# Mechanical Biological Treatment as a Solution for Mitigating Greenhouse Gas Emissions from Landfills in Thailand

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## EXECUTIVE SUMMARY

Open dumping and landfilling are the two predominant waste disposal methods in Thailand. In 2009, only 23% of Municipal Solid Waste (MSW) was separated for recycling. As far as on land disposal is concerned, it has been estimated that 47% of collected waste is being landfilled and 53% is being openly dumped. These simple MSW management methods are causing negative socio-economic impacts, environmental pollution, and contributing to climate change; their many drawbacks are becoming increasingly recognised. Moving toward biological treatment methods is by many regarded by many as an appropriate strategy for reducing the Greenhouse gas (GHG) emissions from the waste sector. Therefore, in this study, the GHG mitigation potential of Mechanical Biological Treatment (MBT) is assessed in comparison with the two most common disposal practices from a life cycle perspective.

In Phitsanulok Municipality, 78 tonnes/day of MSW is treated by MBT instead of landfilling or open dumping. The MBT process consists of several steps such as unloading, homogenisation, piling, aeration, sieving and separation of compost-like materials and high-energy fractions prior to final disposal. In order to calculate life cycle GHG emissions, data was collected and analysed considering all the phases of the life cycle of the existing MSW management system, including energy and raw materials production, MSW collection and transportation, MBT process and final disposal. Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines were followed to estimate GHG emissions from both MBT and base scenarios (open dumping and sanitary landfilling without gas recovery).

According to our calculations, GHG emissions from the MBT amounted to 161 kg $CO_2$-eq/tonne of waste received at the facility. In contrast, GHG emissions from open dumping and sanitary landfilling (without gas recovery) would be 448kg $CO_2$-eq/tonne and 925 kg of $CO_2$-eq/tonne respectively. The results indicate that by adopting MBT, Phitsanulok Municipality can significantly cut down GHG emissions, by 287 kg of $CO_2$-eq and 764 kg $CO_2$-eq per tonne of waste as compared to open dumping and sanitary landfilling respectively. On an annual basis the GHG emissions reduction potential from the system in Phitsanulok amounts to 21,758 t$CO_2$-eq as compared to sanitary landfilling. We conclude that the current waste management model in Phitsanulok has very significant climate benefits and that a widespread adoption of similar systems could contribute substantially to the national GHG mitigation program and improve the overall sustainability of the waste management sector.

**Keywords**: Municipal Solid Waste (MSW), Mechanical Biological Treatment (MBT), GHG emissions, Life Cycle Assessment (LCA)

## INTRODUCTION

In the year 2009, the total generation of Municipal Solid Waste (MSW) in Thailand reached about 15.11 million tonnes, or approximately 41,410 tonnes per day. Of this amount, around 23% was separated and recycled (PCD 2009). More than 20% of the country's MSW is generated in Bangkok Metropolitan Area (BMA), the capital of Thailand, where the daily collected volume amounted to 8,834 tonnes in 2009 (Nithikul et al. 2010). It is forecasted that MSW generation in Thailand will continue to increase by 0.2 million tonnes annually (PCD 2009). This expected increase in solid waste generation is mainly due to urban population growth, economic development and tourism expansion.

Similar to other Asian countries, open dumping and sanitary landfilling (without gas recovery) are the two predominant waste disposal methods in Thailand. As far as on-land disposal is concerned, the percentage of collected MSW disposed in sanitary landfills and open dumpsites is estimated to 47% and 53%, respectively (PCD 2009). The current methods of open dumping and rudimentary landfill disposal have negative effects in the form of environmental degradation as well as economic losses and social burdens. Greenhouse gas (GHG) emissions from waste management activities and their contribution to global warming and climate change are also increasingly recognised as serious environmental concerns. Moving towards biological treatment methods is by many regarded as the most appropriate way to reduce the GHG emissions from the waste sector. This study assessed the GHG mitigation potential of Mechanical Biological Treatment (MBT) compared to the "business as usual" practices from a life cycle perspective based on the case of Phitsanulok Municipality.

### Existing Waste Management in Phitsanulok Municipality

Phitsanulok Municipality covers 18.26 km² and is situated 390 km north of Bangkok. The registered population within the municipal limits was 78,000 residents as of December 2010. In addition, the municipality has some 50,000-100,000 non-registered residents. The total number of households is estimated to 32,000 (Phitsanulok Municipality 2011).

When compared to most other municipalities in Thailand, waste management in Phitsanulok is advanced and the municipality has set the objective to become a "zero waste city". Its waste management system has been improved in a number of ways since 1996 following the approval of a proposal by the German government to provide technical support. For instance, significant efforts have been made to raise public awareness and participation and to encourage residents to separate recyclables for sale. As a result, in 2011, 36 tonnes/day of recyclables (31.5% of generated waste) were separated at the household level. Private waste buyers, community waste buyers and recycle bank waste buyers are all involved in buying recyclables from the community. A significant improvement of the final disposal took place in 2005 when a pilot scale MBT plant was put into operation. In 2011, total MSW collection by the municipality amounted to 78 tonnes/day and 100% of the collected waste was treated by MBT.

#### *Collection and transportation*

Waste is collected and transported by compactor trucks. Previously, there were 32 trucks used for waste collection. However, the municipality recently improved the collection system by rationalising the collection schedule and changing the routes in order to avoid traffic delays. As a result, the number of collection vehicles has been reduced by almost half (14-16 trucks). Around 30% of the waste is collected and transported by natural-gas vehicles (NGV) to the transfer station, reducing the emissions from waste transportation. At the transfer station, the waste is re-loaded to heavy-duty trucks and compacted in order to reduce the number of trips. Natural gas is used as the fuel source for these heavy trucks, further reducing the GHG emissions from transportation.

### *MBT plant*

The MBT plant in Phitsanulok Municipality is one of the biggest pilot-scale plants in developing countries. The main objectives of initiating the pilot-scale MBT in Phitsanulok were to minimise the waste volume, minimise the GHGs emissions (methane) from the landfill, separate valuable materials, such as compost-like materials and high-energy parts after stabilisation and prior to final disposal. At the moment, the running capacity of the MBT plant is 100 tonnes/day. Apart from the waste received from Phitsanulok Municipality (78 tonnes/day), another 22 tonnes/day of waste is received from other nearby municipalities.

The MBT process in Phitsanulok consists of several steps including unloading of the received waste, homogenisation, piling, aeration, sieving and separation of compost-like materials and plastic waste. Homogenisation is the initial treatment step where de-bagging and mixing is done by using a rotating drum for 45 minutes. In this mechanical step, many larger pieces of materials are crushed and most of the tied plastic bags are opened. After the homogenisation, stabilisation piles are built following a design that facilitates both aeration and leachate run-off. The period needed for biological stabilisation and degradation of the organic materials in these piles is 9 months. After that, the piles are dissembled using an excavator. The stabilised material is then screened to separate compost-like materials, plastics and inert materials. The MBT process is shown schematically in Figure 1.


**Figure 1: The MBT process in Phitsanulok Municipality (Source: Phitsanulok Municipality 2011)**

The total mass loss during the 9 months of MBT is 50% due to drying and degradation of organic waste. The stabilised material is separated mainly into three parts: compost-like materials, plastics and inert materials through a screening process, accounting for 43%, 37% and 20% by weight respectively. The separated compost-like material is used as a biofilter material to cover the new waste piles for odour control, while the inert material is landfilled. The plastic fraction is used to produce plastic oil through a pyrolysis process.

## METHODOLOGY

### Life Cycle Framework for Estimating GHG Emissions from MBT

As the initial step of the assessment, the life cycle phases of the MBT process were identified. It includes auxiliary material production (energy and raw materials), MSW collection and transportation, treatment by MBT. Even though the separated plastics from stabilised materials are used for plastic oil production, the pyrolysis process was not included within the system boundary of this study due to lack of data. To calculate the GHG emissions from a life cycle perspective, a framework was designed for the MBT system in Phitsanulok Municipality (including mass balance); see Figure 2.

An inventory analysis was performed to find the required data to quantify the GHG emissions from the direct and indirect activities related to MBT. Through a field survey, site specific data was collected related to auxiliary material consumption (e.g. type of fossil energy used for electricity and thermal energy supplement), collection and transportation (e.g. type of vehicle use, fuel consumption efficiency, transportation distance), MBT process (energy consumption for making piles and operational activates) and final disposal. The functional unit for the assessment was defined as "management of one tonne of waste received at the MBT plant in Phitsanulok ".

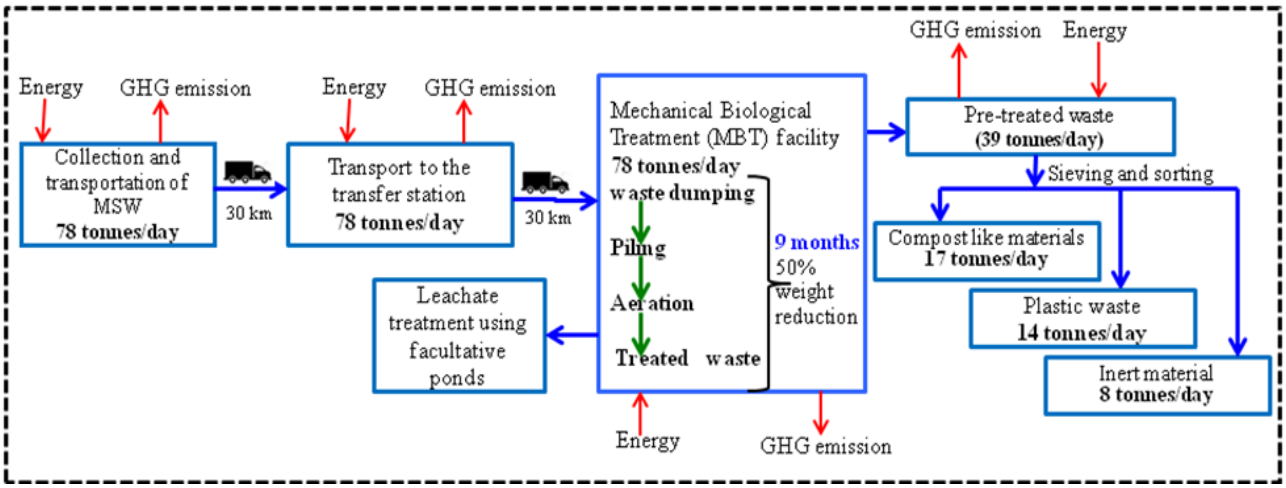


**Figure 2: The LCA framework used for the assessing the GHG emissions from MBT in Phitsanulok Municipality**

## Quantification of Life Cycle GHG Emissions from MBT

Emissions of GHG can occur at every stage of waste management. For instance, all of the activities related to MBT require a significant amount of fossil energy (e.g. diesel, natural gas) or electricity, and will result in emissions of GHG from fuel combustion. In addition, $CH_4$ can be emitted during the waste degradation if parts of the waste piles are in semi-aerobic or unaerobic condition. The effect of $CH_4$ is 25 times worse than $CO_2$ in terms of global warming potential (IPCC 2007). Therefore the GHG emissions potential from each phase were estimated in a systematic way to quantify the total GHG emissions from entire life cycle.

Three major phases were identified with respect to the existing MBT plant in Phitsanulok Municipality. These were waste transportation, operation and maintenance, and waste degradation in the piles. Mathematical formulas were derived to quantify the GHG emissions from each phase by using the theoretical concepts explained in the IPCC 2006 guidelines.

*Phase I*- Total GHG emissions from transportation can be calculated as follows;

$$TE = \sum_j (Fuel \times EF_j \times GWP_j)$$

TE –Transportation Emissions (kg $CO_2$ -eq/tonne of waste)
Fuel – Amount of fuel used (MJ/tonne of waste)
$EF_j$ –Emission Factor of type j GHG (kg/TJ)
$GWP_j$ –Global Warming Potential of type j GHG (kg $CO_2$ -eq/kg of $j^{th}$ emission)

*Phase II*- Total GHG emissions from operational and maintenance activities of MBT plant can be estimated as below;

$$MBTE = \sum_i (EC_i \times EF_{el} + FC_i \times NCV_{FF} \times EF_{FF,CO2})$$

MBTE – MBT plant operational Emissions (kg $CO_2$-eq/tonne of waste)
i - $i^{th}$ activity in BMT ( e.g. Homogenisations, piling, turning, dissembling of files, sieving )
$EC_i$ – Electricity Consumption at the MBT facility to the activity type i (MWh/tonne)
$EF_{el}$ – Emission Factor for grid electricity generation (kg $CO_2$/MWh)
$FC_i$ –Fuel Consumption at the MBT facility to the activity type i (mass or volume/tonne of waste)
$NCV_{FF}$ – Net Calorific Value of the fossil fuel consumed (TJ/unit mass or volume)
$EF_{EF,CO2}$ -$CO_2$ emission factor of the fossil fuel consumed ($tCO_2$/TJ)

*Phase III* – Total GHG emissions from waste degradation in waste piles can be calculated as follows;

$$WDE = E_{CH4} \times GWP_{CH4} + E_{N2O} \times GWP_{N2O}$$

WDE – Waste Degradation Emissions (kg $CO_2$-eq/tonne of waste)
$E_{CH4}$– Emission of $CH_4$ during waste degradation (kg of $CH_4$/tonne of waste)
$GWP_{CH4}$–Global warming potential of $CH_4$ (21 kg $CO_2$-eq/kg of $CH_4$)
$E_{N2O}$– Emission of $N_2O$ during waste degradation (kg of $N_2O$/tonne of waste)
$GWP_{N2O}$–Global warming potential of $N_2O$ (310 kg $CO_2$-eq/kg of $N_2O$)

*Total GHG emissions* - After quantification GHG emission from above three phases, life cycle GHG emissions from MBT process can be estimated as follows;

$$TGHG = TE + MBTE + WDE$$

Where;
TGHG – Total GHG emissions (kg $CO_2$-eq/tonne of waste)
TE - Transportation Emissions (kg $CO_2$-eq/tonne of waste)
MBTE – MBT plant Emissions from operational activities (kg $CO_2$-eq/tonne of waste)
WDE – Waste Degradation Emissions (kg $CO_2$-eq/tonne of waste)

**GHG Emissions Reduction from MBT as Compared to "Business as Usual"**

In order to determine the effectiveness of MBT in terms of GHG mitigation potential, the result was compared with the "business as usual" practices in Thailand. Open dumping and sanitary landfilling (without gas recovery) are the predominant waste disposal methods. Thus, GHG emissions from these MSW management methods were quantified using the Intergovernmental Panel on Climate Change (IPCC) 2006 waste model. The required default values for the assessment were derived considering waste characteristics and climatic conditions, as well as the situation of disposal sites in Phitsanulok. In addition, indirect GHG emissions related to waste transportation and operational activities at the landfill sites were quantified by using the same approach as explained above. Total GHG emissions from the base scenarios were estimated by adding up the emissions from all phases. Emissions of GHG reduction potential of MBT as compared to open dumping or sanitary landfilling (without gas recovery) can then be calculated as follows;

ER = BE – PE
Where, ER-Emissions Reduction, BE-Baseline Emission, PE- Project Emission

## RESULTS AND DISCUSSION

In order to calculate the life cycle GHG emissions from MBT, emissions potential from waste transportation, operation activities, and waste degradation in piles were quantified.

### GHG Emissions from Waste Transportation

Combustion of fossil fuels can emit various GHG such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). Therefore, the emissions were quantified considering the types and the amount of fossil fuel used. IPCC tier 1 approach was used to quantify the GHG emissions from fossil fuel combustion (Waldron, et al. 2006). The total fossil fuel requirement for transportation of one tonne of waste is 5.84 L of diesel and 3.04 kg of compressed natural gas (CNG) (Phitsanulok Municipality 2011). Resulting GHG emissions from fossil fuel combustion are presented in Table 1. $CO_2$ is the major source of GHG from transportation, and the effects of $CH_4$ and $N_2O$ are not significant. The estimated total GHG emissions from waste transportation amounted to 26.33 kg $CO_2$-eq/tonne of waste.

**Table 1: GHG emissions from waste transportation**

| Description | Unit | Type of GHG | | |
|---|---|---|---|---|
| | | **$CO_2$** | **$CH_4$** | **$N_2O$** |
| Emissions from combustion of 5.84L of diesel [a] | kg of emission/tonne of waste | 19.80 | 0.0006 | 0.0001 |
| Emissions from combustion of 3.04 kg of CNG [a] | kg of emission /tonne of waste | 6.48 | 0.0001 | Negligible |
| Total emissions during waste transportation [b] | kg of emission /tonne of waste | 26.30 | 0.0007 | 0.0001 |
| Conversion factor into $CO_2$-eq [c] | kg of $CO_2$-eq/kg of GHG emission | 1 | 25 | 298 |
| Contribution of each GHG | kg $CO_2$-eq/tonne of waste | 26.27 | 0.019 | 0.042 |
| **Total GHG emissions from waste transportation** | **kg $CO_2$-eq/tonne of waste** | | **26.33** | |

(References: [a]Phitsanulok Municipality 2011, [b]Waldron et al. 2006, [c] IPCC 2007)

### GHG Emissions from the Operation of the MBT Facility

Once the waste is received at the MBT plant, it is treated in a series of mechanical steps. In these steps electricity and fossil energy utilisation for running the machinery can cause GHG emissions. Diesel fuel consumption for operation (for operating backhoe, homogeniser, screening machine, etc.) is 3.38L/tonne of waste management. Furthermore, the electricity requirement for operation is 0.2 kWh/tonne of waste (for the weighing machine). Taking into account all the types of fossil energy used for operations, GHG emissions were estimated as 9.23 kg $CO_2$-eq/tonne of waste, see Table 2.

**Table 2: GHG emissions from the operation of the MBT facility**

| **Description** | **Unit** | **Value** |
|---|---|---|
| Diesel consumption for operational activities [a] | L/tonne of waste | 3.38 |
| Heating value of diesel | MJ/L | 36.42 |
| Total energy required for operational activities | MJ/tonne of waste | 123.09 |
| Default $CO_2$ emission factor from diesel combustion [b] | kg $CO_2$/TJ | 74100.00 |
| **GHG emissions from combustion of diesel [c]** | **kg $CO_2$-eq/tonne of waste** | **9.12** |
| Electricity consumption for operational activities | kWh/tonne of waste | 0.20 |
| GHG emissions in grid electricity production in Thailand [d] | kg of $CO_2$-eq/MWh | 566.00 |
| **GHG emissions due to electricity consumption** | **kg of $CO_2$-eq/tonne of waste** | **0.11** |

| | | |
|---|---|---|
| **Total GHG emissions from operational activities** | **kg of $CO_2$-eq /tonne of waste** | **9.23** |

(Reference – [a] Phitsanulok Municipality 2011, [b]Waldron 2006, [d] DEDE 2008. [c] $CH_4$ and $N_2O$ emissions from diesel combustion assumed to be negligible.)

## GHG Emissions from Waste Degradation

According to the physical characteristics of the waste received at the MBT plant, the biodegradable part represents 66% by weight (food waste 57.9%, wood 3.5% and paper/cardboard 4.9%). There is a possibility of GHG generation from the MBT process. Emissions of $CO_2$ from organic waste degradation are not taken into account since they have a biogenic origin (Bogner et al. 2008). Although $CH_4$ generation may take place in the bottom layer of the MBT piles where aeration is insufficient, most of the $CH_4$ can be oxidised in the aerobic sections of the piles. There is no site-specific measured GHG emissions data from the current MBT process. As stated in IPCC 2006 guidelines, GHG emissions from MBT process are considered to be similar to those of composting, so the IPCC default values for composting were used for the estimation in the current study (IPCC 2006). Based on the calculations, GHG emissions from biological degradation amounted to 125.57 kg $CO_2$-eq/tonne of waste, see Table 3. The contribution of $CH_4$ and $N_2O$ for total GHG emissions in waste degradation phase is 53% and 47%, respectively.

**Table 3: GHG emissions from waste degradation at the MBT facility**

| Description | Unit | Value |
|---|---|---|
| Percentage of organic waste in MSW [a] | % (wet basis) | 66.30 |
| $CH_4$ emission factor from composting [b] | kg/tonne of organic waste | 4.00 |
| Methane generation potential from MSW in MBT [c] | kg of $CH_4$/tonne of waste | 2.65 |
| Conversion of $CH_4$ to $CO_2$ equivalents [d] | kg of $CO_2$/kg of $CH_4$ | 25.00 |
| **$CH_4$ based GHG emission** | **kg of $CO_2$-eq/tonne of waste** | **66.30** |
| $N_2O$ emission factor from composting [b] | kg/tonne of organic waste | 0.30 |
| $N_2O$ generation potential from MSW in MBT | kg of $N_2O$/tonne of waste | 0.20 |
| Conversion of $N_2O$ to $CO_2$ equivalents [d] | kg of $CO_2$/kg of $N_2O$ | 298.00 |
| **$N_2O$ based GHG emission** | **kg of $CO_2$-eq/tonne of waste** | **59.27** |
| **Total GHG emissions from MBT process** | **kg of $CO_2$-eq/tonne of waste** | **125.57** |

(References: [a] Phitsanulok Municipality 2011, [b] IPCC 2006. Note: [c] "tonne of waste" referred to MSW received at MBT plant [d] IPCC 2007)

## Total GHG Emissions from the MBT Facility in Phitsanulok

In order to quantify the overall GHG emissions from the MBT process in Phitsanulok Municipality, estimated emissions from each phase were accumulated. It was assumed that the GHG emissions potential from landfilling of compost-like materials is negligible since organic waste was fully degraded during the 9 month period of biological treatment. According to the assessment, life cycle GHG emissions from MBT process in Phitsanulok municipality were found to be 161.14 kg $CO_2$-eq/tonne of waste received at the MBT plant. Transportation, biological treatment and operations contribute at the rate of 16.34%, 5.73% and 77.93% respectively. It should be noted that there are some uncertainties associated with the calculation of the GHG emissions from the biological treatment (waste degradation in piles) since IPCC default values have been used due to the unavailability of plant specific data.

**Comparison to "Business as Usual" Waste Treatment**

If waste management in Phitsanulok was done in a way similar to other municipalities in Thailand, the 78 tonnes waste collected daily would have been disposed of in an open dump or a sanitary landfill (without a gas recovery system). Therefore, open dumping and sanitary landfilling (without gas recovery) practices were considered as base scenarios in order to compare the potential GHG emission reduction as a reward of commencing the existing MBT plant. The IPCC 2006 waste model was used to estimate GHG emission potential from "business as usual" practices.

Methane is the major GHG emitted from open dumps and landfills. Taking into account the waste composition in Phitsanulok and the average condition of the dump sites and landfills in Thailand, the required default values were derived in order to apply the IPCC 2006 waste model for quantifying $CH_4$ emissions. The derived default values for open dumping practice are: Methane Correction Factor (MCF)-0.4 (considered as unmanaged and shallow landfill); Degradable Organic Carbon (DOC)-0.126; Fraction of DOC Dissimilated ($DOC_f$)-0.5; Methane generation rate constant (k)-0.237; and fraction of methane in landfill gases (F)-0.5. $CH_4$ oxidation factor (OX) is considered as zero since there is no landfill cover. In the case of sanitary landfilling (without gas recovery), most of the default values are similar to that of the open dumping practice except MCF and OX. A large number of sanitary landfills exist in Thailand belonging to the category of managed and deep landfills (>5m height). There is a possibility for maximum $CH_4$ production rate under the conditions of such landfills, and therefore Methane Correction Factor (MCF) can be considered as 1. Based on the study by Wangyao et al. (2009), OX factor of $CH_4$ through the landfill cover from a managed and deep landfill in Thailand can be considered as 0.15.

According to the results of IPCC 2006 waste model, $CH_4$ generation potentials from open dumping and sanitary landfilling in Phitsanulok would be 16.87kg and 35.85kg respectively per tonne of waste which corresponds to 422 kg $CO_2$-eq and 896 kg $CO_2$-eq of GHG emissions. It was assumed that GHG emissions from waste transportation would be similar to the existing system in both scenarios (see Table 1). In addition, estimated GHG emissions from operational activities (combustion of fossil fuel to operate the machines) at the sanitary landfill would be 2.74 kg $CO_2$-eq/tonne of waste. Considering all the phases, the estimated life cycle GHG emissions potential from open dumping and sanitary landfilling (without gas recovery) are 448 kg $CO_2$-eq and 925 kg of $CO_2$-eq per tonne of waste.

GHG emissions potential from MBT was compared with that of the "business as usual" scenarios. As shown in Figure 2, currently practicing MBT plant has made a significant influence on GHG emissions reduction compared to the rudimentary practice of bulk collection and mass disposal. For instance, GHG mitigation potential through MBT process is 287kg of $CO_2$-eq and 764 kg $CO_2$-eq per tonne of waste as compared to open dumping and sanitary landfilling respectively. Furthermore, the contribution of the currently practiced MBT process for annual GHG mitigation is 21,758 tonnes of $CO_2$-eq as compared to sanitary landfilling and 8,170 tonnes of $CO_2$-eq as compared to shallow open dumping.

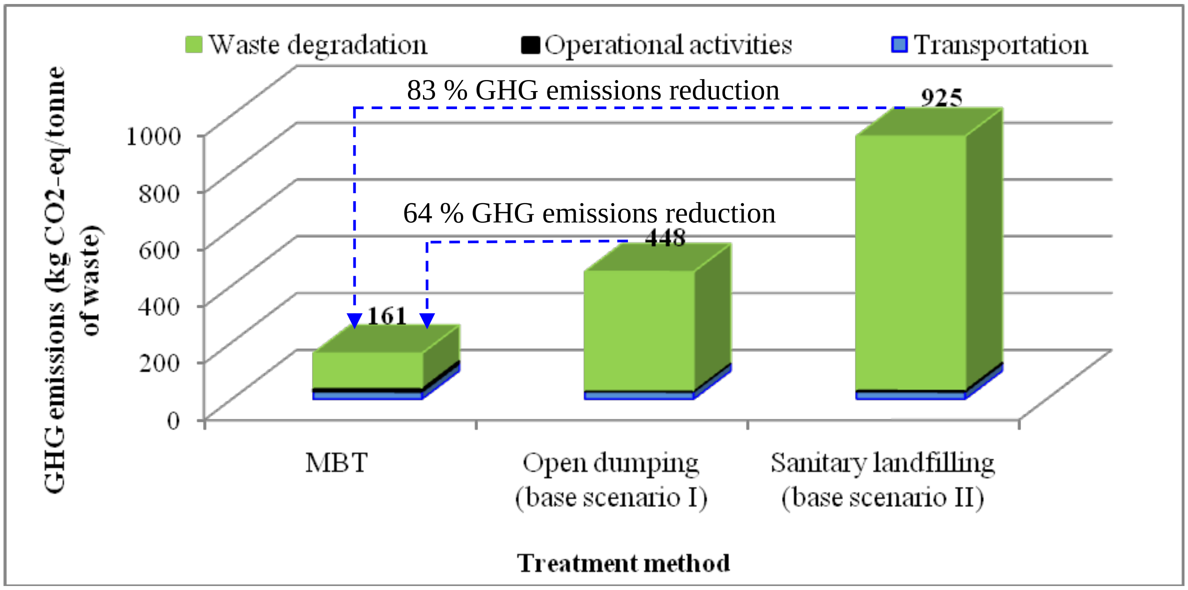


**Figure 2: Comparison of GHG emissions potentials of MBT and two base scenarios**

## CONCLUSIONS

Phitsanulok Municipality has replaced its former rudimentary waste treatment system with an MBT facility. This study demonstrates the GHG mitigation potential of adopting MBT systems. The figures presented show that GHG emissions have been reduced by 64% and 83%, as compared to shallow open dumping and sanitary landfilling (without gas recovery). We conclude that the current waste management model in Phitsanulok has very significant climate benefits and that a widespread adoption of similar systems could contribute substantially to the national GHG mitigation programme and improve the overall sustainability of the waste management sector.

Besides, other benefits of MBT have been identified. In fact, a drastic reduction of the waste volume has been achieved (50% of mass) through applying MBT prior to final disposal. Furthermore, high calorific value components are separated from the treated waste and can be used as fuel. Only a small fraction of compost-like material and inert materials remain to be disposed of. This means reduced need for valuable land and lower costs for the municipality. The study clearly demonstrates the multiple benefits obtainable from MBT, and we expect the findings to be useful for sound decision making on waste management in Thailand and other developing countries in Asia.

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## REFERENCES

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L. et al. (2008): *Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report*. Working Group III (Mitigation). Waste Management & Research: 26: 11–32.

DEDE *(Department of Alternative Energy Development and Efficiency)* (2008): Annual report, Ministry of Energy, Thailand .

IPCC (2006): 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*, *Prepared by the National Greenhouse Gas Inventories Programme.* Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC (2007): *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon S., Qin D., Manning M., Chen Z., Marquis., Averyt K.B., Tignor M. and Miller H.L. (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nithikul, J., Karthikeyan, O.P. and Visvanathan, C. (2010): *Reject management from a Mechanical Biological Treatment plant in Bangkok, Thailand*. Resources Conservation Recycling, 55, 4, pp. 417-422.

PCD (2009): *State of Municipal Solid Waste. The Pollution Control Department*, Thailand. Available in http://infofile.pcd.go.th/mgt/Municipal_191153.pdf?CFID=2232333&CFTOKEN=76854121. Accessed on 3 January 2012.

Phitsanulok municipality (2011): *Personal communication with Officials in the Municipality*, Phitsanulok Municipal Office, Baromtrilokanat Road, Muang District, Phitsanulok 65000, Thailand.

Waldron, C. D., Harnisch, J., Lucon, O., McKibbon, R. S., Saile, S. B., Wagner, F., Walsh, M. P., Maurice, L. Q., Hockstad, L., Hohne, N., Hupe, J., Lee, D. S., et al. (2006): *Mobile Combustion.* Energy, for the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html accessed 03 October 2011.

Wangyao, K., Towprayoon, S., Chiemchaisri, C. and Shabbir H. Gheewala, S.H. (2009): *Application of the IPCC Waste Model to solid waste disposal sites in tropical countries: case study of Thailand.* Environmental Monitoring and Assessment, 164, 1-4, pp. 249-261.