
Space requirement (1000 m^2/MWe)	1,5	1,5	1,5						
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	10	10	10	7,5	12,5	7,5	12,5		
Minimum load (% of full load)	20	20	20	15,0	25,0	15,0	25,0		
Warm start-up time (hours)	0,5	0,5	0,5	0,4	0,6	0,4	0,6		
Cold start-up time (hours)	2	2	2	1,5	2,5	1,5	2,5		
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (million $/MWe)	6,8	6,3	5,6	5,1	7,0	4,2	7,0		
- of which equipment	4,0	3,4	2,8	3,0	3,5	2,1	3,5		
- of which installation	2,8	2,9	2,8	2,1	3,5	2,1	3,5		
Fixed O&M ($/MWe/year)	243.700	224.800	193.500	195.000	304.600	154.800	241.900		
Variable O&M ($/MWh)	24,1	23,4	22,6	18,1	30,2	16,9	28,2		
Start-up costs ($/MWe/start-up)									
Technology specific data									

7.4 Retrofit of coal-fired blocks

7.4.1 Brief technology description

The retrofit of existing coal fired units to incinerate biomass is a well-known technology. The major benefit being that it is a cheap way of reducing CO_2 emissions since no new facility is needed, but only modifications of existing unit. Existing infrastructure around the plant can be utilized as well as existing personnel and supply lines.

Various consideration, from a technical perspective, are to be taken before considering a retrofit. The type of boiler is important and how suitable it is for the desired type of fuel. For example, pellets will need a grinding facility and burning system. On the other hand, larger solids from waste will be more suitable for grate type firing. Typically, most coal fired boilers with an output relevant for retrofit are either drumtype or Bensontype boilers, both with a coal grinding facility and are not equipped with a grate firing system. If a grate is required for burning the waste, then retrofitting is probably not feasible due to the associated high costs.

When retrofitting a coal fired boiler the composition of the fuel must be taken into consideration. As with co-combustion, problems related to corrosion mainly due to fertilizers, is an issue for the boiler tubes an initiation of corrosion issues.

Soot blowing is normally an aspect that is considered during the design phase of a boiler and then it becomes an important part of normal operation but does not provide further issues throughout a boiler lifetime other than normal maintenance. When retrofitting a typical coal fired boiler, the lower melting point of the fly ash of especially most biomass, but also solid waste depending of its composition, is to be considered. The lower melting point results in the fly ash still to be sticky when entering the hanging superheaters leaving a need for either a new soot blowing system or frequent stops for cleaning.

Remarks:

- Lifetime assumption of unit should be evaluated prior to retrofit.
- Low melting point straw ashes.
- Atmosphères explosibles (ATEX) problems (ATEX only in EU, however).
- Pellets must be produced and cannot be stored outside.
- Pellets must be milled, not for crate fired boilers.

7.4.2 Inputs

If a grate is installed in the boiler: solid waste and biomass.

If a grate is not installed: Pellets.

7.4.3 Outputs

Electricity is the main product; heat can be used for other applications if deemed feasible. If not for heating purposes steam can be extracted from the turbine for process applications.

7.4.4 Capacities

By nature, this will rely on the boiler that is being retro fitted and the capacity of this. There is no lower or upper limit to retro fitting a boiler.

The nominal energy in and output however must remain as designed. The boiler as such remains the same, only the fuel feeding system is prepared to accommodate more types of fuel. Also, the turboset would normally not be modified.

7.4.5 Ramping configuration

The ramping conditions would be the same or slower than designed. Again, the boiler is the same and the turboset as well, so load gradients would normally have to be respect according to design if no other modification had been done.

7.4.6 Advantages/disadvantages

Advantages:

- Cost-effective reduction in CO_2 emissions
- Relative low cost for retro fitting since the unit and all auxiliary systems are existing, compared to building a new power unit.
- Flexibility in fuels.
- High process availability.
- Known operation regime.
- Low auxiliary power consumption.

Disadvantages:

- Increased complexity of flue gas cleaning due to incineration of waste.
- Space requirements for fuel storage.
- Increased logistics handling.

7.4.7 Environment

Conventional power plants must follow legal requirements for emission to air and emission to wastewater. These would normally be stated in the Environmental Permit issued by the Environmental Agency in the country. When commencing to co-combust waste in a coal fired boiler the requirement to emissions to air will be increased and it would be expected that the flue gas treatment system must be upgraded.

7.4.8 Employment

Staffing for retro fitted power or incineration plants vary according the number of units and the complexity of these. It would however be the same numbers as mentioned in earlier chapters relating thermal energy units. It would be the same systems like flue gas cleaning, fuel handling, harbour area for unloading of fuels, process steam/ heat distribution that would determine the amount of people needed for production and daily maintenance. Again, the level of automation of the systems would be a factor and the level of education and experience of personnel involved.

A normal setup would be 4–6 persons for plant management and in the plant administration staff. In plants with an advanced distributed control system there will typically be 2 persons on night shift for operation and 4 persons on day shift for operation and maintenance but again this rely heavily on the overall complexity of the unit and plant.

For major overhauls the manning must be higher and this is typically done by having contractors to do the work. For these types of jobs normally specially trained personnel is needed which would not be feasible to have as inhouse employees.

7.4.9 Research and development

Retrofit of coal-fired blocks is a category 3 technology. The technology for retrofitting coal fired block for incineration of pellets based biomass is well-known.

Most technologies within traditional boiler setup have matured over long time and research and development have been ongoing for many years, especially in relation to choice of steel materials and alloys for boiler piping as well as improvements in high temperature resistance. When retro fitting a boiler and thus introducing new fuels, their composition is relevant due to new types of corrosion. New intervals for inspection and types of non destructive testing (NDT) might be needed

As mentioned, research and development in relation the flue gas cleaning system are well matured and is not a hindrance for retro fitting. In overall the technology for flue gas treatment has reached a level where there are not really any larger improvements that can done and the main products out of the stack on most of the recently build power plants in Europe, is water and CO_2.

7.4.10 CAPEX

Estimating Capex for a retrofitting of an existing facility is very difficult without having any assumptions for the condition and the technology but a range of 10-50% of a new build of a similar capacity should be expected.

7.4.11 Examples

There are examples of retro fitted boilers throughout Europe where this has been thought to be feasible. Especially at smaller thermal unit where water-based heat delivery is relevant.

Amagerværket unit 1 in Denmark was original coal-fired but was in 2010 retrofitted for wood pellets. The unit is producing 250 MW heat and 68 MWe. 250.000 tons wood pellets per year is incinerated and the wood pellets are produced from waste wood.

7.5 Two-chamber technology with ORC turbine

7.5.1 Brief technology description

This technology is small scale systems with two-chamber technology (gasification and combustion) and ORC (Organic Rankine Cycle) turbine. The combination of gasification and combustion with an ORC turbine system is essentially a configuration with a standard gasifier. However, instead of a gas motor, the gasification gas/syngas is processed in a combustion chamber where the ORC process converts the heat to electricity.

7.5.2 Brief description of how the technology works and for which purpose

The gasification part of the process is identical to the technology described in section 8.1.

After the gasifier, the syngas is combusted in a combustion chamber in a stable process where the temperature is kept constant via flue gas recirculation. In the combustion chamber heat surfaces, thermal oil is heated to approximately 300°C. The thermal oil is then used to transfer heat to the ORC process.

The Organic Rankine Cycle's principle is based on a turbogenerator working as a conventional steam turbine to transform thermal energy into mechanical energy and finally into electric energy through an electrical generator. However, instead of generating steam from water, the ORC system vaporizes an organic fluid, characterized by a molecular mass higher than that of water, which leads to a slower rotation of the turbine, lower pressures and no erosion of the metal parts and blades (ref 1).

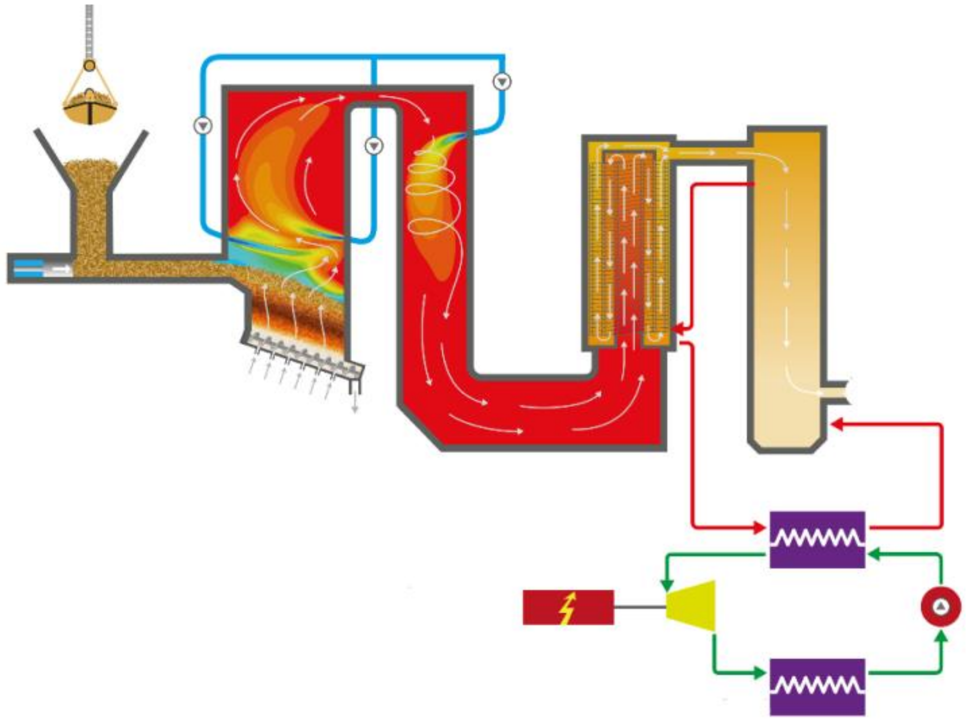


Figure 15: Gasifier with thermal oil boiler and ORC technology (Source: Dall Energy).

A primary advantage of the ORC cycle is the closed system operating with relative low temperature and pressure resulting in reliable low-maintenance operation. However, the electrical efficiency is not as high as more conventional technologies. An electrical efficiency of 20-25% is common (ref 2).

When the flue gas leaves the combustion chamber, the flue gas cleaning process is similar to conventional boilers with normally a dry or a wet flue gas treatment system. A wet system consists typically of an electrostatic precipitator followed by a spray drier, a fabric filter and a wet scrubbing system. A dry system consists typically of an electrostatic precipitator followed by a spray drier and a fabric filter.

7.5.3 Inputs

Pre-treated fuel is best suited for gasifier operation, this can be industrial waste. MSW is less suited for gasification.

7.5.4 Outputs

Electricity and heat. Slag from gasification process shall be disposed of.

7.5.5 Capacities

The ORC technology is mostly seen in the range of 1-10 MW electric power, where larger plants can be configured with a large gasifier coupled with two or more ORC turbines. With a unit size of 10 MW electric, the thermal input would be expected around 50 MW thermal. The fuel consumption in t/h will depend on the heating value of the appropriate fuel type.

Smaller units can be feasible due to the scalability of the ORC units.

7.5.6 Ramping configuration

No info available.

7.5.7 Advantages/disadvantages

Advantages:

- ORC cycle is reliable and has low maintenance cost.
- Scalable to very low capacities.

Disadvantages:

- Limitations for fuel specification.
- Relatively low electrical efficiency.
- Very few references with waste fired gasifiers coupled with ORC systems.
- High CAPEX per treated kg waste.
- Low capacity compared to waste incineration.

7.5.8 Environment

With full combustion of the syngas, the emissions of the two-chamber solution is similar to incineration on grate or in fluid bed and the corresponding emissions to air shall be considered according to legal requirements. Pollution control with various initiatives and CEMS are expected to be installed.

7.5.9 Employment

For a smaller scale plant in the range 1-10 MW electric, the staffing should be suited for a feasible operation with a core staff that can handle several functions.
A suitable operational staff is expected to be 2 persons on night shift for operation and 4 persons on day shift for operation and maintenance. Additional administration and plant management expected 3-5 persons.

7.5.10 Research and development

Biomass gasification with ORC is a category 3 technology. The deployment is moderate so far and it is only the companies Turboden from Italy and Dall Energy from Denmark which in combination supplies this technology.

The ORC system is generally well-developed; however the number of technology providers is low with one main supplier Turboden having a large part of the references for this technology.

The configuration with waste fired gasification and ORC is not generally applied and the limited application for the technology means that little research and development is generally available. It is evaluated that development of this technical solution is progressing slowly.

7.5.11 CAPEX

In general ORC technology and two-chamber technology providers operates with standard setups for keeping the CAPEX relatively low compared with other technologies. Figures around 240 USD/tpa could be expected.

7.5.12 Examples

Because Turboden is the main ORC supplier, the references from this technology provider gives an appropriate overview of the application of ORC for waste to energy purposes. See reference 1.

Sindal combined heat and power plant in Denmark is biomass gasification furnace with an ORC turbine. The plant consists of a gasifier, a gas burner, a thermo-oil boiler, a flue gas condenser and an ORC-turbine plant. When the flue gas is passed through the heat exchangers of the thermal oil plant, the temperature is about 950 °C. After yielding its energy to the thermal oil plant, the temperature is about 185 °C. From the thermal oil plant, the heat can be directed to district heat exchangers or to the ORC plants turbine that produces electricity and heat. In the quench, the flue gas is cooled to 60 °C, and in the flue gas condenser, the flue gas is cooled further, and the final energy is extracted. When the flue gas is led to the chimney, the temperature is as low as 40 °C. Key figures for the plant:

- Input power: 5.5 MW.
- Electricity production: 800 kW.
- Heat production: 5.0 MW.
- 20-100% load.
- Fuel: Wood chips, garden/park waste.

7.5.13 References

1 www.turboden.com/products/2463/orc-system

2 COWI report: *Feasibility study - Power generation, biomass availability and feedstock supply, Earth Energy Limited, Uganda*, September 2020.

7.5.14 Data sheet

Technology

Technology	Small Scale Systems - Municipal Solid Waste								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	5	5	5					Variable standard sizes, 1-10 Mwe	1
Generating capacity for total power plant (MWe)								Total capacity as sum of multiple units.	1
Electricity efficiency, net (%), name plate	25%	26%	27%	24%	28%	26%	29%	Small efficiency increase estimated. Uncertainty interval depends highly on actual application.	1
Electricity efficiency, net (%), annual average	22%	23%	24%	21%	25%	23%	26%	Small efficiency increase estimated. Uncertainty interval depends highly on actual application.	1
Forced outage (%)									
Planned outage (weeks per year)	8,0	8,0	8,0	4,0	12,0	4,0	12,0		
Technical lifetime (years)	20	20	20	15	25	15	25		2
Construction time (years)	1,5	1,5	1,5	1	2	1	2		2
Space requirement (1000 m^2/MWe)	2	2	2	1	3	1	3	Depends highy on capacity	1
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (million $/MWe)	3,0	2,8	2,5	2,3	3,1	1,9	3,1	Depends on capacity 1-10 Mwe	1
- of which equipment									2
- of which installation									2
Fixed O&M ($/MWe/year)	300.000	300.000	300.000	100.000	700.000	100.000	700.000	Depends on capacity 1-10 Mwe	1
Variable O&M ($/MWh)								Inkl. in Fixed O&M	
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	10,0	10,0	10,0						

References:

1 - COWI report: Feasibility study - Power generation, biomass availability and feedstock supply, Earth Energy Limited, Uganda, September 2020.

2 - Basic assumption for industrial energy plants, evaluated for small scale system.

8 Other thermal technologies

8.1 Gasification

8.1.1 Brief technology description

A gasifier heats waste to a temperature above 1,000ºC in an atmosphere starved of oxygen in order to have an incomplete combustion of the waste. This yields a gas, called a syngas, which can be used as a fuel. The gas stream comprises mostly of carbon monoxide, hydrogen and methane. The precise composition of the gas is determined by the temperature, the air and water content can be adjusted to yield the required gas composition.

To prepare the fuel is demanding and costly. Many different types of wastes may be mixed for feeding it to the gasifier. The pre-treatment for this involves manual or mechanical: sorting, shredding, mixing with other materials (usually that are easier to gasify, such as coal), drying and pelletization. The purpose of the pre-treatment is mainly to produce consistency in the chemical and physical characteristics of the fuel.

The syngas from this process is very corrosive and the tendency for ash fusion within the gasifier can be quite substantial.

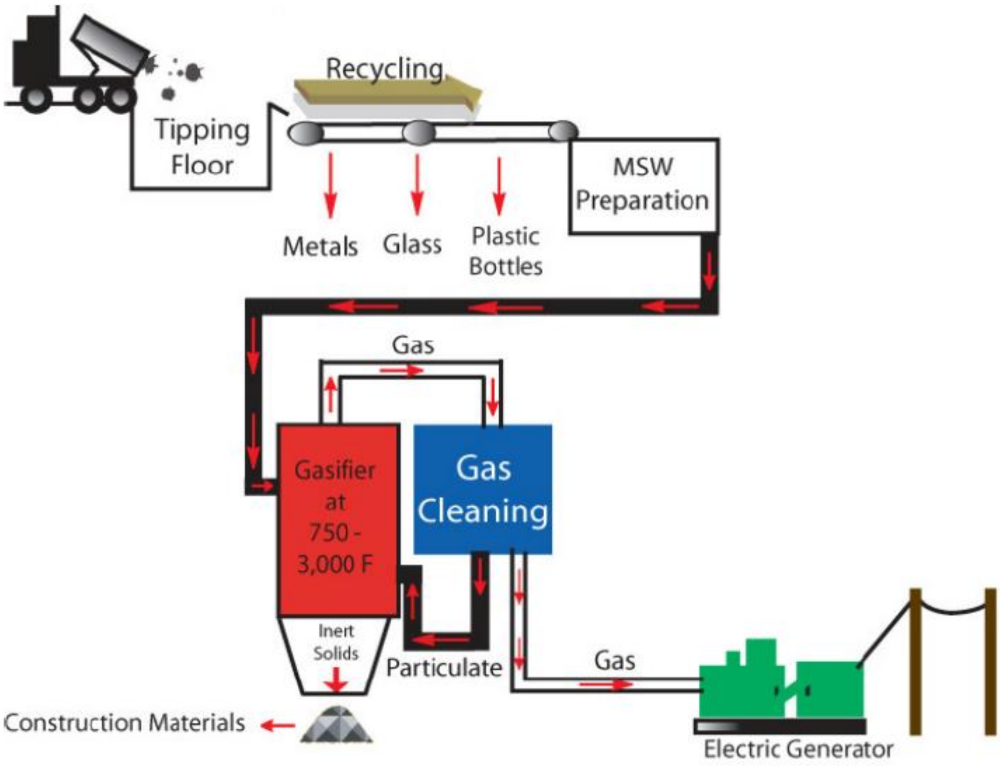


Figure 16. Simple gasification process overview.

A process called Thermoselect Gasification was developed in Switzerland between 1985 and 1992. A pilot plant and two plants were constructed based on this technology, but they suffered technical and commercial problems and never went into stable operation (ref 1).

In Japan, similar plants have been built by JFE (Japan Steel Engineering), licensing the Thermoselect technology. The first plant was completed in 1999 at a steel mill in Chiba with the synthesis gas produced being used in a mill. A further six JFE plants using the Thermoselect technology had begun operation by 2006 (ref 1). The process is shown in below figure.

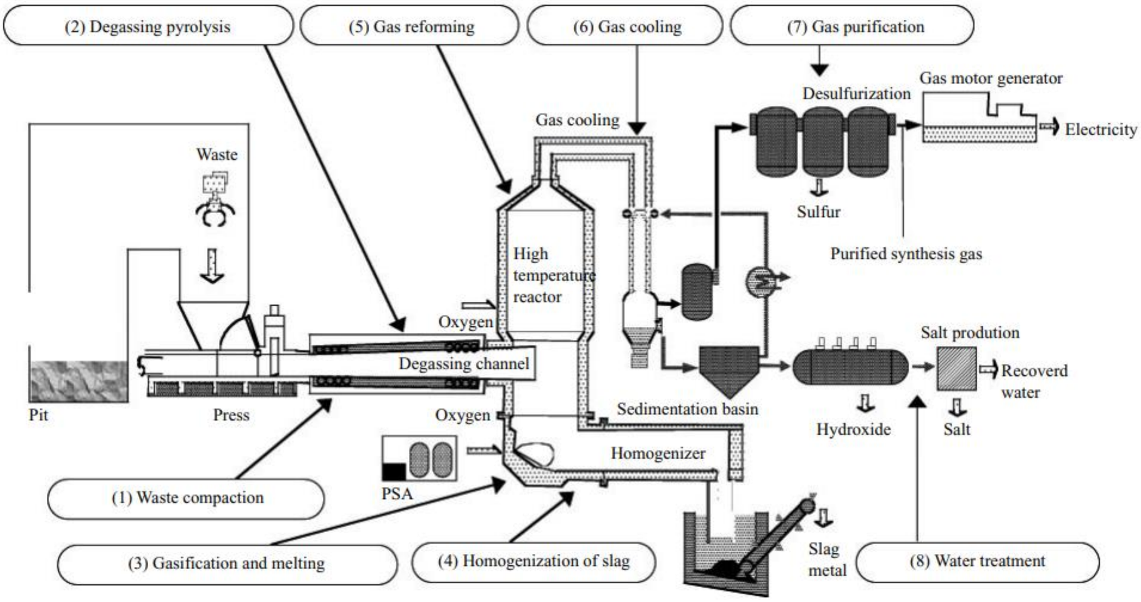


Figure 17. Thermoselect process according to Japan Steel Engineering.

The plants build by JFE Engineering Corporation are in capacity from around 50 tons/day to 125 tons/day times 2 lines.

8.1.2 Inputs

Pre-treated fuel mixed with other materials (usually that are easier to gasify, such as coal).

8.1.3 Outputs

Synthetic gas.

8.1.4 Capacities

The capacity for single line for gasification is small compared to grate incineration. The capacity can be from around 2 tonne/h up to 6 tonne/h. An incineration plant can consist of several incineration lines, often 2, so that it is possible to take a line out for overhaul.

8.1.5 Advantages/disadvantages

Advantages:

- Low emission of dioxins and no generation of fly ash.
- No flue gas (no flue gas cleaning required).
- Gas can be utilized after purification.

Disadvantages:

- No commercial plants are in operation outside Japan.

- High requirements for preparation of fuel and addition of other fuels such as coal.
- Not a mature technology.
- The technology has never proved to be profitable.

8.1.6 Environment

Since there is no flue gas from the process, emissions to air are low.

8.1.7 Research and development

The technology is in category 2. As mentioned above only a few plants has been built in Japan and the technology has never developed to be commercial beneficial.

Producing methanol form syngas based on waste is on a research and development level.

No information is available regarding whether research and development is ongoing regarding the gasification process based on among other municipal solid waste.

8.1.8 CAPEX

See section 8.1.11.

8.1.9 Examples

Name	Clean Hill Homan (Chikushino/ Ogori/ Kiyama Waste Treatment Facility Association)
Capacity	250 tons/day (125 tons/day × 2 lines)
Completion	March 2008

Name	ECO CLEANCENTER (Hamada District Regional Administrative Association)
Capacity	98 ton/day (49 tons/day × 2 lines)
Completion	November 2006

Name	Kita Waste Disposal Center, Kakamigahara City
Capacity	192 tons/day (64 tons/day × 3 lines)
Completion	March 2003

Name	Eco Center Banjo, Saiki City
Capacity	110 tons/day (55 tons/day × 2 lines)
Completion	March 2003

Figure 18. Reference plants based on gasification [www.jfe-eng.co.jp]

8.1.10 References

1 H. Spliethoff, *Power Generation from Solid Fuels*, 2010.

2 JFE Technical Report, *Thermoselect Waste Gasification and Reforming Process,* July 2004.

3 Ecotec Research and Consulting *Costs for Municipal Waste Management in the EU*, 2002.

8.1.11 Data sheet

Technology

Technology	Gasification - Solid Waste and Biomass								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	13	13	13	20%	20%				1
Generating capacity for total power plant (MWe)	13	13	13	20%	20%				
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average	26%	26%	26%	20%	20%				1
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)	20	20	20						
Construction time (years)	2	2	2						
Space requirement (1000 m^2/MWe)	0,15	0,15	0,15						
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (million $/MWe)	1,1	1,0	0,9	0,8	1,1	0,7	1,1		1
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	45.000	41.607,0	37.260,0	36.000	56.300	29.800	46.600		
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	12,5	12,5	12,5						1

References:

1 Ecotec Research and Consulting "Costs for Municipal Waste Management in the EU", 2002

Notes:

8.2 Pyrolysis

8.2.1 Brief technology description

Pyrolysis is thermal degradation in the absence of air. It is the fundamental chemical reaction that is the precursor of both the combustion and gasification processes. At temperatures below 400-500°C the pyrolysis products are mainly tar, charcoal, pyrolysis oil and synthetic gas (syngas).

A wide range of biomass feedstocks can be used in pyrolysis processes, however the pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%.

The technology for pyrolysis of waste has never reached a state where it has been profitable to construct plants based on this process. The technology which has reached the highest degree of development in Europe was a process bases on rotary kiln (pyrolysis drum) followed by a mechanical sorting system of the residues. The separated coke and the pyrolysis gases are combusted in a downstream melting furnace.

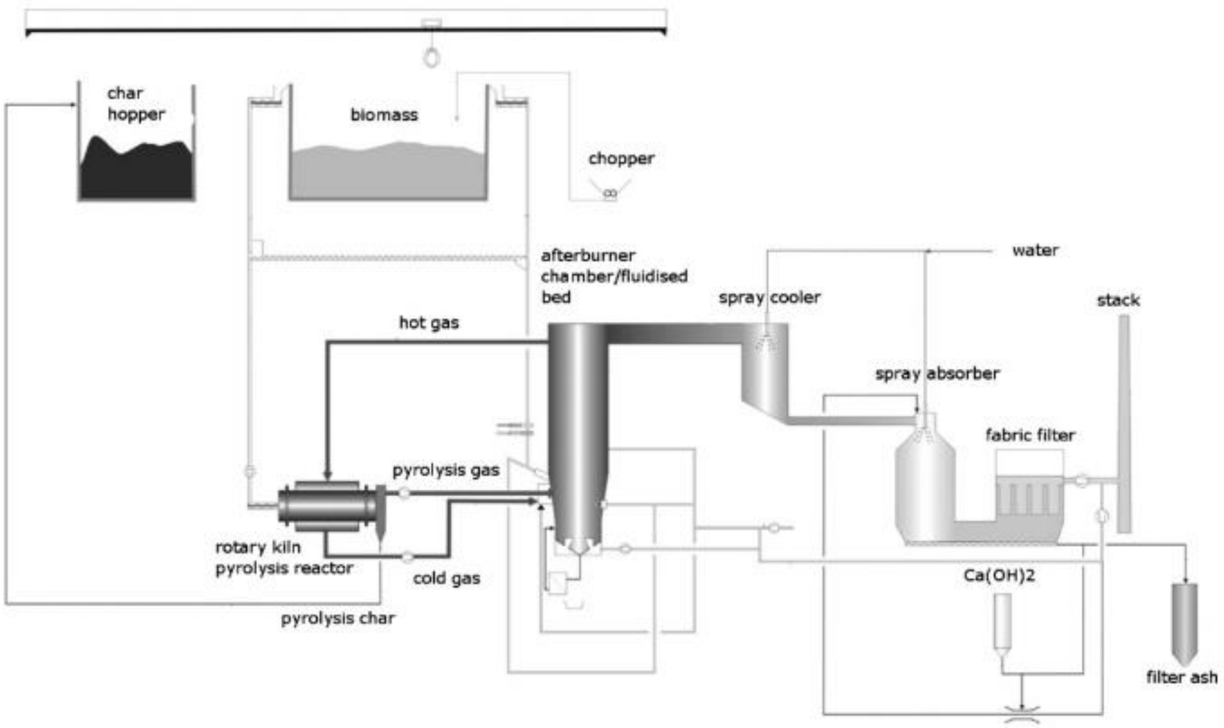


Figure 19. Pyrolysis plant [5].

8.2.2 Inputs

Pre-treated fuel mixed with other materials (that are easier to gasify, such as coal).

8.2.3 Outputs

The pyrolysis products are mainly tar, charcoal, pyrolysis oil and synthetic gas (syngas).

8.2.4 Advantages/disadvantages

Advantages:

There are no significant advantages of the pyrolysis of waste technology.

Disadvantages:

- High requirement for pre-treatment for the waste input, leading to extra costs.
- Requirements for quality of 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 downstream the pyrolysis part pf the plant. The costs for additional repairing and maintenance reduces the positive economy of the plant.
- High demand for maintenance requirements and associated costs.

8.2.5 CAPEX

As stated above there are only pyrolysis plants in operation in Japan, but there are no CAPEX and OPEX data available from these plants.

8.2.6 Examples

A pyrolysis plant for waste was commissioned in 1997 in Germany. The plant had severe technical problems including the waste pre-processing and it was decided to dismantle the plant. Since then no further projects with this technology has been seriously considered in Europe (ref 4).

Licences for the technology have been acquired by companies in Japan, which have constructed several commercial plants subsequently. There is very little information about the operational performance of these plants. In general, the waste-to-energy plants in Japan are relatively small in capacity.

8.2.7 Environment

In relation to fulfilling the environment requirement for a pyrolysis plant, this is not an issue. The required technology for flue gas treatment and emission control is in place.

8.2.8 Research and development

The technology is in category 2. As mentioned above only a few plants has been built in Japan and the technology has never developed to be commercial beneficial.

No information is available regarding whether research and development is ongoing regarding the pyrolysis process based on among other municipal solid waste.

8.2.9 References

1 Martin F. Lehmann, *Waste Management*, 2008.

2 Walter R. Nissen, *Combustion and Incineration Processes*, 2010.

3 Naomi B. Klinghoffer, *Waste to Energy Conversion Technology*, 2013.

4 H. Spliethoff, *Power Generation from Solid Fuels*, 2010.

5 Kern etal. *Rotary kiln pyrolysis of straw and fermentation residues in a 3 MW pilot plant.*

6 Ecotec Research and Consulting *Costs for Municipal Waste Management in the EU*, 2002.

8.2.10 Data sheet

Technology

Technology	**Pyrolysis - Solid Waste and Biomass**								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)									
Generating capacity for total power plant (MWe)									
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average									
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)	20	20	20						
Construction time (years)	2	2	2						
Space requirement (1000 m^2/MWe)	0,2	0,2	0,2						
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment ($/ton/year)	99,0	91,5	82,0	74,3	102,5	61,5	102,5		
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	73	67,1	60,1	100	100	0	100		
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	5,0	5,0	5,0					A	

References:

1 Ecotec Research and Consulting "Costs for Municipal Waste Management in the EU", 2002
2 H. Spliethoff, "Power Generation from Solid Fuels", 2010

Notes:

A This process is without electrical production

8.3 Plasma/electric arc gasification

8.3.1 Brief technology description

The plasma gasification technology is a method where an electrical arc creates very high temperatures in order for gasification of solids to happen. Temperatures above 2,000 °C are created and solid wastes are broken down and creates synthesis gases or syngas to be used in other applications afterwards.

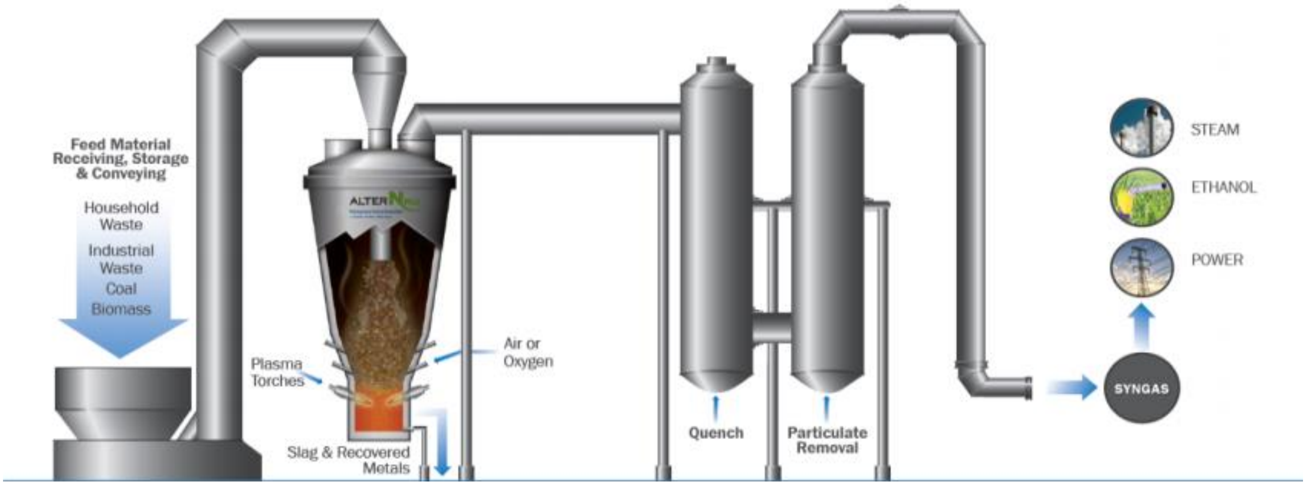


Fig. 14. Plasma arc plant.

In an oxygen starved atmosphere for pyrolysis, the plasma ARC method can be used most effectively for creating synthesis gas. The high temperature gasifies the solid waste and since no oxidation occurs, the gasses can be used later for energy conversion. In an oxygen rich/ pure oxygen atmosphere the plasma method can also be used. In this atmosphere the plasma arc can clean especially for tar residues, which are unwanted in an environmental context an in the system for which the synthesis gas is used for example in gas turbines.

There aren't many known Original Equipment Manufacturers (OEMs) of the plasma arc system and not many facilities are in operation. Maintenance for these systems are thought to be relatively high due to few relevant OEMs and that the technology has yet to mature and expand.

8.3.2 Inputs

Electrical energy for creating the plasma arc and solid waste for gasification.

8.3.3 Outputs

The output of the plasma gasification is syngas. The gas can be used for various purposes; for energy production in a gas turbine or further refinement to bio diesel etc.

8.3.4 Capacities

These systems in principle can be scaled to size needed.

8.3.5 Ramping configuration

There is not as such a ramping condition for this method.

8.3.6 Advantages/disadvantages

Advantages:

- Can process waste of low value into a product with high value (syngas). There are however other and cheaper ways to heat waste until gasification, but the plasma arc method is a clean method not leaving a need for flue gas cleaning etc.

Disadvantages:

- High energy consumption leaving the method to be used mainly when normal gasification is not relevant. The method is often suggested used as a last stage cleaning to have a higher grade of synthesis gas which is then possible to be used in gas turbines or gas engines.

- The electricity for the plasma process is often produced at a power plant creating CO_2 leaving the potential net reduction irrelevant. However, if for example the electrical grid often has periods of overproduction due to other technologies like wind or tidal energy, over filled water reservoir or solar power, a plasma arc system could be beneficial. Also, as a levelling factor for electrical net frequency during night, where electrical consumption is low and for example power plants must be in operation.

- Pre-treatment of the waste needs to be quite severe leading to extra cost.

8.3.7 Environment

Environmental requirement in relation to the plasma arc method can be dealt with by existing technologies for flue gas treatment and emission control. However, the plasma arc gasification as a process is deemed to have no environmental impact.

8.3.8 Research and development

The technology is in category 2. Only a few plants have been built in Japan and the technology has never developed to be commercial beneficial. In general, the process is seen as a matured technology.

No information is available regarding whether research and development is ongoing regarding the plasma/electric arc gasification process based on among other municipal solid waste.

8.3.9 CAPEX

Due to the very low number of existing plants there are no valid data for CAPEX and OPEX available. Maintenance costs are thought to be high relatively to possible revenue.

8.3.10 Examples

There are not many examples of plasma arc gasification plants. Some plants exist in Japan. The success of these initiatives is not known.

The plasma arc gasification plant Mihama-Mikata in Japan gasifies 25 tonne per day of municipal solid waste and 4 tonne per day of wastewater treatment plant sludge. The plant generates steam and hot water for local industries.

The plasma arc gasification plant Utashinai in Japan gasifies 300 tonne per day of municipal solid waste. The plant generates 7.9 MWe with 4.3 MWe to grid.

8.3.11 References

1 Lamers, Fleck, Pelloni & Kamuk, *ISWA White Paper on Alternative Waste Conversion Technologies*, 2013.

8.4 Liquefaction - thermal depolymerization

8.4.1 Brief technology description

The liquefaction process is a hydrothermal process where biomass is thermally reduced, and oxygen is removed due to the combined process of high temperature and pressure. Oxygen is removed mainly as water and CO_2 thus creating a light crude oil or bio oil based on the refracted carbohydrates. The oil produced, due to the reaction, results in a biofuel with a high carbohydrate content, that can be utilized for various purposes as fuel or base for further refinement. The residence time in a reactor helps to reach proper quality of the oil.

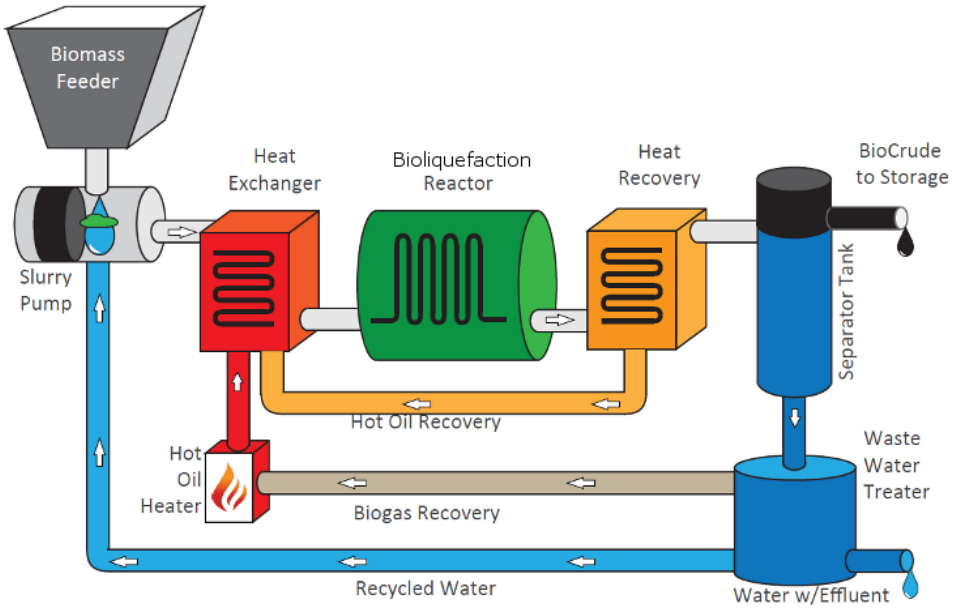


Fig. 15 Liquefaction process.

Normally the liquefaction process operates at 250-300°C but higher temperatures are used as well to gain a higher value of the produced oil. Combined with high pressure, up in to excess of 300 bar, the biomass turns into water and oil, and in a later step of the process, the oil and water can be separated. Gases are produced as well, and these gases can be utilized in order to provide the heat input needed for the process.

The process of liquefaction is an old technology and well known. It has however, not yet been utilized but is beginning to gain attention due to the overall prospect of turning bio waste into oil products that hopefully could be able to replace normal crude and heavy fuel oils.

8.4.2 Inputs

Various types of biomass but other organic material like for example sewage could be refined the same way as agricultural waste. Heat (from gas produced), water (recycled from process) and catalyst other than the water which also has dissolving abilities.

8.4.3 Outputs

Bio oil and water. After separation, the water can be led back into the process.

8.4.4 Capacities

The main restriction for capacity lies in the availability of biomass material to be processed. No larger plants liquefaction has been built yet, but size and number of reactors will determine output.

8.4.5 Ramping configuration

There is not a ramping configuration for this method, however all steel alloys must be secured from induced stress and fatigue due to rapidly temperature changes.

8.4.6 Advantages/disadvantages

Advantages:

- The liquefication process converts biomass into bio oil. Turning a low value item into a desired product is of interest to many and the method is gaining more attention. The process gives hope for substitution of crude oil and other fossil oils. The oil produced has a lower oxygen content compared to the end product of other processes like gasification helping towards a combustion behaviour suited existing purposes like internal combustion engines etc.

- The biomass for the liquefication process does not need to be dried prior to handling.

- The liquification process is considered environmentally sustainable since the main energy input for the process in form of heat can be delivered by the process itself.

Disadvantages:

- A vast amount of biomass is needed for large scale production which is required for creating revenue. This could create logistic challenges and be demanding in relation to space and collection.

- The basics of the biooil are different from fossil oils. Viscosity and flame point for example are lower and could imply modifications to existing machinery.

8.4.7 Environment

Biofuels produced by hydrothermal liquefaction are considered to have little or no imprint on CO_2 levels. CO_2 is produced when burning biofuels but the CO_2 produced is thought to have recently been absorbed by photosynthesis in the plant material meaning that there are no net carbon emissions produced and the net CO_2 emission is significantly lower than when burning fossil fuels.

The liquefaction process doesn't leave any harmful products like nitrogen oxides (NOx), sulphur oxides (SOx) or ammonia and there is no other by-products that cannot be handled with existing technologies.

8.4.8 Research and development

This liquefaction technology is a category 1. It has not been proven that the technology works in semi-commercial plants. Research and development is relation to the technology and the produced oil must be done, before this can evolve to be a category 2 technology.

8.4.9 CAPEX

This technology is not economically feasible, meaning there are no valid data for CAPEX and OPEX available.

8.4.10 Examples

No real scale plant for liquefication exists but the technology is gaining momentum and is expected to become a relevant part of biowaste handling moving forward.

8.4.11 References

1 Elliott, Biller, Ross, Schmidt & Jones: *Hydrothermal liquefaction of biomass: Developments from batch to continuous process*, 2014.

2 Danish Energy Agency: *Technology Data for Renewable Fuels*, 2017.

9 Biological treatment

9.1 Introduction

As opposed to thermal treatment of waste products, biological methods for treatment of solid waste are effectively controlled microbial culture systems designed to transform large amounts of carbonaceous material into more inoffensive products. Processes range from mesophilic and thermophilic composting of materials with relatively low water content to the transformation of matter dissolved or suspended in relatively large volumes of water.

Biological treatment methods for solid waste includes in principle two methods, namely aerobic decomposition of carbonaceous materials (composting), and anaerobic digestion (AD). The main difference between the two is the type of microbial cultures that are applied. In composting, mainly microbial cultures requiring oxygen are applied, whereas in anaerobic digestion bacteria are applied that require an oxygen-free environment.

If the conducted biological process is aerobic, the microbial culture decomposes the carbonaceous material into lighter fractions with the release of mainly CO_2. If the decomposition process instead is managed with limited access to free oxygen, other microbial cultures will dominate and the resulting products may include CH_4, CO, H and others. In both cases, total decomposition takes long time and is rarely achieved under artificial conditions.

9.2 Landfill gas extraction

9.2.1 Brief technology description

Where waste is piled up in dumpsites or proper landfills anaerobic conditions (absence of oxygen) are rapidly reached within the bulk of the waste. As the result of the biological decomposition landfill gas (LFG) is generated, usually containing around 50%-55% CH_4 (methane), 45%-50% CO_2 (carbon dioxide), and over 100 gaseous compounds. It takes up to 50 years or more before the stabilisation of organic wastes is achieved and generation of landfill gas is discontinued. Nevertheless, the main part of it is generated during the first 10 to 20 years after disposal.

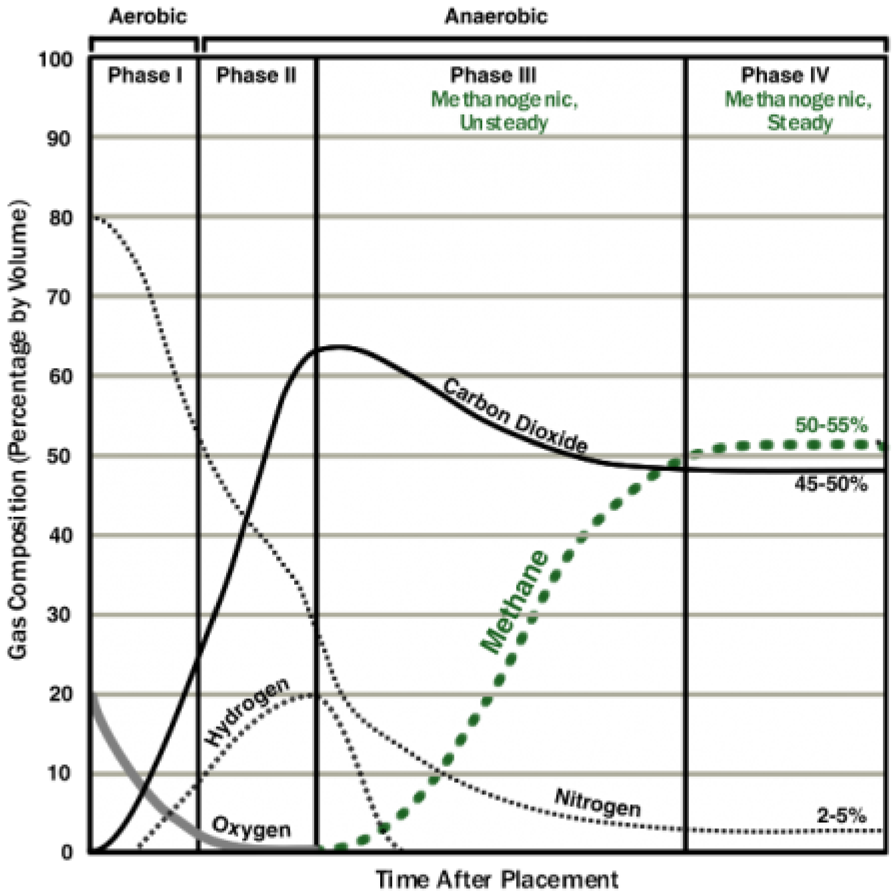


Figure 20 Landfill gas formation and changes in composition after waste placement[1].

Methane (CH_4) is a potent greenhouse gas (GHG) with 21 times the global warming potential of carbon dioxide (CO_2). An estimated 8 percent of the world's methane emissions comes from landfills. If LFG is captured combusted (in an energy-converting machine or by flaring) the methane GHG emissions are greatly reduced (because CH_4 converts to CO_2) and there is a possibility to displace fossil fuel use.

The potential for capturing LFG depends on many factors, e.g. composition of the waste and its age.

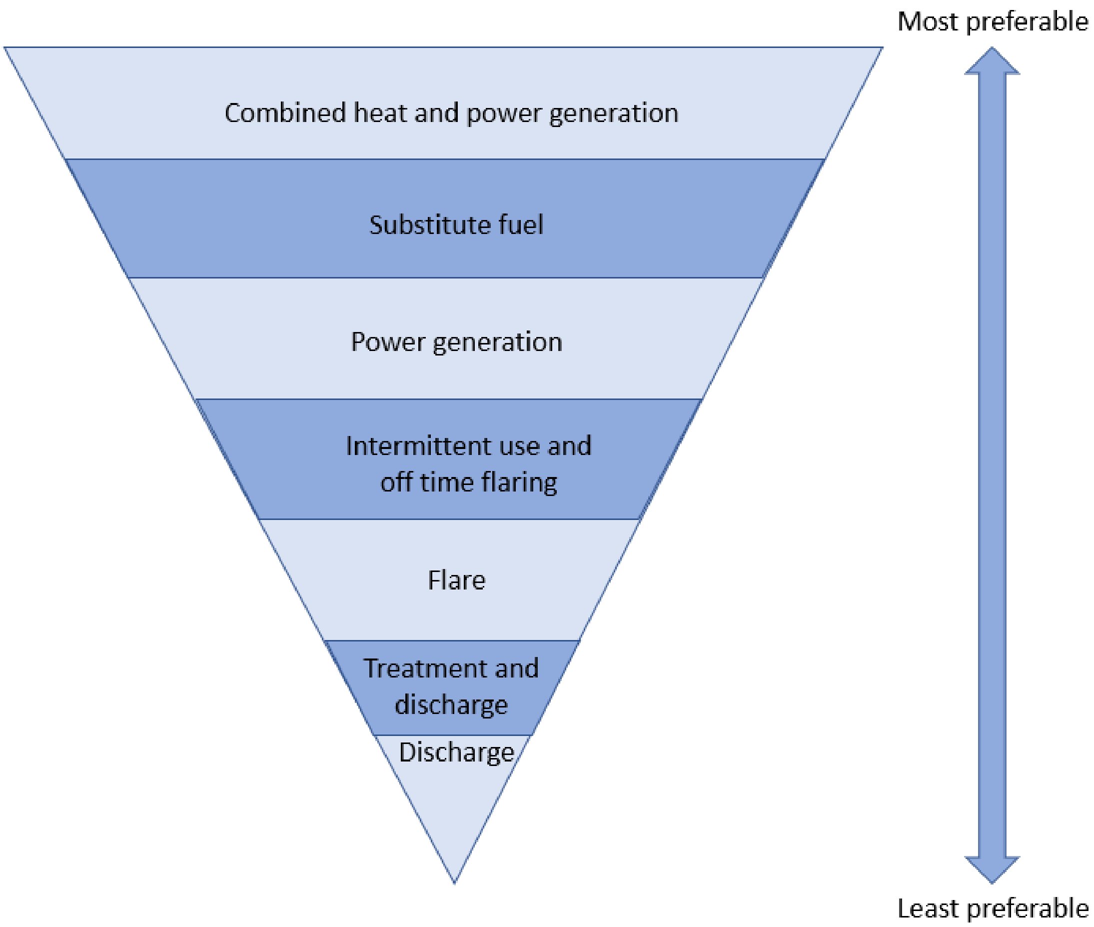


Figure 21 Landfill gas management hierarchy[2].

A typical collection system (either passive or active) is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area.

The collection wells are typically constructed of perforated or slotted HDPE and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. The typical (active) gas collection system includes vertical or horizontal gas collection wells connected by pipes gas boosters or pumps that move the gas. The size, type, and number of gas boosters required in an active system to pull the gas from the landfill depend on the amount of gas being produced.

Gas can be captured from non-engineered as well as engineered (sanitary) landfills.

The necessary works for capturing and utilization of LFG from a non-engineered landfill can be summarized as follows:

- ➢ Soil works and capping the old landfill, including:
- ○ Contouring and levelling works including reshaping of the existing slopes on an inclination 1:3 and the top area on a plateau area with inclination min. 5%
- ○ Construction of leachate drainage system .
- ○ Construction of the gas collection system.
- ○ Final surface sealing.

- Surface water drainage system.
- Installation of gas management and utilization system.

A typical final surface sealing system comprises (seen from the bottom to up):

- Support layer of about 20 -40 cm thickness (minimum 20 cm).
- 0.3 m gas drainage layer.
- 0.5 m mineral sealing layer of clay, silt or loam, placed and compacted in 2 layers, each of h ≥ 0.25 m, and with a permeability coefficient ≤ $1*10^{-9}$ m/s, or similar geosynthetic liner.
- geotextile layer, permeable, weight ≥ 400 g/m² (filter mat).
- 0.5 m drainage layer of sand/gravel 4/32 mm, permeability coefficient ≥$1*10^{-3}$ m/s.
- 0.5 m sand/gravel with clay content, not compacted, as cultivable soil.
- 0.5 m topsoil with short grass (vegetation resistant to erosion).

The gas management system will comprise

- Gas collection wells.
- Gas transport pipes and condensation valves.
- Gas treatment system.
- Gas flare.
- Gas pressure pumps.
- Gas engine.

The electrical system comprises

- Generator.
- SCADA.
- Transformers, switch boxes and connection to grid.

For engineered landfill, the technology is similar, however with some differences:

- All new sanitary landfills must be designed and equipped with a proper gas management system, leachate collection systems and other measures mentioned above.

- Gas extraction wells may be installed consecutively during filling of the individual cell and connected to the gas management plant as soon as filling of the cell is completed.

Figure 22 Contouring work for preparation of capture of LFG from existing landfill (Semarang, Java).

Figure 23 Gas collection well/pipe and top liner for capture of LFG from existing landfill (Semarang, Java).

Figure 24 A containerized motor/generator system (0.8 MW) for LFG management at a landfill (Semarang, Java).

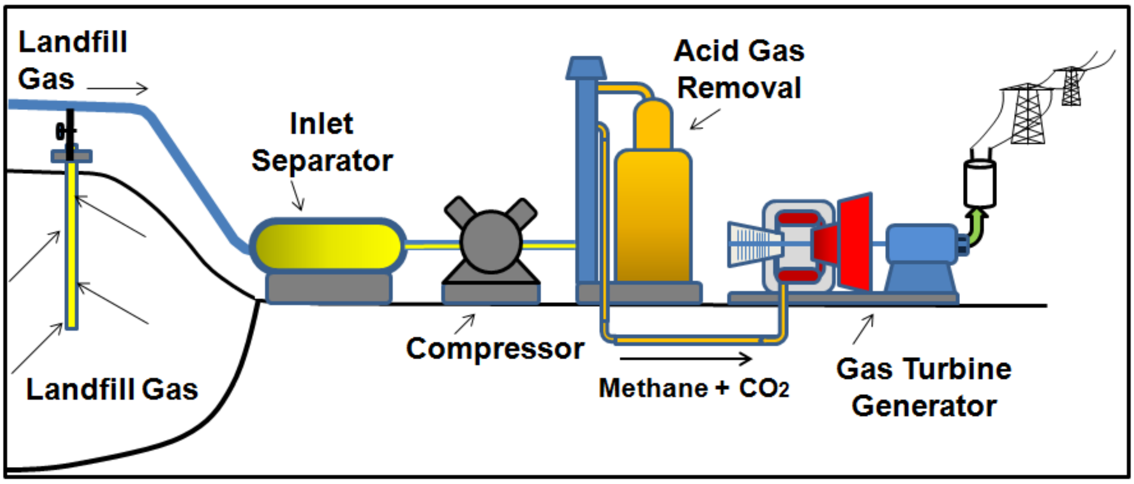


Figure 25 Principles of a LFG capture system.

9.2.2 Inputs

As described in sections 6.1.5 and 6.2.5, both Lombok and Batam has existing landfills that would qualify for LFG capture systems. Both locations plan the establishment of new sanitary landfills that will have (mandated by regulation) gas management systems.

The typical potential gas extraction from MSW landfills varies and is under influence by many factors. The methane production rate from a single years waste deposit is a function of the ultimate methane yield, the decay rate per year, and the time elapsed.

A commonly used model for estimating the gas generation is the IPCC calculation model, as presented below.

$$[OC]_j^{available} = Waste\ amount \cdot fOC_j \cdot [OC]_{MIN/MAX} \qquad (t = i)$$

$$[OC]_j^{deg\,raded} = [OC]_j^{available} \cdot 1 - \exp^{-kj}$$

$$CH_4\ production = a \cdot \zeta \cdot [CH_4] \cdot \sum_{t=i}^{n} [OC]^{deg\,raded} \qquad (kg.a^{-1})$$

$$CH_4\ production = \frac{a \cdot \zeta \cdot [CH_4] \cdot \sum_{t=i}^{n} [OC]^{deg\,raded}}{0.714} \qquad (m^3.a^{-1})$$

$$[OC]_{t=i+1\ j}^{available} + [OC]_{t=i\ j}^{available} - [OC]_{t=i}^{deg\,raded} \qquad (t = i + 1)$$

Figure 26 IPCC gas calculation model[5]

For a first estimate of gas production one can use apply an average of 5 m³ LFG per year per tonne of waste landfilled. This will apply for 20% moisture and a 66% capture rate of the gas. Large variations among landfills should be expected[3].

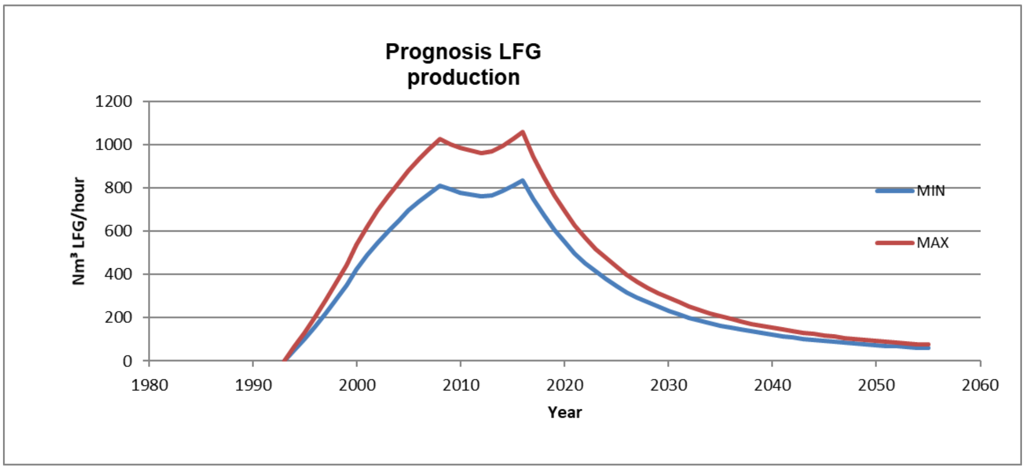


Figure 27 Typical prognosis for LFG generation from a landfill. It started operation in 1994 and was closed in 2015. Gas generation continues for many years, albeit at lower rates.

9.2.3 Outputs

Electricity (heat can be recovered in cogeneration systems).

9.2.4 Capacities

Typical gas engines for LFG utilization produce between 0.35 and 1.2 MW electricity per engine for which LFG between 210 Nm³/hour and 720 Nm³/hour are needed (the engine will produce between 0.6 and 2.4 MW thermic). Gas turbines can be used for flowrates over 2400 Nm³/hour, but this flowrate is not likely to appear in the two project areas.

9.2.5 Ramping configuration

Gas engines and gas turbines for landfill gas must be baseload to cake the continuous gas supply extracted from the landfill, as otherwise you would need to have a gas storage.

9.2.6 Advantages/disadvantages

Advantages:

- Reduces the GHG emissions from landfills/dumpsites considerably over many years.
- Offers the possibility to replace other fuels, most notably fossil fuels thus creating additional GHG reductions.
- Capturing LFG reduces risk of fires and explosions caused by unmanaged LGF which is potentially fatal.
- Capture technology is simple and can be operated by staff without specialized training.
- Energy conversion technologies can easily be adapted to local conditions and fitted to size.

Disadvantages:

- Gas production declines over the years starting when the landfill is closed and does not receive more waste. Therefore, for the single landfill or landfill cell, power generation cannot be maintained at a constant level over a long period of time.
- However, for a continuously operating landfill, cells can be closed consecutively, and production thus maintained at a nearly constant rate.

9.2.7 Environment

LFG capture will greatly reduce the GHG emissions from landfills/dumpsites in the entire lifetime of the landfill, and it offers the possibility to replace other fuels, most notably fossil fuels, thus creating additional GHG reductions.

The GHG potential when capturing and destroying methane by oxidation is a 21-fold reduction compared to the direct release of methane into the atmosphere. The reduction of GHG emission as a result of displacement of other fuels in the energy system depends of the actual composition of the energy mix and thus the nature of replaced fuels.

9.2.8 Research and development

The technology is fully developed and in operation numerous places around the world. It is therefore categorized as Category 4: *Commercial technologies, with large deployment worldwide.* For Indonesia as such, there is currently (2020/21) only a single plant in operation, but more planned. Therefore, for Indonesia, the technology may be characterized as Category 3 *Commercial technologies with moderate deployment* so far.

9.2.9 CAPEX

Investments for a landfill gas capture for existing landfills/dumpsites depends very much on specific circumstances.

For a 0.8 – 1 MW gas capture system including dumpsite remediation work (waste levelling/contouring work, waste capping), gas collection -treatment and -utilization system, and electrical system requires an investment of about USD 3.5-4 million. Civil works (landfill rehabilitation etc.) comprises about 35% of total costs. Equipment (gas motor, blowers, scrubber system, electrical equipment) comprises about 50% of CAPEX.

In this example, the landfill contained approximately 1.75 million m^3 of waste, scattered over 9 hectare (ha).

9.2.10 Examples

Worldwide, there are perhaps thousands of LFG schemes in operation. For the US, as of August 2020, there are 565 operational LFG energy projects and 477 landfills that are good candidates for projects (ref 4).

In Indonesia, a couple of projects exists and the only in operation is the project in Semarang that has been in operation since 2019.

Puente Hills Landfill is the largest landfill in the United States, 150 meters high and covering 2.8 km^2. Puente Hills accepted four million tons of waste in 2005. As of October 31, 2013, its operating permit has been terminated and it no longer accepts new refuse. 850 m^3 per minute of landfill gas created by the landfill is funnelled to the Puente Hills Gas-to-Energy Facility, which generates more than 40 MWe.

9.2.11 References

1 *Landfill Methane Outreach Program*, USEPA.

2 Guideline—*Landfill siting, design, operation and rehabilitation. Environmental Regulatory*. Department of Environment and Heritage Protection, State of Queensland, 2013.

3 Th. Christensen (ed), *Solid Waste Technology and Management*, 2011. Wiley.

4 United States Environmental Protection Agency, EPA, *Landfill Methane Outreach Program.*

5 This model has been developed for NV Afvalzorg by Jeroen Braspenning (Wageningen Agricultural University)

9.2.12 Data sheet

Technology

Technology	Landfill Gas Power Plant - Municipal Solid Waste								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	1	1	1	0,5	10	0,5	10		1
Generating capacity for total power plant (MWe)	1	1	1	0,5	10	0,5	10		1
Electricity efficiency, net (%), name plate	35	35	35	25	37	25	37		2
Electricity efficiency, net (%), annual average	34	34	34	25	37	25	37		2
Forced outage (%)	5	5	5	2	15	2	15		4
Planned outage (weeks per year)	5	5	5	2	15	2	15		4
Technical lifetime (years)	25	25	25	20	30	20	30		3
Construction time (years)	1,5	1,5	1,5	1	3	1	3		3
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	2,5	2,5	2,5	2,3	2,8	2,3	2,9	A	3
- of which equipment	0,7	0,7	0,7	0,7	0,8	0,7	0,8		5
- of which installation	0,3	0,3	0,3	0,3	0,3	0,3	0,3		5
Fixed O&M ($/MWe/year)	125.000	125.000	125.000	113.640	137.500	113.636	143.750	A	3
Variable O&M ($/MWh)	13,5	13,5	13,5	10,1	16,9	10,1	16,9		
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1 OJK, 2014, "Clean Energy Handbook for Financial Service Institutions", Indonesia Financial Service Authority, Jakarta, Indonesia
2 Renewables Academy" (RENAC) AG, 2014, "Biogas Technology and Biomass", Berlin, Germany.
3 IEA-ETSAP and IRENA, 2015. "Biomass for Heat and Power, Technology Brief".
4 PLN, 2017, data provided the System Planning Division at PLN
5 MEMR, 2015, "Waste to Energy Guidebook", Jakarta, Indonesia.

Notes:

A Uncertainty (Upper/Lower) is estimated as +/- 10-15%.

9.3 Mechanical Biological Treatment of MSW

9.3.1 Brief technology description

The mechanical-biological pre-treatment of waste predominantly aims at volume reduction and stabilisation of the waste as well as the mechanical separation of specific parts of the waste (e.g. plastic, metal) for recycling, and separation of high-calorific fractions that can be used to produce RDF/SRF[21]. The mechanical biological treatment (MBT) plants often comprise unit processes commonly known from waste management.

For the current context, the MBT process can be divided into two main categories, Bio drying and Sorting. This refers to the initial process in the MBT plant (see Figure 28). The actual lay-out and design of the plant will determine the flow of materials through the plant and thus the quantity (and quality) of recyclables, RDF, and residual products.

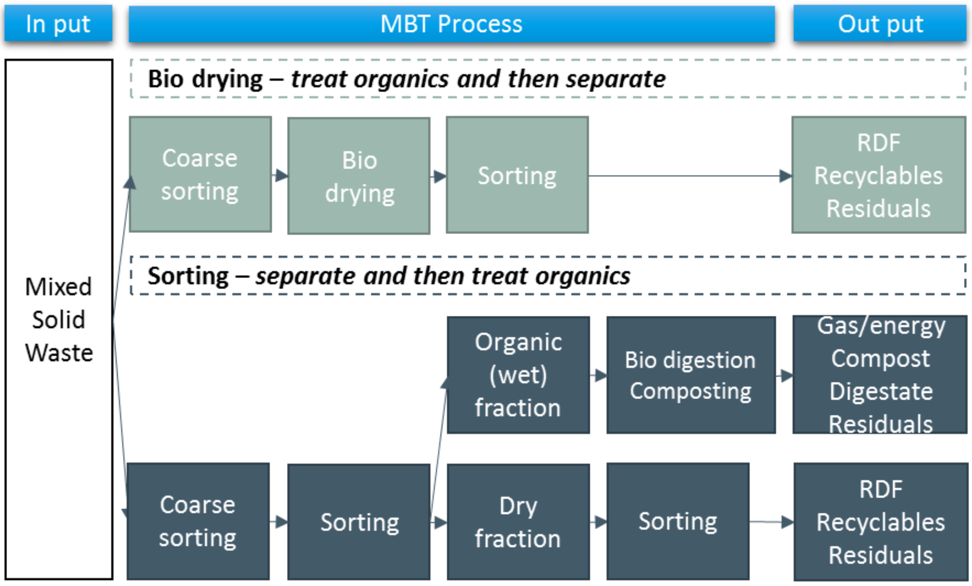


Figure 28 *MBT design - Two different approaches: Treat organics and then separate or* Separate and then treat organics.

Typically, bio-drying reactors within MBT plants receives unsorted residual municipal solid waste (MSW) which is then shredded and processed by bio-drying. The output then undergoes more or less extensive mechanical post-treatment. Within the bio-drying bioreactor the thermal energy released during aerobic decomposition of readily degradable organic matter is combined with excess aeration to dry the waste.

Bio-drying reactors use a combination of engineered physical and biochemical processes. Reactor design includes a container coupled with an aeration system; containers can be either

[21] There is no fixed definition of RDF/SRF. Solid Recovered Fuel (SRF) is usually considered a higher quality product made from residual waste once recyclable materials, non-combustible materials (and contaminants) have been removed. It is thus fibres and fragments of paper, plastics, wood, and textiles and have high calorific value, low moisture and low chlorine content. Refuse Derived Fuel (RDF) is usually considered a lower specification product than SRF with a lower calorific value. Usually produced by simple shredding and drying mixed (and pre-sorted) MSW, thus still containing significant percentage of plastic, paper, etc.

enclosed, or open tunnel-halls, or rotating drums. On the biochemical side, aerobic biodegradation of readily decomposable organic matter occurs. On the physical side, convective moisture removal is achieved through controlled, excessive aeration. Therefore, the main drying mechanism is convective evaporation, using heat from the aerobic biodegradation of waste components and facilitated by the mechanically supported airflow.

Limited amount of free water may seep through the waste matrix and be collected at the bottom of the bio-drying reactor as leachate.

Optimal bio-drying can be achieved through effective reactor design and conditioning of the input material, combined with suitable process monitoring and control. Typical retention times are in the range of 7-15 days.

Figure 29 From Municipal Solid Waste (left) to RDF pellets (right)

The bio-drying process reduces the mass of the waste significantly (up to 25% loses, mainly by evaporation of water) and at the same time only marginally reduces its biodegradable content, and thus the calorific value. The gain in calorific value because of lower moisture outweighs the consumption of power for e.g. blowers for operating the process.

9.3.2 Inputs and outputs

The proposed mass balance of the example plant is given below in the next table and input outputs per material component are given in the table after.

Table 23 Overall mass balance, bio-drying facility 40.000 tpa. tpd=tonne per day.

	In	Shredder	Drying units	Screen (<20 mm)	Screen Oversize	Heavy re-jects	Screen 20-150 mm RDF/SRF
		Out	out	out	out	out	out
Total (tonne/day)	112	110.88	55.6	6	6	4	40
Dry matter (%)	43%	43.4%	82.9%	90%	90%	94%	80%
Water (%)	57%	56.6%	17.1%	10%	10%	6%	20%
Dry matter (tpd)	48	48	46	5.4	5.4	3.8	31.6
Water(tpd)	64	63	9.5	0.6	0.6	0.24	8.1
Loss (water), tpd			50				
Loss (materials), tpd		0	2				
Loss (leachate), tpd		1.1	3				

Table 24 Examples of input and outputs per material component – bio-drying facility (112 tons MSW/day).

Input per day	112	tons				
Item	**Input % of wet weight**	**Total input in Tons/year**	**Output Materials**	**Total out-put per day (tons)**	**Output per year 365 days/year**	**% of in-coming**
Organic material	67%	27,390	RDF/SRF	40	14,460	35%
Plastic	17%	6,950	Oversize materials	6	2,190	5%
Paper	6%	2,453	Compost like product	6	2,190	5%
Rubber	1.50%	613	Heavy fraction	4	1,460	4%
Textile	7%	2,862			0	0%
Glass	0.40%	164	Material loss	2	745	2%
Metal	0.90%	368	Water loss	50	18,212	45%
Others	0.20%	82	Leachate	4,4	1,623	4%
Total	**100%**	**40,880**	**Balance**	**112.0**	**40,880**	**100%**

As can be seen from the tables above, the main output material, namely the RDF/SRF product, will have an estimated water content of 20% and will be produced at a rate of 40 tons/day by 112 tons/day input.

Figure 30 Aeration boxes with forced aeration and semi-permeable cover material over the waste for drying the waste.

The mechanical sorting of the processed waste in the bio drying MBT is often limited to sorting out metals by magnetic and eddy current mechanisms.

Recyclables derived from the various MBT processes are typically of a lower quality than those derived from a source segregation system and therefore possesses a lower market value. The types of materials recovered from MBT processes almost always include metals (ferrous and non-ferrous) and for many MBT systems this is the only recyclable extracted.

Other materials which may be extracted from MBT processes include glass, textiles, paper/cardboard, and plastics. The most common of these is glass. These materials are typically segregated as the "dense" fraction from air classifiers or ballistic separation. However, segregating glass for recycling from residual waste or a mixed waste from an MBT plant will require material-specific sorting techniques.

9.3.3 Capacities

Typical plant capacities vary according to input. Typical and low-tech bio-drying facilities requires quite extensive footprint areas for drying cells. The footprint area is about 3 ha for a 75-100,000 tons/year, however this depends on the design and the desired extent of pre-sorting of the input material (MSW) and post-sorting of the products.

9.3.4 Ramping configuration

Not relevant

9.3.5 Advantages/disadvantages

Bio-drying with the production of RDF/SRF is considered attainable taking into consideration the following:

Advantages:

- The technology is simple and draws on unit processes well-known from waste management.
- It is possible with relatively simple means to achieve high rates of water removal of the waste without significant loss of calorific value.
- The technology does not require a sophisticated waste collection system with separate collection of various waste fractions to function. This will enhance the public acceptance of the system and facilitate rapid implementation.

Disadvantages:

- For the technology to be useful in terms of achievement of over-all waste policies and target for e.g. landfill diversion and recycling, there must be a (potential) market for products, most notable the RDF product.
- The technology is simple in nature. However, depending on the requirements for pre-sorting and post-treatment, some mechanical equipment is required, and control over process parameters must be obtained constantly. Therefore, more than basic staff qualifications are needed, but in general a plant can be operated by staff without high-level specialized training.

9.3.6 Environment

By production of RDF/SRF, significant reduction in GHG emissions from waste can be achieved by replacing other (fossil) fuels. The size of GHG emission reduction depends of the actual composition of the energy mix and thus the nature of replaced fuels. The achieved

GHG emission reduction is greatest if lignite or coal is replaced, and less if the replaced fuel is natural gas.

Moreover, if the alternative disposal of the MSW is open dumping without landfill gas capture, MBTs with bio-drying solutions will contribute significantly to reduced GHG emissions by avoiding methane emissions from such open dumping. Further benefits are material recovery and thus preservation of resources.

9.3.7 Employment

Employment benefits of MBT/bio-drying depends largely on the degree of mechanization of the processes, and the extent of post-sorting and pre-processing of the product.

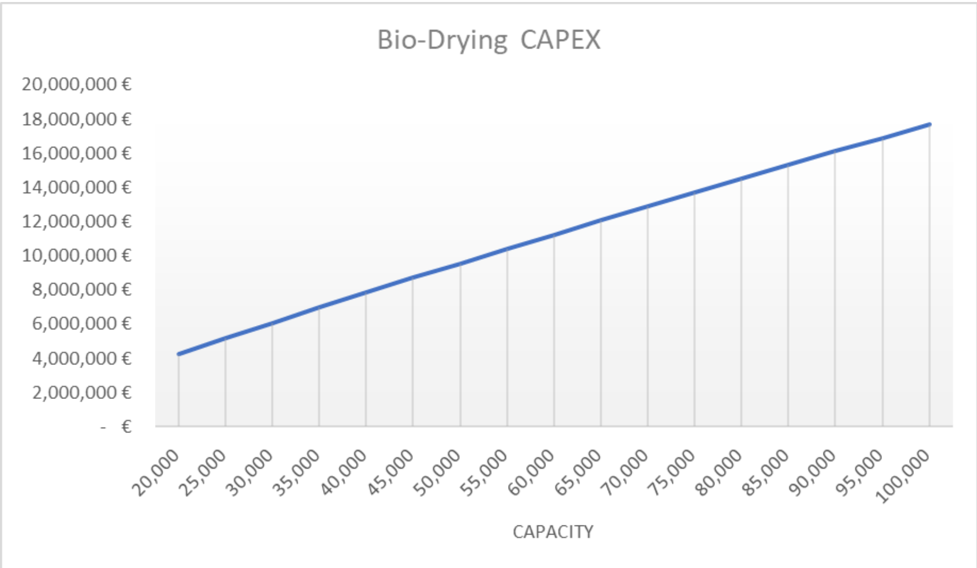
9.3.8 Research and development

The technology is fully developed and in operation numerous places around the world. It is therefore categorized as Category 4: *Commercial technologies, with large deployment worldwide.* For Indonesia as such, there is currently (2020/21) only a single plant in operation, but more planned. Therefore, for Indonesia, the technology may be characterized as Category 3 *Commercial technologies with moderate deployment* so far.

Unit processes within the MRF/Bio-drying plant are well known. This applies to pre-sorting (manual), shredding, conveyer belt transport, sieving, over-band-magnetic separation. The biological/drying process is less known in Indonesia, but relatively simple and can be mastered after relatively short training.

9.3.9 CAPEX

Investments for MBT/Bio-drying plants depends very much on specific circumstances, especially on the degree of mechanization of the processes, and the extent of post-sorting and pre-processing of the product. CAPEX can be estimated at United States dollar (USD) 90-180 per tonne annual capacity. A simple cost-function is shown below for plant capacities between 20,000 and 100,000 tons/annum.



9.3.10 Examples

In Germany, 45 MBT plants process 6.2 million tons MSW/year (2013 figures)[1]. About 55% of the produced RDF went to dedicated power plants, 17% to MSW incinerators (Waste to Energy (WtE) plants), 12% to cement plants, 10% for coal-fired power plants (as supplementary fuel), and 6% for other applications.

Indonesia has one RDF plant in operation (in Cilacap, Central Java). The plant was established in a collaboration between the Public works and public housing (PWPH) Ministry with the Ministry of environment and forestry, Danish Embassy – DANIDA, Central Java provincial government, Cilacap regency government[2] and cement producers, PT Solusi Bangun Indonesia Tbk (IDX: SMCB) with a total investment value of Rp90 billion (USD 6.29 million).

9.3.11 References

1 ASA-Strategie 2030, *Ressourcen- und Klimaschutz durch eine stoffspezifische Abfallbehandlung*, ASA e.V. 2016.

2 https://dlh.cilacapkab.go.id/; https://dlh.cilacapkab.go.id/tempat-pengelolaan-sampah-terpadu-refused-derived-fuel-tpst-rdf/.

9.4 Renescience process

9.4.1 Brief technology description

The renescience process has many similarities to the Mechanical Biological Treatment (MBT) as previously described. The overall idea is to reuse municipal solid waste in the best way possible, hence making the waste a resource for energy in a more differentiated matter.

The renescience process is to sort the waste prior to handling. The sorting naturally being based on the afterward uses and how the waste best can be refined.

Main basis for sorting is:

- Directly reusable materials.
- Unusable solid waste for incineration. Could be nonbiodegradable plastics.
- Biodegradable products and organic waste usable for anaerobic digestion.

The last stage of anaerobic digestion turns the organic waste into biogas during an oxygen free process where bacteria converts the organic waste into biogas which after extraction, can be used for the purpose best suited. An anaerobic digester/ oxygen free tank system is needed for the process. For further information on anaerobic digestion see 7.4.

See Figure 31 for principle of the process.

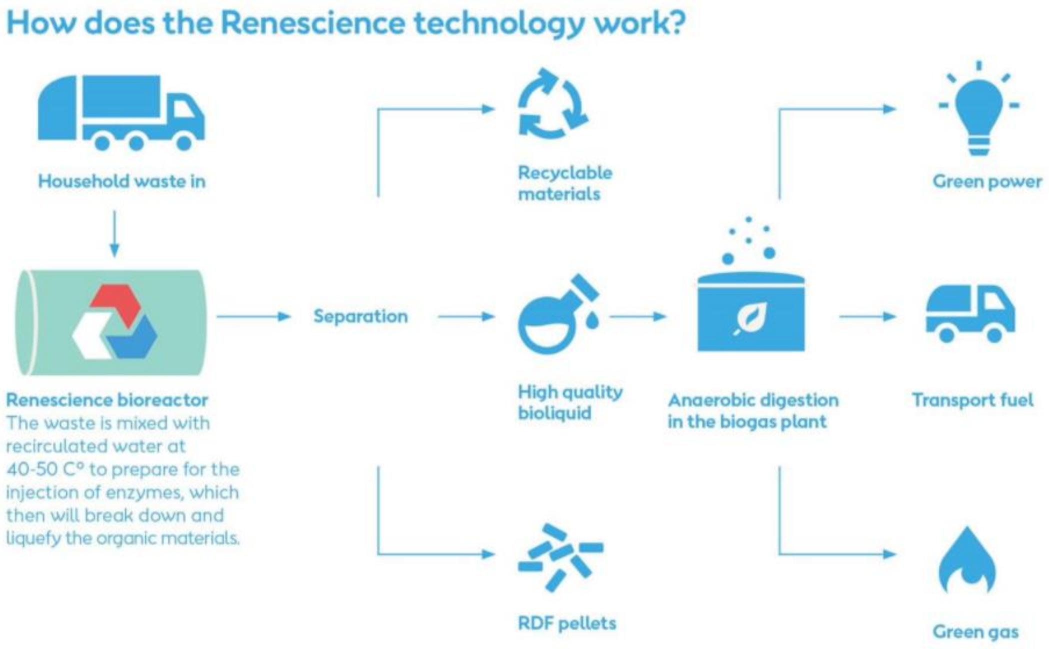


Figure 31. Principle for renescience process (orsted.co.uk/energy-solutions/renescience).

Renescience makes sense as an overall more differentiated approach to waste handling. The added benefit of initial sorting process of the waste will benefit other areas of waste handling as well. After the production of biogas through the anaerobic process the remaining residue from the digester has potential to be redistributed as fertilizer in agriculture.

9.4.2 Inputs

Un shredded municipal solid waste.

9.4.3 Outputs

Biogas for producing electricity and heat.

9.4.4 Advantages/disadvantages

Advantages:

- Un-shredded municipal solid waste is used for the process.

Disadvantages:

- The technology is not mature. Only one full scale plant in the world exists.

9.4.5 Research and development

The technology is in category 2. As mentioned in section 9.4.7 only one full scale plant has been built, meaning it is still in the pioneer phase. There is reason to believe that research and development is ongoing based on operating experiences from the plant in Nortwich, UK.

9.4.6 CAPEX

Ørsted informed in 2017 the CAPEX for the first full scale renescience plant in Nortwich, UK (see section 9.4.7), to be 100 million USD.

9.4.7 Examples

Worlds first full scale renescience plant was commissioned in 2020 in Nortwich in UK. The capacity is 80,000 tonne of MSW per year. Around 6,000 tonne of recyclables are collected for reuse each year. The digestate is reused for soil restoration. The produced biogas is used in gas engines for producing heat and 3 MW power. The non-recyclable parts such as shoes, pieces of wood, textiles, foils with no recycling interest etc. will become fuel material for cement kilns and/or incineration plants elsewhere.

9.4.8 References

1 Ørsted (Danish energy company), orsted.co.uk/energy-solutions/renescience.

9.5 Biogasification

9.5.1 Brief technology description

The process described in this section is single stage, thermophile process with the slurry-based technology based on a mix of MSW/abattoir waste/manure/waste water sludge.

Biogasification is a method of converting biologic material into biogases. In an enclosed oxygen free environment for creation of anaerobic conditions, bacteria convert the biowaste into gasses, mainly methane.

Bio gasification/ anaerobic digestion: anaerobic digestion or bio gasification involves the biological decomposition of organic matter of biological origin (bio-waste) under anaerobic conditions and results in the production of methane and other secondary gases. The main process takes place inside enclosed and insulated steel or concrete digester(s). The process involves different types of micro-organisms at three more or less distinct stages. As the process is anaerobic, no heat is produced directly, and the temperature of the slurry must be maintained. The digestion will typically destroy 40-70% of the volatile organic compounds of the waste. There are three main anaerobic treatment methods available i.e. separate digestion (dry method), separate digestion (wet method) and co-digestion (wet method).

9.5.2 Inputs

Inputs are all sorts of bio waste. Either from agriculture but could also be sewage or solid organic wastes from households. Anything that can be part of an anaerobe digestion. Composition of bio waste can be modified in relation to the end product.

9.5.3 Outputs

The output of the bio waste digestion is biogas.

The biogas can be used in power production, hence the goal of producing biogas is to substitute fossil gas and thus reducing the net carbon impact to the environment. This means the output is electricity and heat produced for example either in a gas turbine or engine. Therefore the biogas can also be used for any process that demands revolutions like for example propulsion.

Residues of biowaste after the gasification has value as fertilizer in agriculture and should be an easy product to discharge of.

9.5.4 Capacities

The capacity for biogas production would normally be determined by the amount of biowaste available.

The afterwards usage of the produced biogas is also determined by availability but would typically range from 10- 50 MW.

9.5.5 Ramping configuration

The ramping conditions for biogas plant are similar to a conventional gas power plants, biogas power plants can ramp up and down according to the machinery it is fuelling. However, there is a biological limit to how fast the production of biogas can change. This is not the case for the plants which have biogas storage. Biogas storage would be crucial to accommodate when demand is higher or lower than the biogas production and the buffer this provides is of great value at a low cost.

9.5.6 Advantages/disadvantages

Advantages:

- Since methane emission by nature of the process is mitigated, The CO_2 abatement cost is quite low.
- There is not a foreseeable limitation to biowaste other than local scenarios.
- Environmentally critical nutrients, primarily nitrogen and phosphorus, can be redistributed from overloaded farmlands to other areas.
- The fertilizing value back in the soil of the digested biomass is better than the raw bio waste. Digestion of solid biomass thus has the advantage of recycling nutrients to the farmland in an economically and environmentally feasible way.
- A biogas plant eliminates odour problems since manure etc. will be collected instead of other alternatives.

Disadvantages:

- There are no significant disadvantages with this technology.

9.5.7 Environment

Biogas is thought to be CO_2 neutral. This is mainly due to methane being removed for energy production. This methane would otherwise be emitted to the atmosphere. Captured CO_2 by photosynthesis in the plants used later as bio waste for biogas production is thought to have a net abatement of 0 due to short conversion time within a year.

There is no negative environmental issues with a biogas plant which cannot be handled in a practical simple manner.

9.5.8 Employment

The overall industry related to biogas production, other than the industries and systems supplying organic waste (agriculture, sewage, household waste etc.), has potential to become an established part of energy production. Depending on growth in this sector, a significant employment rate could be foreseen.

Manning needed for production at facilities for biogas depends on the type of system. The different types and sizes of biogas systems like covered lagoon biogas systems and Continuously Stirred Tank Reactor (CSTR) or industrial biogas plants would demand different number of manning. When application is scaled for the production of electricity, the facilities, in order to be commercially relevant, will need to have manning for maintenance and operation. However, the number would be lower than for example a traditional power plant due to reduced complexity.

9.5.9 Research and development

Biogasification is a category 4 technology. There is a large deployment of the technology; prices and performance are well known. Research and development are therefore not ongoing, except where minor improvement can be expected.

9.5.10 CAPEX

A biogas plant commissioned 2020 in Sønderborg, Denmark, had a cost of 40 million USD. It treats 378,000 tonne waste per year and produces 17.5 million m^3 biogas per year. The gas is upgraded for delivering to the natural gas distributed piping system in Denmark.

For information regarding CAPEX see section 9.5.13.

9.5.11 Examples

There is about 70 smaller and larger biogasification plants in Denmark. Some of them use the gas for local power production in gas engines and some of them deliver the cleaned biogas for the overall gas system in Denmark used for mainly natural gas.

Solrød Biogas A/S in Denmark are producing 6,000,000 m^3 biogas per year from 200,000 tonne manure, industrial food waste and seaweed.

Figure 32. Biogas plant in Solrød Strand Denmark.

Fangel Bioenergy in Denmark are producing 10,000,000 m^3 biogas per year from 132,000 tonne manure and industrial food waste.

One of the largest biogas plants in the world is Nature Energy Korskro, Denmark, and covers about 13ha. The facility process 1,050,000 tons of agricultural biproducts and organic waste. It produces 41 million Nm^3 of biomethane (equal to 45.4MW) per year to the Danish gas grid.

9.5.12 References

1 Bigadan A/S, www.bigadan.dk/c/cases.

9.5.13 Data sheet

Technology	**Biogas power plant**								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	1	1	1						3
Generating capacity for total power plant (MWe)	1	1	1						3
Electricity efficiency, net (%), name plate	35	35	35						4
Electricity efficiency, net (%), annual average	34	34	34						4
Forced outage (%)	5	5	5						1
Planned outage (weeks per year)	5	5	5						1
Technical lifetime (years)	25	25	25						7
Construction time (years)	1,5	1,5	1,5						7
Space requirement (1000 m^2/MWe)	70	70	70						12
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	20	20	20	10	30	10	30		11
Minimum load (% of full load)	20	30	15	30	50	10	40		10
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	2,15	1,96	1,72	1,55	2,15	1,3	2,2	B	3,5,8,9
- of which equipment	65	65	65	50	85	50	85		
- of which installation	35	35	35	15	50	15	50		
Fixed O&M ($/MWe/year)	97.000	89.200	77.600	72.800	121.300	58.200	97.000	A	5,7,9
Variable O&M ($/MWh)	0,11	0,1	0,1	0,1	0,1	0,1	0,1	A	6,9
Start-up costs ($/MWe/start-up)									

References:
1 PLN, 2017, data provided the System Planning Division at PLN
2 ASEAN Centre of Energy (2016). Levelised cost of electricity generation of selected renewable energy technologies in the ASEAN member states.
3 Winrock, 2015, "Buku Panduan Konversi POME Menjadi Biogas, Pengembangan Proyek di Indonesia", USAID - Winrock International.
4 RENAC, 2014, "Biogas Technology and Biomass, Renewables Academy (RENAC)".
5 IFC and BMF, 2017, Converting biomass to energy - A guide for developmers and investors".
6 OJK, 2014, "Clean Energy Handbook for Financial Service Institutions", Indonesia Financial Service Authority.
7 IEA-ETSAP and IRENA, 2015, "Biomass for Heat and Power, Technology Brief".
8 PKPPIM, 2014, "Analisis biaya dan manfaat pembiayaan investasi limbah menjadi energi melalui kredit program", Center for Climate Change and Multilateral
9 Learning curve approach for the development of financial parameters.
10 Vuorinen, A., 2008, "Planning of Optimal Power Systems".
11 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating
12 Chazaro Gerbang Internasional, 2004, "Utilization of Biogas Generated from the Anaerobic Treatment of Palm Oil Mills Effluent (POME) as Indigenous Energy Source for Rural Energy Supply and Electrification - A Pre-Feasibility Study Report"

Notes:

A Uncertainty (Upper/Lower) is estimated as +/- 25%.

B For 2020, uncertainty ranges are based on cost spans of various sources. For 2050, we combine the base uncertainity in 2020 with an additional uncertainty span based on learning rates variying between 10-15% and capacity deployment from Stated Policies and Sustainable Development scenarios separately.

10 Utilization for SRF/RDF

10.1 SRF/RDF for cement kilns

10.1.1 Refuse Derived Fuel (RDF)

Production of Refuse Derived Fuel (RDF) is a thermal/mechanical pre-treatment method generally suitable for general waste. Such processes produce higher quality fuel products with a higher calorific value than the initial waste. RDF is a non-defined term and refers to waste that has not undergone proper processing. Before the MSW can enter the RDF production process, valuable commodities such as paper, metal, glass and wood should have been removed for recycling.

RDF is not standardised and the properties of RDF (composition, contaminants, calorific value) are undetermined.

RDF is widely used for cement kilns even though it does not fulfil the requirement for Solid Recovered Fuel (SRF).

10.1.2 Solid Recovered Fuel

Solid Recovered Fuel SRF is a much more refined resource compared with RDF and produced from non-hazardous waste which usually has undergone a prior sorting process.

SRF is a fuel produced from non-hazardous waste in accordance with EU standards for SRF, especially EN15359. It is typically produced from municipal solid waste (MSW), industrial and commercial waste or Construction & Demolition Waste (C&DW). It must be sharply distinguished from RDF. SRF is sampled and tested according to EU standards. The requirements for SRF are well specified and following that SRF is classified. SRF is produced under the regime of a quality assurance scheme of the producer.

For creating SRF the following separating technologies can be used:

- A series of magnets can extract ferrous metals.
- An eddy current separator can extract aluminium that could damage the secondary shredder.
- A vibration screen or trommel can sift out soils and fines.
- An air separation box (wind shifter) can remove large lumps of materials.

The process technology can of course be configured to suit varied end user specifications. Following this sophisticated SRF manufacturing process, the end product is a resource from which energy can be harnessed. It is used in cement kilns, paper mills and power stations as an alternative to fossil fuels.

10.1.3 Utilizing SRF/RDF for cement kilns

SRF/RDF can be used as secondary fuel as shown in below Figure 33. Several other fuels can also be used as secondary fuel: natural gas, petroleum coke, coal, chipped tires, wood chips, nut shells, non-hazardous liquid waste. The flow for supplying SRF to a cement kiln is in the area of 5 tonne per hour.

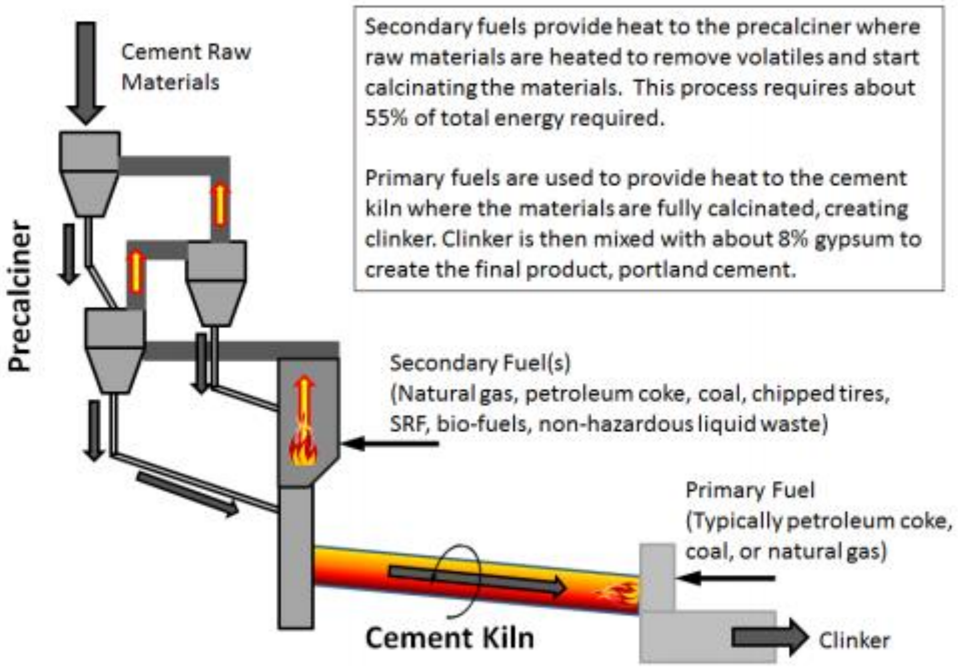


Figure 33. Rotary cement kiln using SRF as secondary fuel[2].

10.1.4 Research and development

Utilization of SRF/RDF for cement kilns is a category 4 technology. There is a large deployment of the technology; prices and performance are well known.

10.1.5 CAPEX

A facility for handling up to 120 tons of MSW per day for producing RDF with a bio drying method had a cost in 2017 of around 4.2 million UDS. The facility is placed in TPA Tritih Lor, Jeruklegi District, Cilacap Regency, Central Java.

10.1.6 Examples

The facility mentioned above in section 10.1.5 was built on a 1 ha land. At the operational stage, this facility will be able to absorb up to 120 tons of MSW per day, that will be processed with a bio drying method to become RDF. The RDF is used to substitute the traditional fuel (coal) in Holcim Cilacap cement plant (ref 3).

10.1.7 References

1 ERFO (European association for recovered fuel from solid non-hazardous waste); *The role of SRF in a Circular Economy*.

2 John R- Fyffe et al.: *Residue-Derived Solid Recovered Fuel for Use in Cement Kilns*, 2012.

3 Pre-processing waste for cement kilns: www.geocycle.com/our-processes

11 Biogas utilization

11.1 Biogas utilization in spark engines and turbines

11.1.1 General for spark engines and turbines

The calorific value for biogas is 23-36 MJ/m³ corresponding to a methane concentration between 50-75%. The type of biowaste determines the methane content and the rest of the gas consisting mainly of CO_2. For a consistent and unified combustion and thus stable power production, a calorific value of 40-45 MJ/m³ is desired.

After production the biogas needs to be cleaned in a gas cleaning system to remove sulphur and moisture before entering for example a gas engine to produce electricity. The excess heat from power generation with internal combustion engines can be used for space heating, water heating, process steam covering industrial steam loads, product drying, or for nearly any other thermal energy need.

The overall efficiency of a biogas power plant is about 35% if it is just used for electricity production. In combination with other systems the efficiency can go up to 80%, if the plant is operated as combined heat and power. In areas where heat is not needed, the idea of a combination with for example internal combustion engines seems feasible. The mechanical energy hereby produced could be used for other applications such as irrigation or other processes not in need of fixed frequency, thus avoiding conversion efficiencies etc.

11.1.2 Brief technology description spark engines

The spark engine or spark ignition engine is a type of engine suited for fuels with low flammability such as biogas. More commonly, the engine type is referred to as gasoline engine since it is the type of engine used in most cars and vehicles other than diesel engines. Liquified gasses such as LPG and Liquified Natural Gas (LNG) would also be suited for a spark engine.

Gas engines, which are covered below, are often used even in large-scale plants because they can be built in modules/containers of 1 MW units.

The engine works by converting chemical energy, as bound in the biogas, into mechanical energy in form of revolutions on an axle. The fuel is ignited by a electrical spark, thus igniting the fuel within a cylinder chamber creating pressure that moves the cylinder. The engine type is a low-pressure engine opposite of a diesel type engine were the high pressure within the cylinder chamber ignites the fuel when injected.

The engine should of course be designed to the type of fuel in question, but the overall principles remain the same. According to in flammability and combustion cycle the ignition system would have to be designed to the fuel used.

11.1.3 Brief technology description turbines

Commercial-scale biogas turbine projects can be found operating in industrialized regions, including the USA and Europe. Biogas turbines are similar to natural gas turbines except that, because of the lower quality gas, twice the number of fuel regulating valves and injectors are used. The majority of gas turbines currently operating at landfills are simple cycle, single-shaft machines. Gas turbines generally have larger outputs than internal combustion engines and are available in various sizes from 1 MW to more than 10 MW.

Use of turbines on biogas is rare, because only the very largest biogas applications would produce sufficient biogas fuel for combustion turbines. The very smallest of combustion turbines is about 800 kW; most families start at 5,000 kW capacity and go up to hundreds of megawatts. Turbines are also sensitive to biogas impurities, and require fuel conditioning (ref 3).

Gas turbines are available as modular and packaged systems, allowing for flexibility when responding to changes in LFG quality and flow.

Gas turbines require a high-pressure fuel supply in the range of 11 to 14 barg and for this reason a gas compressor must be installed upstream the turbine.

11.1.4 Inputs

The input is biogas as fuel for the engine and turbine. The biogas can be from landfill extraction of from an anaerobic biogas plant.

11.1.5 Outputs

The output is mechanical energy and heat. The mechanical power can be converted into electricity by a generator.

11.1.6 Capacities

There are no technical restrictions to the capacity of a system based on spark ignition engines.

For power production based on a biogas turbine the range would typically be 10-50 MW.

11.1.7 Ramping configuration

Depending on the configuration of the engine and generator the generator set can ramp up from cold start to full power in 2 to 10 minutes.

A gas turbine can ramp up 50 MW/minute.

11.1.8 Advantages/disadvantages

Advantages:

- The spark ignition engine is a well-known principle.
- Easy maintenance and repair.
- Easy to install and modify.

Disadvantages:

- The fuel (biogas) is more challenging to store compared to for example fossil oil.
- The engine must have a more robust design to accommodate for variances in fuel quality thus being slightly less efficient.
- Gas turbines are expensive, sensitive, high-tech equipment.

11.1.9 Environment

Biogas is thought to be CO_2 neutral. This mainly due to methane being removed for energy production. This methane would otherwise be emitted to the atmosphere.

Emissions from exhaust gas must be handled to comply with environmental requirements. Noise issues must be handled with enclosures or similar.

11.1.10 Employment

Depending on the configuration of the power plant the required manning can be from 1 to 20 persons.

11.1.11 Research and development

Biogas utilization as fuel in spark engines and turbines is a category 4 technology. There is a large deployment of the technology; prices and performance are well known.

Most research and development regarding spark ignition engines have been done but higher efficiency is always sought after.

11.1.12 CAPEX

In Table 25 is listed typical and annual operating and maintenance costs of large and small internal combustion engines (ref. 1).

Technology	**Typical capital costs ($/kW installed)**	**Typical annual O&M costs ($/kW)**
Internal combustion engine (> 800 kW)	1,800	180
Small internal combustion engine (< 800 kW)	2,400	220
Gas turbine (> 3 MW)	1,800	180
Microturbine (< 1 MW)	2,800	230

Table 25. Capital and O&M cost for gas engines and turbines.

11.1.13 Examples

Internal combustion engines have generally been used at landfills where gas quantity is sufficient of producing 500 kW to 10 MW, or where sustainable LFG flow rates to the engines are approximately 240 to 1,920 m^3/h at 50 % methane. Multiple engines can be combined for projects larger than 1 MW Gas engines, which are covered below, are often used even in large-scale plants because they can be built in modules/containers of 1 MW units. Indonesia already has a good network of gas engine distributors who can supply suitable engines, spare parts and service support for LFG power projects. This is not the case for more sophisticated technologies, such as gas turbines (ref 2).

Figure 34. Example a Jenbacher 1 MW gas engine at Bantergebang (ref 2).

11.1.14 References

1 U. S. Environmental Protection Agency Combined Heat and Power Partnership, *Biomass Combined Heat and Power Catalog of Technologies*, 2007.

2 Ministry of Energy and Mineral Resources, Republic of Indonesia, *Waste to Energy Guidebook,* 2015.

3 Danish Technological Institute, *Report: Biogas and bio-syngas upgrading*, 2012.

11.1.15 Data sheet

Technology

Technology	Biogas utilization - Engines & Turbines								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe) Engine	1	1	1						
Generating capacity for one unit (MWe) Turbine	3	3	3						
Electricity efficiency, net (%), Engine	40%	40%	41%						1
Electricity efficiency, net (%), Turbine	33%	33%	34%						
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)									
Construction time (years)									
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)	33%	33%	33%						1
Minimum load (% of full load)	25%	25%	25%						1
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment ($/KWe) Engine	1.800,0	1.664,3	1.490,4	1350,0	1863,0	1117,8	1863,0		
Nominal investment ($/KWe) Turbine	1.800,0	1.664,3	1.490,4	1350,0	1863,0	1117,8	1863,0		
Annual O&M ($/KWe/year) Engine	180,0	166,4	149,0	135,0	186,3	111,8	186,3		
Annual O&M ($/KWe/year) Turbine	180,0	166,4	149,0	135,0	186,3	111,8	186,3		
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)									

References:

1. EPA Combined Heat and Power Partnership, Biomass CHP Catalog

11.2 Biogas for upgrade to use in vehicles

11.2.1 Brief technology description

Biogas used for transportation is a well-known and widely used technology. Especially in public transport it is used were the infra structure allows for this. Also, the collection of household waste by the use of garbage trucks has utilized this method of fuelling.

For transport, the biogas is put to good use as fuel for busses, trucks and other vehicles. The purpose of using biogas is as earlier described to reduce the use of fuels based in fossil oil. This especially makes good sense within transportation where the biogas can fuel the engine of the vehicle just as diesel would. Engine type suited for biogas utilization was described in previous section.

Buses and waste collection vehicles typically have a driving pattern, where they run a fixed route daily and are stationary in the evening/night. Vehicles with this type of driving pattern have greater potential for conversion to compressed biogas, because they have the ability to refuel during the night (slow fill). In addition, buses and waste collection vehicles on contract are a secure investment basis for the establishment of a gas filling station. The resale value for heavy gas vehicles is uncertain because there is no real market for this, which means that the contracts may be longer than usual.

Infrastructure is of relevance when discussing the use of biogas for transportation. At least one biogas station with fuel storage needs to be stablished. With the purpose of for example introducing busses in a city based on biogas a single biogas station would be sufficient. Biogas can be stored in tank facilities and if as demand for biogas increases more storage can be built just as regular petrol stations.

11.2.2 Inputs

Biogas in a combustion engine.

11.2.3 Outputs

Mechanical energy in form of revolutions in an engine used for propulsion. Heat is also produced which must cooled away.

11.2.4 Capacities

According to engine configuration.

11.2.5 Ramping configuration

The spark ignition engine fitted in the vehicle can increase its load by throttling and thus increasing or decreasing revolutions.

11.2.6 Advantages/disadvantages

Advantages:

- Using biogas for transportation is a well-known technology and relatively easy to implement.
- Using biogas for vehicles gives less emissions compared to for example diesel.

Disadvantages:

- The fuel is more challenging to store and liquify compared to diesel or gasoline.
- The engine must have a more robust design to accommodate for variances in fuel quality thus being slightly less efficient (compared to gasoline).

11.2.7 Environment

Since the biofuel has no or little CO_2 abatement and more or less directly can substitute gasoline or diesel for engines there is a significant environmental advantage.

11.2.8 Employment

The implementation of biogas for transport could maintain or slightly increase jobs by substituting transport jobs from other transport sectors. However, the overall need of transportation is not thought to be direct depending on fuel type.

11.2.9 Research and development

Biogas for upgrade to use in vehicles is a category 4 technology. There is a large deployment of the technology; prices and performance are well known

Projects for investigation possibilities for utilizing biogas for public transport logistics etc. is ongoing, hereunder the required storage and transportation systems for the biogas. Main part of research and development in relation to converting fuel into biogas has been done.

11.2.10 CAPEX

In overall it is slightly more expensive to operate vehicles with biogas compared to diesel. According to experience in Denmark for public tendering of bus service on biogas the price level is 7% higher compare to operation on diesel. This difference is most likely not the same in Indonesia due to different level in value added tax, toll etc.

11.2.11 Examples

In the city of Vaasa in Finland 12 biogas buses started to operate in 2017. These 12 biogas buses can substitute an equivalent of 280,000 litres of diesel fuel every year.

In Sweden at the end of 2014, almost 60% of all produced biomethane was used to fuel some 50,000 vehicles, including over 2,300 buses, which constitutes 17% of all buses in Sweden.

In the city Lille in France, 108,000 tonne of waste are processed annually, producing more than 4,000,000 m^3 of biogas (which corresponds to 4,500,000 litres of diesel oil. All 430 buses in the Lille agglomeration are fuelled by biogas (partially mixed with natural gas).

One example is Romerike Biogas Plant in Norway. The biogas liquefaction plant produces biomethane from household food waste to be used as biofuel for buses in Oslo.

The plant is located in Nes, Romerike, an agricultural region northeast of Oslo, and treats 50,000 tons of food waste a year to produce around 14,000 Nm^3/day of biomethane. The liquefied biogas can be efficiently converted to be used as fuel.

Figure 35. Biogas plant for replacing LPG for busses in Oslo, Norway.

11.2.12 References

1 Fremsyn, *Biogas for transport in 2020 - potential for roll-out of biogas for heavy transport*, 2017.

2 Ministry of Energy and Mineral Resources, *Waste to Energy Guidebook,* 2015.

3 European Regional Development Fond, *Applications for CBG and LBG for transport,* 2020.

11.3 Biogas replacement for LPG

11.3.1 Brief technology description

Liquified Petroleum Gas (LPG) covers two natural gas liquids: propane and butane, or a mix of the two. Propane and butane are chemically quite similar but the small differences in their properties mean that they are particularly suited to specific uses. Often, propane and butane will be mixed to get the best energy yields and properties. Propane and butane are normally transported and delivered in bottles tanks.

Biogas cannot be liquefied under normal temperature and pressure like LPG. The Wobbe index for LPG is approximately double that of biomethane indicating that they are not interchangeable gases. The density of LPG is also 2 - 3 times that of biomethane which results in incompatible calorific or heating values and flow rates, assuming constant pressure (ref 1). The calorific value of LPG is around 46 MJ/kg, whereas raw biogas has a calorific value around 21 MJ/kg and upgraded biogas has a calorific value around 43 MJ/kg (even if the biogas is upgraded it cannot replace LPG without modification/replacement of the apparatus).

11.3.2 Capacities

The capacities of replacing LPG gasses with biogas rely mainly on the availability of biogas and the capacity for biogas refinement. Motivation and incentives will help the conversion. Biogas production could be the preferred fuel in gas systems partially replacing the LPG.

11.3.3 Advantages/disadvantages

Advantages:

- CO_2 emissions are reduced when LPG is replaced by biogas.

Disadvantages:

- The lower calorific value of biogas means more demanding to transport and store compared to LPG.
- Since it is not possible to replace LPG bottles with bottles with biogas and the apparatus for LPG are not designed for biogas, storing and transport system for biogas must be installed and the apparatus must be modified or replaced for operating on biogas.

11.3.4 Environment

The are no major environmental issues related to converting from LPG to biogas.

11.3.5 Employment

Replacement of LPG with biogas has potential to provide new jobs. The production of biogas and the associated industries should expect higher levels of employment.

11.3.6 Research and development

The technology is a category 1, since it is not proved to be possible to replace LPG bottles with bottles with biogas, but research is ongoing. See reference 3

11.3.7 Examples

There are no examples for proven projects for replacing LPG with biogas.

11.3.8 References

1 Distributed Generation & Alternative Energy Journal: *Converting LPG Stoves To Use Biomethane*, S. Suwansri et. al. 2015.

2 Presentation: *Biogas Upgrading and Bottling Technology Developed for Vehicular Applications*, Prof. Virendra K. Vijay.

3 Waste to Fuel: *Bottling Biomethane for Transport And Cooking* https://www.engineeringforchange.org/news/waste-fuel-bottling-biomethane-transport-cooking/, Virendra Kamur Vijay, India, 2019.