







### 3. Results and Discussion

#### 3.1 Biogas production potential from landfill organic waste

Assuming that all waste is fed as substrate into an anaerobic digester, the annual biogas potential is calculated to be 14 096 057 m<sup>3</sup> with an energy potential of 291 274 giga joules (GJ) as presented in Table 2 The bio methane composition of the biogas is 60% on average. Anaerobic digestion of the landfill waste is a biological process by which communities of microorganisms consisting of bacteria metabolically break down complex organic molecules in the absence of oxygen to produce the biogas (Ong et al., 2014). Other energetic equivalent of biogas produced from the organic fraction of the municipal waste at a local landfill is presented in Table 1. The theoretical annual CO<sub>2</sub> reduction from diverting this waste into an anaerobic digester is calculated as 124 327 tCO<sub>2</sub>eq.

Table 2. Energy potential of all organic waste quantified\*

Type organic waste	Organic material	Quantity organic (tons/yr)	Biogas (m <sup>3</sup> /yr)	Energy (GJ/yr)	Energy production
Collected refuse	56%	101 426	7 099 820	140 167	48%
Restaurants waste	1%	1 252	97 489	2 106	1%
Fruit and Vegetable	9%	16 936	1 318 806	28 486	10%
Garden waste	34%	61 345	5 579 941	120 516	41%

#### 3.2 Selection of upgrading technology

Physical absorption, chemical absorption, membrane separation and cryogenic technologies were research upon to evaluate their performance characteristics against each criterion. The priority vector of each alternative technology against each criterion were calculated and presented in Table 3. Of the four alternatives investigated, membrane technology is most preferred in satisfying the main goal alongside it adaptability to the local environmental conditions and technical knowhow. The alternative technologies that are also competitive with membrane are absorption with 99% preference to membrane.

Table 3. Rankings of the various biogas purification methods

Environmen tal	Product purity	Economics	Ease of Tech	Overall Priority	Idealized Priority	
Absorption	0.08	0.13	0.04	0.02	26.9%	99%
Membrane	0.10	0.08	0.03	0.06	27.2%	100%
Cryogenic	0.11	0.09	0.005	0.01	20.6%	76%

#### 3.3 Energy requirement for upgrading method

The energy requirement of the upgrading process is also a factor to be considered in technology adoption. Physical absorption, adsorption, membrane and cryogenic upgrading techniques are highly dependent on electricity. Table 4 summarises the electricity and energy requirements of four upgrading techniques. The heating value for bio methane (100% CH<sub>4</sub> concentration) is approximately 35 MJ, which is equivalent to 9.7 kWh. This was used to estimate the energy required for upgrading in column 3 of Table 3.

Table 4. Electricity and energy demand of the upgrading techniques

Separation method	Electricity demand (kWh/m <sup>3</sup> bio methane)	Upgrading energy/ CH <sub>4</sub> heating value (%)
Physical absorption with water	0.2-0.5	2.1-5.2
Physical absorption with organic material	0.10-0.33	1-1-3.4
Chemical absorption with amines	0.06-0.18	0.6-1.9
Membrane separation	0.18-0.30	1.9-3.1
Cryogenic separation	0.18-0.63	1.9-6.5

Chemical absorption upgrading energy demand is the least of the four techniques and demand ranges between 0.6-1.9% of CH<sub>4</sub> heating value but requires temperature as high as 120 °C for regeneration when MEA is used as absorbent (Table 4). Generally, absorption processes are best operated at low temperature and high pressure while

desorption process requires an increased temperature hence a heating and cooling system is required. Cryogenic requires the highest demand on electricity which ranges between 1.9-6.5% of CH<sub>4</sub> heating value for the upgrading process. The energy requirement of a cryogenic plant is reported to be about 580.9 kJ/m<sup>3</sup> of bio methane with a heat pump cycle operating between -100 °C to 40 °C. Adsorption technique was also high because of the compression energy required but membrane technique was about the average of all the processes. The energy demand ranges between 1.9-3.1% of CH<sub>4</sub> heating value. From comparisons of both the easy of technology and the energy demand, chemical absorption was then chosen as the bio methane upgrading technique.

### 3.4 Proposed bio methane enrichment process

The biogas from the municipal waste is first desulphurized to remove hydrogen sulphide (H<sub>2</sub>S). After that the desulphurized biogas is compressed to 12 bars and then cooled and filtered to remove contaminants. Adsorption is then carried out for the removal of water, remaining H<sub>2</sub>S and other impurities in the biogas. The biogas is then sent for bio methane enrichment applying either absorption or membrane separation. The enriched bio methane at this stage can be sent for combined heat and power (CHP) uses. The other bio methane can be further compressed to 220 bars and distributed as a source of vehicle fuel. The detailed process flow diagram is shown in Figure 2.

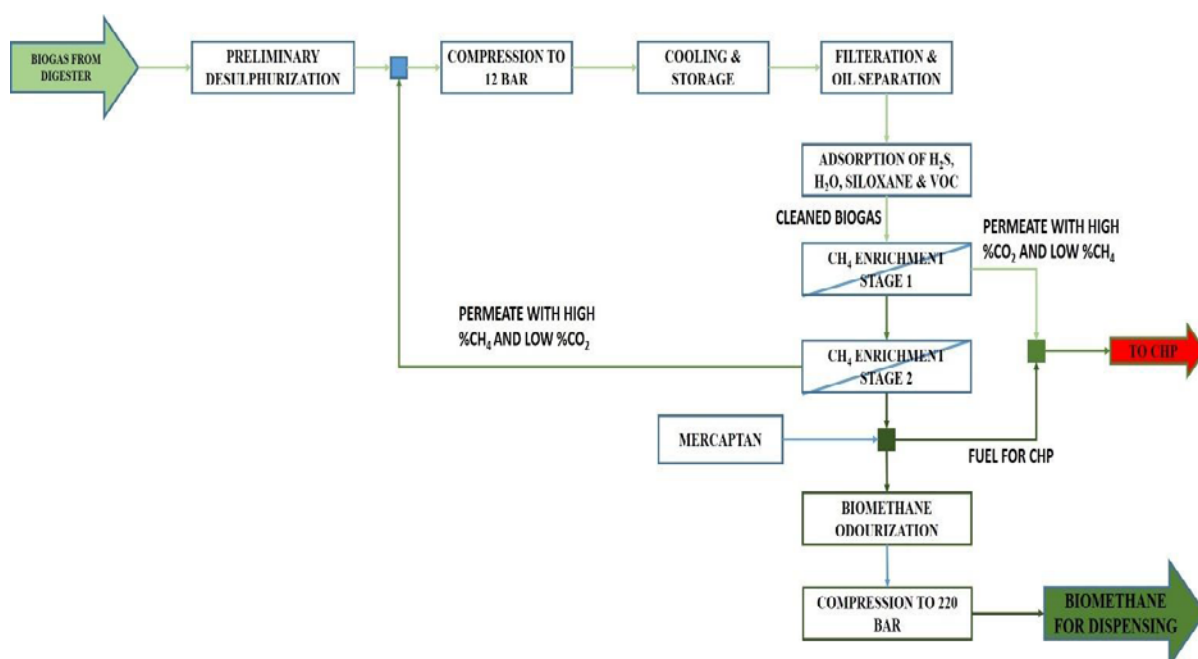


Figure 2. Biogas purification process

## 4. Conclusion

Potential exist for the conversion of landfill waste to biogas which can be upgraded to bio methane. Biogas upgrading is critical for obtaining high purity bio methane with minimal pollutants. Absorption and membrane separation of the bio methane from the biogas are ideal separation methods in terms of easy of technology and energy usage.

## References

- Abatzoglou, N., and Boivin, S., A review of biogas purification processes. *Biofuels, Bioproducts and Biorefinery*, vol. 3, pp. 42–71, 2009.
- Biernat, K., and Samson-Brek, I., Review of technology for cleaning biogas to natural gas quality. *Chemik*, vol. 65, no. 5, pp. 435-444, 2011.
- Horikawa, M. S., Rossi, F., Gimenes, M. L., Costa, C. M. M., and da Silva, M. G. C., Chemical absorption of H<sub>2</sub>S for biogas purification. *Brazilian Journal of Chemical Engineering*, vol. 21, no. 03, pp. 415 - 422, 2004
- Hoyer, K., Hultheberg, C., Svensson, M., Jernberg, J., and Nørregård, O., Biogas upgrading - Technical review Report 2016:275. 2016 ENERGIFORSK.
- Kaparaju, P., Evaluation of potential technologies and operational scales reflecting market needs for low-cost Gas Upgrading Systems. Valorgas

Available [http://www.valorgas.soton.ac.uk/Deliverables/111129\\_VALORGAS\\_241334\\_D5-1\\_Final\\_version.pdf](http://www.valorgas.soton.ac.uk/Deliverables/111129_VALORGAS_241334_D5-1_Final_version.pdf) Accessed 19.05.2012.

Niesner, J., Jecha, D., and Stehlík, P., Biogas upgrading technologies: State of art review in European Region. *Chemical Engineering Transactions*, vol. 35, pp. 517-522, 2013.

Ofori-Boateng, C and Kwofie, E.M., Water scrubbing: A better option for biogas purification for effective storage. *World Applied Sciences Journal*, vol.5, pp. 122-125, 2009.

Ong, M. D., R. B. Williams, S.R. Kaffka. (California Biomass Collaborative, University of California, Davis). 2014. *Comparative Assessment of Technology Options for Biogas Clean-up*. Contractor Report to the California Energy Commission. Contract CEC-500-11-020.

Ramaraj, R., and Dussadee, N., Biological Purification Processes for Biogas Using Algae Cultures: A Review. *International Journal of Sustainable and Green Energy*. Special Issue: Renewable Energy Applications in the Agricultural Field and Natural Resource Technology. vol. 4, no. 1-1, pp. 20-32, 2015. doi: 10.11648/j.ijrse.s.2015040101.14.

Zhao, Q., Leonhardt, E., MacConnell, C., Frear, C., and Chen, S., Purification technologies for biogas generated by anaerobic digestion. CSANR Research Report 2010 – 001 Climate Friendly Farming.

## **Biography**

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