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Biodigester and Waste Plastic-to-Oil Unit as Methods to Convert Waste Into Fuel in Tukku-tori Area, Helsinki, Finland

Metropolia University of Applied Sciences

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The current thesis suggests two main possible solutions to address issues in the precarious waste management system at Tukkutori Area, Helsinki, Finland.

The two solutions are the deployment of a Biodigester and a waste plastic-to-oil units to convert waste into biogas (plus fertilizer as a secondary by-product) and oil (mainly diesel), respectively.

In order to study the feasablity of these two solutions, waste disposal data was gathered from restaurants and other businesses at Tukkutori Area, from now on called the T Area. According to the quantity and type of biowaste and plastic waste, a fixed dome type biodigester of 50 m3 and the Blest NVG-200 pyrolysis unit were evaluated for each kind of waste, respectively.

The results of the evaluation showed that the biodigestor can convert the yearly 240 tonnes of biowaste into 297 MWh of electricity and 370 MWh of heat per year. Also, it can produce 209 tonnes of fertilizer, which is divided into 188 tonnes of liquid fertilizer and 21 tonnes of solid compost.

The Blest NVG-200 unit, in contrast, can convert the 120 kg/day of plastic into 120 litres of oil, including 72 liters of diesel that could be used to heat the biodigester to transport the fertilizer, for instance.

Keywords	biodigester, biogas, anaerobic digestion, waste plastic-to-oil

Contents

1 Introduction

There is a significant amount of biowaste and plastic waste at the T Area which is actually being disposed of in the traditional way incurring unnecessary costs of transportation and later recycling or incineration. Besides the impact on costs, there is also an impact on the environment considering the greenhouse gases emitted during the transportation of waste and later even more during the incineration of the waste.

Therefore, in line with the present circular economy paradigm, the present thesis proposes two solutions as follows: firstly, the conversion of biowaste into biogas through a biodigester; and secondly plastic waste into oil fuel through a plastic-to-oil unit, based on the pyrolysis method.

2 Project Review

2.1 Objectives

The objective of the project was to supply the Tukkutori Area with the following:

- Energy Component:
    - biogas to the restaurants for cooking;
    - electricity from biogas engine;
    - diesel, gasoline and kerosene fuel from waste plastic-to-oil unit;
    - waste heat from biogas' engine.

- Farming Component:
    - solid and liquid fertilizer from biodigester effluents.

2.2 Technologies selection

In the case of the biodigester, biowaste is decomposed in anaerobic conditions by bacteria and microorganisms to form methane, which can then be used as biogas for different purposes such as cooking or heating among others.

The Waste Plastic-to- Oil unit could be provided by the Japanese company Blest Co., LTD whose devices are based on the Pyrolysis method explained later on this thesis.

The two solutions above would be placed in situ at T Area which could avoid the issues of waste transportation, recycling or incineration by converting waste into fuel, thus reducing greenhouse emissions and also the use of fossil fuels considering the new two types of fuels, biogas and oil, that would be obtained.

2.3 Environmental Impact

The main contribution of the present thesis' solutions are as follows:

(a) Electricity from fossil fuels would be replaced by electricity produced from biogas. The generated electricity will be used to contribute to T Area daily operations.

(b) Plastic waste would be converted into Oil (mainly ready to use Diesel), therefore saving costs and time on waste management and transportation in T Area and avoiding plastic pollution on the environment.

(c) The biowaste used by the project activity would have decomposed naturally producing a significant amount of methane emissions. [1]

3 Project Location

Tukkutori Area is a 17300 m2 area located close to Helsinki downtow, and it includes several restaurants and supermarkets. More details of the area can be seen in Figure 1 below.

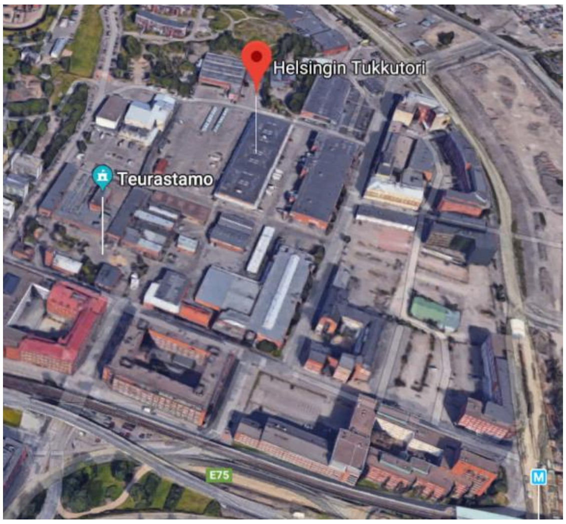

Figure 1: Tukkutori location in Helsinki

The current problem with the biowaste disposal of these businesses is that it is time-consuming, the containers are often full, there is waste on the floor and even rats in the waste center. Also, there are several waste centers instead of a centralized one, as shown in Figure 2.

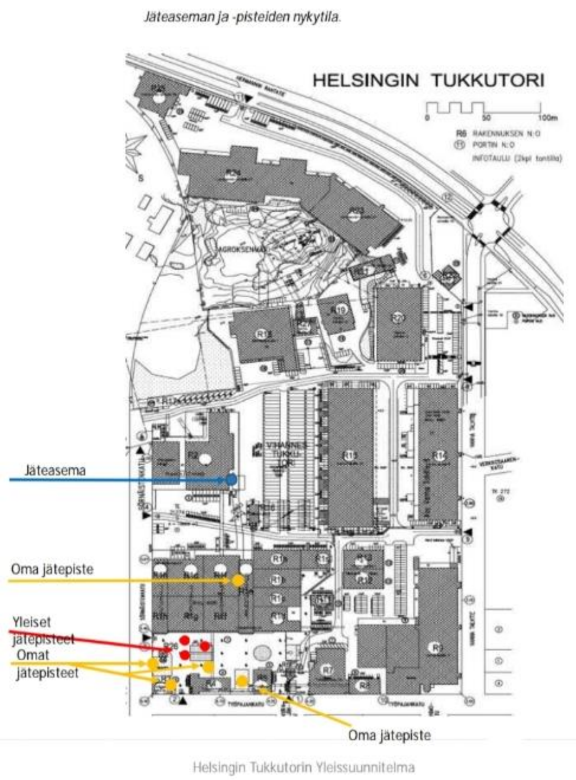

Figure 2: Tukkutori waste plan map

4 Biogas Anaerobic Digestion Process

A biodigester is based on an anaerobic fermentation process in which bacteria decomposes organic mass and methane is produced by the bacteria. Anaerobic means there is no presence of oxygen in the process.

4.1 Biowaste availability for the biodigester

As shown in Table 1, biowaste at Tukkutori accounts for almost 240 tonnes per year.

Paperinkeräys

KOKONAISJÄTEMÄÄRÄT (tn) JAKEITTAIN 2017
Helsingin Kaupungin Tukkutori

Jätejae	Yhteensä tn	Tammikuu	Helmikuu	Maaliskuu	Huhtikuu	Toukokuu	Kesäkuu	Heinäkuu	Elokuu	Syyskuu	Lokakuu	Marraskuu	Joulukuu
Puu	*156.02*	8.6	9.9	18.4	12.2	18.0	11.4	9.9	11.9	17.5	11.9	15.1	11.1
Biojäte	*83.52*	3.5	3.6	4.6	4.2	7.0	15.6	9.1	9.0	9.4	5.78	7.98	3.72
Yhteensä tn	**239.54**	**12.18**	**13.48**	**22.96**	**16.40**	**24.98**	**27.06**	**19.09**	**20.89**	**26.96**	**17.68**	**23.04**	**14.82**

Table 1: Encore Ympäristö-Palvelut

According to the Swedish Gas Technology Centre Ltd, sorted food waste has a biogas production yield of 618 m3/ton (Total Solid or Dry Matter), which includes a 63% methane concentration.[3]

Considering that in a Combined Heat and Power plant, the ratio of heat to power depending on the scale and technology is 35-40% converted to electricity, and 40-45% to heat; this typically equates to 2 kWh of electricity and 2.5 kWh of heat per m3 of biogas, a 60% methane concentration.[4]

Therefore, the yearly 240 tonnes of biowaste at T Area would produce approximately 148,000 m3 of biogas, which would yield both 297 MWh of electricity and 370 MWh of heat per year.

If we consider that an average 100 m2 bar/restaurant consumes an estimated 28 MWh of energy yearly (both electricity and heating) and a medium business consumes 30 MWh of electricity and 45 MWh of Gas, the above biodigester energy production could well provide most of the energy needed for the 34 bars, restaurants and medium businesses at both the Teurastamo and Tukkutori area. [11;12]

4.2 Biogas production optimal conditions

In order for the biogas production to be constant, the following conditions should be met:

- Temperature: biodigesters start producing biogas where average daily temperature is minimum 18°C or where the mean annual temperature is around 20°C. Between 20 to 28°C of mean temperature, the increase in gas production is more than proportion with respect to the temperature rise. [8]

The following types of digestion are distinguished according to the temperature in the biodigester:

  - Psychrophilic range (10-20 °C, holding/production time over 100 days)
  - Mesophilic range (20-35 °C, holding /production time over 20 days)
  - Thermophilic range (50-60 °C, holding /production time over 8 days) [9]

In the case of low mean temperatures locations as Helsinki, the msophilic digestion can be achieved by first heating the Biodigester with electricity or gas from the local grid for instance. After the first biogas production, the biodigester could be heated with a fraction of its own biogas production, therefore turning the system self-sufficient.

- pH value: the methane-producing bacteria live performs best in pH values between 7 and 8.5. If the pH is lower than 6.2, the bacteria dies. [8]

4.3 Biodigester size

In order to determine the Biodigester's size, we should first calculate the total volume of biowaste and water that is fed with. An approximate daily biowaste input can be obtained dividing the yearly 240 tonnes by 365 days, which results in 657 kg of biowaste per day.

Biowaste at T Area can be divided into 3 categories with their corresponding densities: wood waste (400 kg/m3); restaurants waste (362 kg/m3); and vegetable and fruits waste (282 kg/m3). Considering the present work does not require such a level of precision, an

average value of 348 kg/m3 for the density of biowaste as a whole will be taken into account. [6]

A Biodigester must be filled with a 1:1 ratio of water and biowaste, which results in also 657 liters of water to be fed in the biodigester daily. If we consider that water density is 1000 kg/m3, the 657 kg of water would take 0.65 m3 of space daily in the biodigester.

Therefore, the input of 657 kg would take 1.9 m3 of space daily and added to the 0.65 m3 of water results in a total of 2.5 m3 daily. Considering the biodigester at T Area will operate under mesophilic digestion conditions with a retention/production time of 20 days per each batch of biogas, thus a 50 m3 fixed dome type biodigester will be enough for T Area. As follows in Figure 3, a fixed dome biodigester diagram.

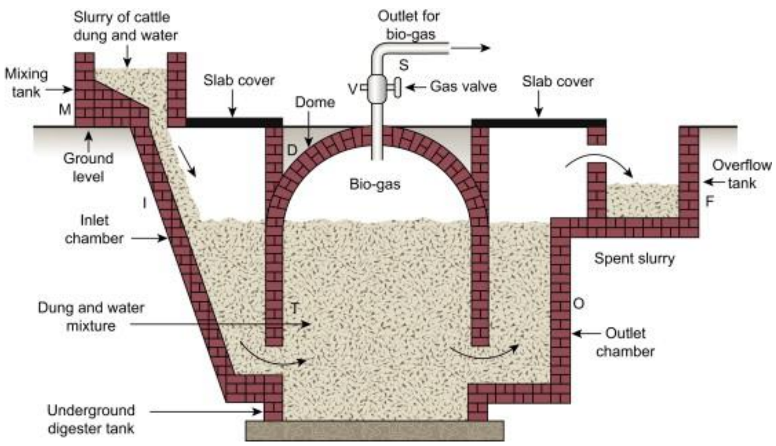

Figure 3: Diagram of a Fixed Dome Biodigester.

5 Combined Heat and Power Unit (1 x 1063 kWe)

As mentioned above, the 240 tonnes of organic waste at Tukkutori would produce 148,320 m3 of Biogas per year which in turn can yield approximately 297 MWh of electricity and 370 MWh of heat yearly.

This conversion can be done with the use of the CHP unit JMS 320 GS-B.L whose technical data is available in the Appendix section.

Regardless of the CHP unit's theoretical values, the following Energy consumption and losses should be considered (Tampio et al. 2014). The Biodigester consumed 9% of the produced total energy as electricity for the pretreatment and hygienization of the biowaste; also 5% for gas conversion in the CHP; and 8% for the anaerobic digestion itself. The hat consumption of the biodigester represented 10% of the total energy produced, including hygienization of the biowaste; heating of the biodigester and heat losses. [5]

In the following Figure 4, a process diagram of the whole biogas plant is presented.

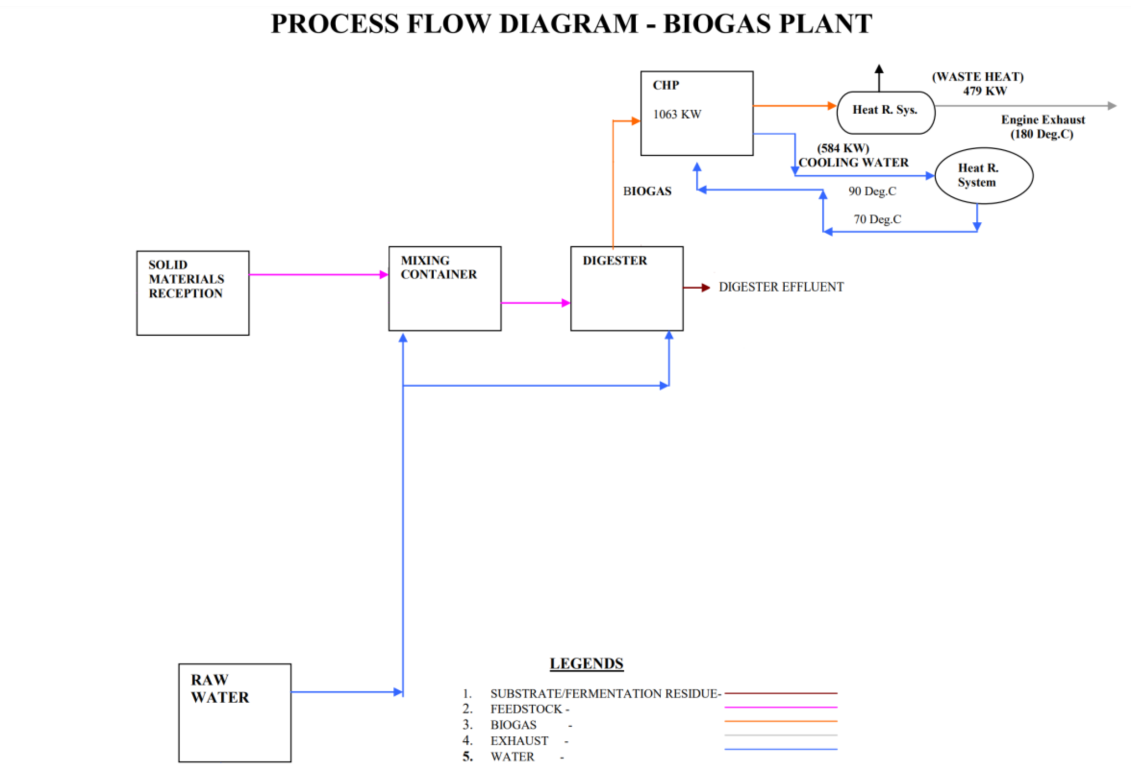

Figure 4: Process Flow Diagram of the Biogas Plant

6 Fertilizer Unit

The discharge from the biodigester is directed to the fertilizer unit for separation between solids and liquids. The solids part can is processed into composting with the addition of other organic matter. On the other hand, the liquid part of the effluent is filtered in several steps in order to reduce the amount of total suspended solids (TSS) to an average of < 50 ppm of total dissolved solids (TDS). [1]

6.1 Fertilizer unit components and steps

The main components and steps in order of appearance are as follows:

1st Filter Press
2nd Flocculation Chamber
3rd Centrifuge unit
4th Pressure Sand Filter
5th Ultra Filtration unit
6th Reverse Osmosis unit

6.2 Process description

The discharge from the biodigester has an approximate TSS value between 5.5 - 7% and is directed via the filter press to separate the solids until it reaches a value of 3% TSS left in the effluent liquid and also a moisture level in the range of 30 to 40% when is ready to be directed to the organic composting unit. On the other hand, the liquid is sent through the flocculation unit to lower the TSS below 150ppm and these remaining solids in the flocculator are delivered to the fertilizer unit. Liquid coming out of the flocculator should have a TSS level reduction to less than 30ppm by being passed through a centrifuge first and then via a pressure sand filter to lower the TSS below the visible level. These liquid has as well a TDS in the scope of 10,000 to 20,000 ppm and is sent through a final ultra-filtration unit that filterss missing TSS. The discharge from this latter unit is subjected to a reverse osmosis process to lower the TDS value below 50 ppm which results in 60% to 70% of the initial liquid being recovered. The liquid that has been rejected usually has a TDS value of around 40000 ppm (including dissolved potassium and ammonium) and therefore is utilized as liquid fertilizer. Please refer to Figure 5 for more details. [1]

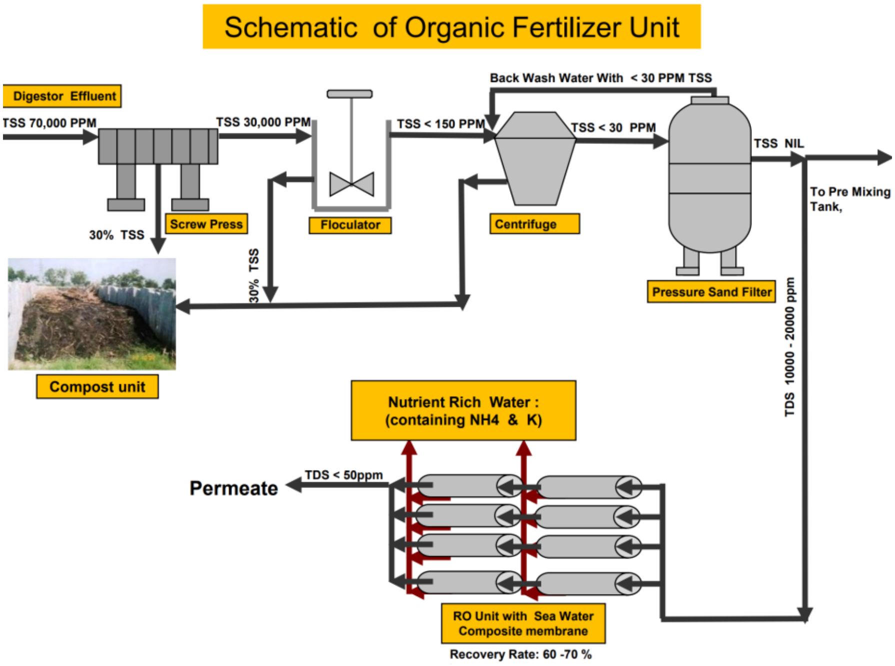

Figure 5: Schematic of Fertilizer Unit

According to Tampio, E. et al, from the total initial feedstock fed in the biodigester, approximately 13% is transformed into biogas and 87% into fertilizer, whereas the latter is then separated resulting in 90% liquid fertilizer and 10% solid compost. [5]

Therefore, from the total yearly 240 tonnes of Biowaste at the T Area, the final yield would be 209 tonnes of fertilizer, which is then divided into 188 tonnes of liquid fertilizer and 21 tonnes of solid compost.

The positive impacts on the environment of using fertilizer from biodigester are:

a. Decrease of food waste odor
b. Prevention of CH_4 emissions caused by food waste decomposition
c. Reduction of ground water pollution
d. Closing of the nutrient cycle by using this fertilizer with minimum losses caused by transportation, storage and the biogas production itself.

7 Waste Plastic-to-Oil unit

This unit is based on the pyrolisis techique which consists on warming / vapouring (not burning) plastic waste to approximately 430 C in anaerobic conditions. When the waste

plastic changes its chemical composition and physical phase into gas state, then this gas is later condensed with water to form oil as the final product. For more details, please refer to Figures 6, 7 and 8 below.

The amount of plastic waste at T. Area is around 120 kg/day. [2] Therefore, the appropriate choice for this amount of waste would be the NVG-200 pyrolysis plant from Blest Co., LTD. which can process 200kg of plastic per 24 hours of continuous operation and has an oil ratio of approximately 80%, depending on the type of plastic waste. It takes 1 kWh of energy, 1 kg of plastic to produce 1 litre of oil, from which 60% is diesel. [10]

Therefore, the Blest NVG-200 unit could convert the 120 kg/day of plastic at the T Area into 120 litres of oil, including 72 liters of ready-to-use diesel.

Figure 6: Blest NVG-200 prolysis plant

Figure 7: Blest NVG-200 feeder unit

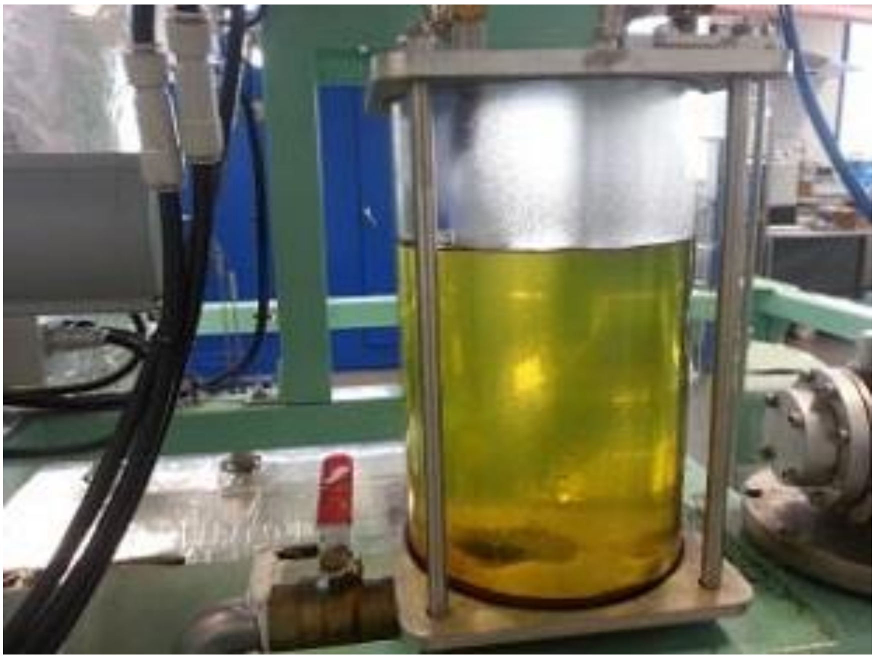

Figure 8: Ready-to-use Diesel from Blest NVG-200

8. CONCLUSION

The two solutions discussed in this thesis would not only save costs and time by avoiding the current expenditures of waste management and transportation, but also save a significant portion of the electricity and heating for both Teurastamo and Tukkutori businesses that could now be partly provided by the burning of both biogas and oil (mainly ready-to-use diesel).

Furthermore, the deployment of these two solutions would generate revenue to T. Area by selling the fertilizer and diesel from those technologies.

Finally, the environmental benefits are significant considering the following:

- Methane from the biogas is burnt instead of letting it free to the atmosphere through natural biowaste decomposition; and the CO2 released after its burning is approximately 30 times less damaging as a heat-trapping gas than Methane. [14]

- Plastic waste would be converted into oil (mainly ready to use Diesel), therefore saving costs and time on waste management & transportation in T. Area and avoiding plastic pollution on the environment.

- Burning of both biogas and oil for generating electricity and heat partially replaces the consumption of fossil fuel fed grid that otherwise will provide those services.

- The placement of these solutions is in line with the circular economy paradigm studied in the Programme and currently implemented in both the private and public sectors' practices around the world.

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Technical Description: Cogeneration Unit JMS 320 GS-B.L

Technical Description

Cogeneration Unit

JMS 320 GS-B.L

Biogas Version C21

Electrical output	**1063 kW el.**
Thermal output	**609 kW**

Emission values
NOx < 500 mg/Nm³ (5% O2)

Jenbacher gas engines
Technical Specification

JMS 320 GS-B.L
Biogas 1.063kW el.

CO-GEN Module data:		
Electrical output	kW el.	1.063
Recoverable thermal output (180 °C)	kW	1.088
Energy input	kW	2.607
Fuel Consumption based on a LHV of		
5 kWh/Nm³	Nm³/h	521
Electrical efficiency	%	40,8%
Thermal efficiency	%	41,7%
Total efficiency	%	82,5%
Heat to be dissipated (LT-Circuit)	kW	65
Emission values:		
NOx < 500 mg/Nm³ (5% O2)		

Additional information:		
Sound pressure level (engine, average value 1m)	dB(A)	95
Sound pressure level exhaust gas (1m, 30° off engin	dB(A)	121
Exhaust gas mass flow rate, wet	kg/h	5.645
Exhaust gas volume, wet	Nm³/h	4.389
Max.admissible exhaust back pressure after engine	mbar	60
Exhaust gas temperature at full load	°C [8]	450
Combustion air mass flow rate	kg/h	5.179
Combustion air volume	Nm³/h	4.006
Max. inlet cooling water temp. (intercooler)	°C	50
Max. pressure drop in front of intake-air filter	mbar	10
Return temperature	°C	70
Forward temperature	°C	90
Hot water flow rate	m³/h	46,7

Engine data:		
Engine type		J 320 GS-C21
Configuration		V 70°
No. of cylinders		20
Bore	mm	135
Stroke	mm	170
Piston displacement	lit	48,67
Nominal speed	rpm	1.500
Mean piston speed	m/s	8,5
Mean effe. press. at stand. power and nom. sp	bar	18,00
Compression ratio	Epsilon	12,5
ISO standard fuel stop power ICFN	kW	1095
Spec. fuel consumption of engine	kWh/kWh	2,38
Specific lube oil consumption	g/kWh	0,30
Weight dry	kg	5.000
Filling capacity lube oil	lit	370
Based on methane number	MZ	100

Alternator:		
Manufacturer		STAMFORD
Type		PE 734 C2
Type rating	kVA	1.550
Efficiency at p.f. = 1,0	%	97,1%
Efficiency at p.f. = 0,8	%	96,0%
Ratings at p.f. = 1,0	kW	1.063
Ratings at p.f. = 0,8	kW	1.051
Frequency	Hz	50
Voltage	V	400
Protection Class		IP 23
Insulation class		H
Speed	rpm	1.500
Mass	kg	2.967

Technical parameters:

Applicable standards:	Based on DIN-ISO 3046	
	Based on VDE 0530 REM with specified tolerance	
Standard conditions:	Air pressure:	1000 mbar or 100 m above sea level
	Air temperature:	25°C or 298 K
	Relative Humidity:	30%
Engine output derating:	for plants installed at > 500m above see level and/or intake temperature > 30°C, the reduction of engine power is determined for each project.	
Gas quality:	according to TA 1000-0300	
	Gas flow pressure:	80 - 200 mbar (Lower gas pressures upon inquiry)
	Max. variation in gas pressure: ±10%	

Jenbacher gas engines
Technical Specification

>>> Scope of supply genset - JGS 320 GS-B.L

Basic engine equipment:
*Exhaust gas turbocharger, Intercooler
*Motorized carburator for LEANOX control
*Electronic contactless high performance ignition system
*Lubricating oil pump (gear driven)
*Lubricating oil filters in main circuit
*Lubricating oil sump; Lubricating oil heat exchanger
*Jacket water pump
*Fuel-, lubricating oil and jacket water pipe work on engine
*Flywheel for alternator operation; Exhaust gas manifold
*Viscous damper
*Knock sensors

Engine accessories:
*Electric starter motor
*Electronic speed governor
*Electronic speed monitoring device including starting and overspeed control
*Transducers and switches for oil pressure, jacket water temp., jacket water pressure, charge pressure and mixture temperature
*One thermocouple per cylinder

Supplied loose:
Gas train according to DIN-DVGW consisting of:
*Manual stop valve, fuel gas filter, two solenoid valves, Leakage control device, gas pressure regulator

Documentation:
*Operating and maintenance manual
*Spare parts manual
*Drawings

Assembly, painting, testing in Jenbach/Austria

Module equipment:
*Base frame for gas engine, alternator and heat exchangers
*Internal pole alternator with excitation alternator and with automatic voltage regulator; p.f. 0,8 lagging to 1,0
*Flexible coupling, bell housing
*Anti-vibration mounts
*Air filter
*Automatic lube oil replenishing with level control
*Wiring of components to module interface panel
*Crankcase breather
*Jacket water electric preheating

Module control panel:
*Totally enclosed , single door cubicle, wired to terminals and ready to operate, protection IP 41 outside, IP 10 inside, according to VDE-standards

Control equipment:
*Engine-Management-System dia.ne (Dialog Network)
**Visualisation (industry PC-10" color graphics display): Operation data, controller display,Exh. gas temp.,Generator electr. connection,etc.
**Central engine- and module control: Speed-, Power output-, LEANOX-Control and knock control, etc.
*Multi-transducer
*Lockable operation mode selector switch
Positions: "OFF", "MANUAL", "AUTOMATIC"
*Demand switch

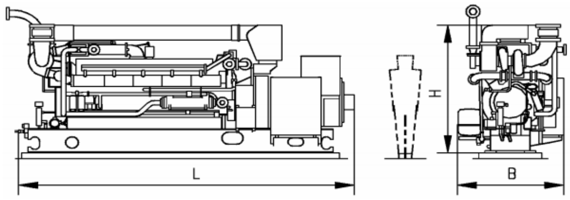
>>> Scope of supply module - JMS 320 GS-B.L

Identical to Genset except that heat recovery is included.
*jacket water heat exchanger mounted on module frame
*exhaust gas heat exchanger mounted as separate heat recovery module
*all heat exchangers with complete pipework
*Heat exchangers and all inherent auxiliaries

>>> Scope of supply container - JG(M)C 320 GS-B.L

*Identical to module/genset but installed in 40' ISO container (65 dB(A) @ 10m); complete with all pipework and fittings
*Twin circuit radation cooler for dissipation of intercooler jacket water and lube oil thermal output; ventilation equipment
*Gas & smoke detectors; exhaust silencer; lube oil equipment; starting system; flexible connections
*Seperate control room complete with generator switchgear and all internal power and monitoring cables

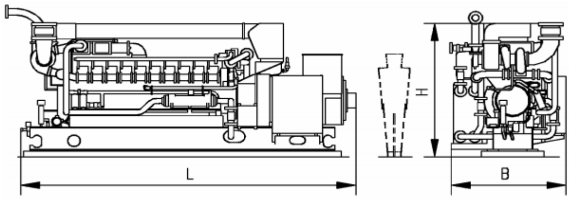
Genset



Main dimensions and weights (approximate value)		
Length L	mm	5.700
Width B	mm	1.700
Height H	mm	2.300
Weight empty	kg	10.500
Weight filled	kg	11.000

Connections (at genset)		
Jacket water inlet and outlet	DN/PN	80/10
Exhaust gas outlet	DN/PN	250/10
Fuel gas (at gas train)	DN/PN	100/16
Intercooler water connection:		
Low Temperature Circuit	DN/PN	65/10

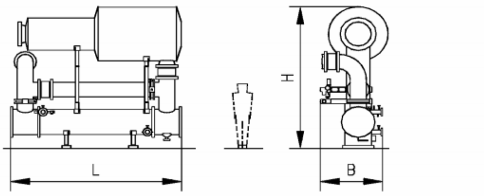
Module



Main dimensions and weights (approximate value)		
Length L	mm	5.700
Width B	mm	1.900
Height H	mm	2.300
Weight empty	kg	11.000
Weight filled	kg	11.500

Connections (at module)		
Hot water inlet and outlet	DN/PN	80/10
Exhaust gas outlet	DN/PN	250/10
Fuel gas (at gas train)	DN/PN	100/16
Intercooler water connection:		
Intercooler water-Inlet/Outlet 2nd stage	DN/PN	65/10

Heat recovery module



Main dimensions and weights (approximate value)		
Width B	mm	1.800
Height H	mm	3.750
Length L	mm	4.700

Connections (on heat recovery module)		
Hot water inlet and outlet	DN/PN	80/10
Exhaust gas outlet	DN/PN	250/10
Condensate drain	DN/PN	50/10
Drain line	½"	½"

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