# Management of the Biodegradable Fraction of Municipal Solid Waste with Drying Technology: A Case Study

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**Abstract**

It is imperative to provide an alternative rational management of biodegradable waste. The implementation of sophisticated methods such as drying technology, which achieve treatment, recycling and recovery of urban solid waste has numerous environmental and economic advantages. This study focuses on drying technology for the treatment of the organic fraction of the municipal solid waste (biowaste) so as to homogenize it and to reduce the weight and volume of biowaste, while securing conditions for prolonged storage without decay. Various types of dryers are considered and compared. A techno-economic assessment of the implementation of this technology for the treatment and recycling of biodegradable waste in a municipality is carried out. Within the context of this study, five alternative drying scenaria (implementation of different types of dryers) of biowaste were considered and assessed from a technical and economic point of view. The interpretation of the results suggests that the most preferable scenario is based on using a flash dryer. This scenario has the lowest cost compared to the other four alternative scenaria. Finally, it is demonstrated that the decentralized management of the pre-sorted biowaste leads to lower cost, while being at the same time more environmentally friendly.

**Keywords:** Drying; Thermal Drying; Biodrying; Thermal Drying of Organic Fraction; Municipal Solid Waste; Biowaste; Dryers; Drying Equipment;

## 1. Introduction

The management of municipal solid waste (MSW) is a major issue and poses serious environmental problems in large cities. The quantities of MSW are increasing and authorities are not able to upgrade or scale up the treatment facilities for proper management. On the other hand, the lack of free space restricts significantly the waste management options. Despite increased efforts to prevent, reduce, reuse and recycle waste, the appropriate management of MSW remains a major environmental concern.

Sustainable MSW management has been adopted by many municipalities in different countries. Many of them have implement a variety of approaches, which mainly involve the promotion of recycling and recovery as well. Such a promotion has been utilized for sustainable MSW management (Guereca et al. 2006; Bovea, M.D. and Powell, J.C., 2006; Eriksson, O., et al., 2005 ) and for the reduction of local pressures of MSW management with consideration to broader effects across the society (Koneczny K. and Pennington, D.W., 2007). On the other hand, the increasing pressure for environmental protection and issues such as decreasing landfill capacity, lead to prevention and reuse, recycling and recovery becoming more popular (Buttol et al., 2007). Furthermore, concerns that emissions from landfilling may pose environmental and health risks have led to the need for seeking management solutions other than landfilling of MSW. Moreover according to the EU legislation, Landfill Directive (1999/31/EC) and Waste Framework Directive (2008/98/EC), the European Union member states are required to reduce the amount of MSW disposed to landfills and to recycle organic fractions using more environmentally viable options. This strategy stems from the need to protect the environment through the development of sustainable MSW management systems, based on the "waste hierarchy", reduce, reuse, recycle/compost and recover energy from waste. In addition, a sustainable MSW management system must be environmentally effective (reduction of environmental burdens and emissions to land, air and water, such as $CO_2$, $CH_4$, $SO_x$, $NO_x$, BOD, COD and heavy metals), economically affordable (acceptable operation cost to the community) and socially acceptable (McDougall, 2001). Therefore sustainable MSW management and advanced treatment technologies are required to tackle the environmental problems of MSW management. The best management approach includes recycling and energy recovery from MSW and leads to an environmental friendly solution with a substantial reduction in both the total greenhouse gas emissions and the total amount of waste destined for the landfill.

The biodegradable fraction of MSW has a considerably high heating value and it is possible to convert solid waste to a valuable product, such as alternative fuels within a short period of time. The high water content of MSW, however, reduces the efficiency of energy recovery and the feasibility of mechanical separations for beneficial utilization. The implementation of sophisticated drying technologies can achieves dewatering of MSW (reduction of its water content), with obvious environmental and economic advantages. Furthermore, the drying of MSW achieves the modification of the waste characteristics. In addition the produced dry material is handled easier, and may separated better, while the collected recyclable materials from the dry material are more homogeneous, cleaner, sanitized and with low odor emissions.

This study focuses on drying as a method for treatment the biowaste fraction of the MSW(biodegradable wastes), in order to reduce its weight and volume, while securing conditions for prolonged storage without decay or for using as alternative fuel and/or as fertilizer of high quality. Five types of dryers, namely rotary drum dryer, flash dryer, belt dryer, fluidized bed dryer and rolling bed dryer are compared. The selected types are state-of-the-art and the ones most commonly used in modern waste management systems. Consequently, five alternative drying scenaria (in each, a different type of dryer is considered) of biowaste generated in a municipality of 100.000 residences were considered and assessed from a technical and economic point of view. Each of these alternatives includes the recycling of the recyclable MSW at the source, the collection of biowaste in specific bins, the gathering from bins, the transportation of biowaste by trucks to the process (location inside the municipality) and the drying of biowaste. The dried biowaste becomes then a valuable biomass product (Food Residue Biomass). It can be transported to suitable storage or utilization locations. To identify the best option a spreadsheet model was constructed in order to design the five alternative scenaria considering the quality characteristics and the stoichiometry of MSW. The spreadsheet model has the capability to estimate the quantity of the raw materials, fuels and energy and to evaluate the cost of alternative scenaria.

## 2. Goal and Scope Definition

The goal of this study is the comparison of five alternative drying scenaria for the management of biowaste generated in a municipality of 100.000 residents from a technical and economic perspective. The average amount of MSW generation is about 96 tons per day or 35.000 tons annually (about 300-450kg/inhabitant/year). From the total generated MSW, the annual amount of biodegradable wastes (biowaste) is about 16,800 tons or 46 tons per day. According to the design, each of the alternatives includes recycling of the recyclable MSW at the source, disposal of biowaste in specific bins, collection from bins, transportation of biowaste by trucks to the drying facility (location inside the municipality). .

## 3. Materials and Methods

3.1 Drying methodology

Generated from urban activities, MSW is usually heterogeneous, with varying composition of all components and high water content. Waste to energy (WTE) technologies reduce the volume of waste by as much as 90% and lead to recovery of energy (Wang L., et al., 2009; Kathiravale S., et al., 2003). The production of energy in waste to energy conversion processes depends on the density, the composition and the relative percentage of moisture of the waste (Fobil J.N., et al., 2005). The percentage of moisture is the ratio of the weight of the water contained in the waste to the total weight of the wet waste. Pretreatment processes such as drying can significantly change the physical and chemical properties of waste, including the percentage of moisture. For instance the drying process can reduce the moisture content of MSW from 70 % to 30 %.

Drying processes can be categorised according to the physical conditions used to add heat and to remove water vapor. In order to solve problems of waste management, technologies of drying such as biodrying and thermal drying have become of interest.

Biodrying is an aerobic evaporation process which reduces the moisture content of the waste, with minimum aerobic degradation (Asha P.T., et al., 2016). It is a suitable method to treat very humid waste, which would release high quantity of leachate (Zhang D.Q., et al., 2008) and it aims at removing water from biowaste with high water content using the heat generated during the aerobic degradation of organic substances, in addition to forced aeration. During the process, degradation of the biowaste takes place and a heat is generated by the microbial action on the waste material (Velis C., et al., 2009). Biodrying increases the energy content of waste by removal of moisture (Adani et al., 2002), while increasing the calorific value of the waste by about 20% (Elnaas A., et al., 2015; Asha P.T., et al., 2016). The product of the biodrying process is a renewable fuel (Adani et al., 2002; Calcaterra E., et al., 2000; Rada, E.C., et al., 2005; Sugni M., et al., 2005; Mohn, J., et al., 2008; Staber, W., et al., 2008; Tambone, F., 2011).

In a thermal drying process, the temperature is raised so that the water contained in them is driven off as a vapor. By removing most of the water from the biowaste, thermal drying accomplishes a significant reduction in both volume (it provides up to 80% volume reduction) and mass of wastes and it leads to a significant reduction of transportation and handling cost of the dried product. Furthermore it increases the calorific value of the dried product and makes it efficient for thermal use, while the odors arising from the process can be contained and controlled.

Thermal drying systems may produce a variety of forms of dry material, including fine dust, flakes, small pellets, or larger fragments, depending on the type of drying system used and the characteristics of biosolids processed. The product of the drying process (dried product) has a dry solids content of approximately 90% to 96% (or 10% to 4% water content) and it can be used as alternative fuel in the production process of industrial sectors such as cement, steel, aluminum and power plants. The dried product can be used as a fertilizer, fertilizer supplement or soil conditioner as well. Furthermore due to its characteristics (nutrient content, less noticeable odor, size and shape of material), it may have a positive commercial value.

There is a variety of thermal drying systems which are suitable for the drying of biowaste. Many types of thermal dryers are available, providing several options for biowaste pretreatment. The classification of drying systems is based on the way the thermal energy is transferred to the biowaste during the process. Classification of thermal drying systems is made depending on the heat transfer method at play (conduction or convection) and on whether there is direct contact of the drying medium with the material to be dried.

In the direct heating process, the combustion gases are transferred directly to the dryer and become part of the heating medium. Examples of direct drying equipment are the rotary drum, flash and belt dryers. For instance, in the rotary drum type, a combustion chamber precedes the drying chamber and the hot combustion gases are mixed with the biosolids products. Both rotary drum and belt dryers use the direct heating process. On the other hand in the indirect heating process, the heating medium is heated in a heat exchanger or boiler and the combustion gases are vented separately. Examples of indirect drying equipment are vertical tray dryers, horizontal vessel (paddle, disc or auger) dryers, and an indirect-type of fluidized bed dryer.

## 3.2. Dryers

Dryers can be classified as batch, where the material is inserted into the drying equipment and drying proceeds for a given period of time, or as continuous, for which the material is continuously added to the dryer and the dried material is continuously removed. For the purpose of the study thermal drying with hot air dryers is chosen. Drying systems comprise of a dryer (drying equipment), materials handling and storage equipment, heat generation and transfer equipment, air movement and distribution equipment, air pollution control equipment and ancillary systems.

The selected drying systems include systems for treatment of the air emissions (exhaust vapor and gas) such as cyclones, biofilters and regenerative thermal oxidizer (RTO) emission control systems. It should be noted that most commercial dryers are insulated to reduce heat losses and recirculate hot air to save energy.

Under the study, five different types of dryers for drying of biowaste are examined. In particular, the five main choices for drying biowaste are rotary drum dryer, flash dryer, belt dryer, fluidized bed dryer and rolling bed dryer.

3.3. Alternative Scenaria

The system (Figure 1) is defined as an integrated drying system for the management of 96 tons per day or 35.000 tons per year of MSW. It consists of recycling of the recyclable MSW at the source (household), the disposal of biowaste in bins, the collection from bins, the transportation of biowaste by trucks to the process location (location inside the municipality) and the drying of biowaste. Five different types of dryers are implemented during the drying process. According to the composition of the generated MSW in the municipality, it is estimated that the amount of biowaste is 46 tons per day. The moisture weight of this amount of biowaste is about 32 tons.

The system commences at the point where the generated MSW enters, and ends at the point where dried product exits. It also includes the required fuels and energy and materials for the operation phase.

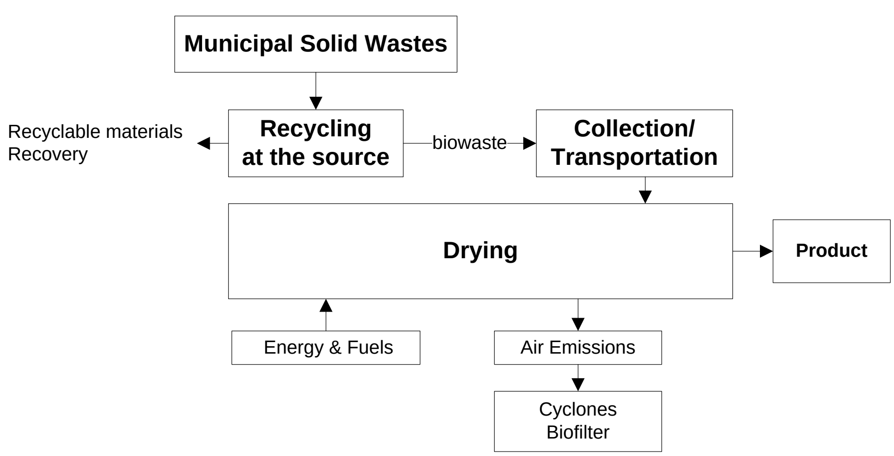


**FIGURE 1 - Schematic Flowchart of System**

The term “generated MSW” includes residential (household) and commercial solid wastes such as food waste, paper, cardboard, plastic, textiles, rubber, leather, wood and yard waste, glass, tin cans, aluminum, ferrous metals, other metals etc. Based on the data of MSW in the Attica region of Greece and the generated MSW consists of 48% organic waste, 15.7% paper and cardboard, 8.5% textiles, 8.1% metals, 2.8% glass, 2.0% plastics, 7.7% inorganic waste and 7.2% other wastes (rubber, leather, wood etc).

As the integrated management of MSW system is complex, several assumptions are required for a proper comparison between the alternative scenaria. Furthermore, all considered alternative scenaria should meet the current nationally (Greek) posed legislation limits regarding waste handling and air emissions (European Commission, BREF, 2006). According to the design, the developed alternative scenaria are able to minimize the amount of waste for landfilling, while maximizing material and energy recovery. Thus it is assumed that 100% of the given municipality's population recycles their domestic waste. Out of the total amount of waste produced in each household, the estimated recycled amount is 18,200 tons per year approximately. The source-separated recyclable materials are collected separately from the other waste.

The collection type is assumed to be a curb collection and includes the disposal of MSW in stainless steel bins with a capacity of 1.3 $m^3$ per bin and the collection of MSW from various locations in the municipality. The collection of the biowaste takes part four days per week and the distance from the collection point (locations of bins) to the treatment location is about 15km. Furthermore, nine (9) closed-body vehicles with a load capacity of 28 tons are also considered part of the collection system. Taking into consideration the fuels consumption for trucks involved in urban waste transport, it is estimated that the collection and gathering cost is about 5 €/km.

In addition, the consumption of energy (electricity consumed during the operation phase) and fuels (natural gas and oil) during the operation phase is taken into account. The annual wage of the staff (employee cost), about twelve (12) working persons, the services (fixed cost), the cost of wear parts, the maintenance cost of the equipment and the insurance of the drying system are estimated in the operation phase.

For all alternative scenaria the construction phase including the budget of raw materials, drying equipment (purchase price) and construction of facilities is taken into account. The production of vehicles is excluded, because the contribution of this activity is normally small, compared to contributions from the operation and construction phases. The exclusion of the production of vehicles does not limit the value of the approach, as this parameter is assumed to be considered equal in all scenaria.

Regarding the scope of the assessment, five alternative scenaria for the drying of 46 tons MSW per day (17,500 tons per year) were investigated. Each scenario presents an integrated solid waste management system. The five scenaria are similar but a different dryer system for the drying process is implemented in each scenario. Specifically:

- Scenario 1: A rotary drum dryer operates during the drying process.
- Scenario 2: A flash dryer operates during the drying process.
- Scenario 3: A belt dryer operates during the drying process.
- Scenario 4: A fluidized bed dryer operates during the drying process.
- Scenario 5: A rolling bed dryer operates during the drying process.

## 4. Results

According to the results of the five alternative scenaria, the capital cost of the drying system (basic equipment and auxiliary equipment) and the cost of the construction of the basic facilities are higher in scenaria 4 and 5. The cost of the construction phase and the annual operation phase are presented in Figures 2 and 3 respectively.

According to the figures for both the construction and operation phases, scenario 2, where a flash dryer is implemented for the drying process, is the most cost effective, while scenario 4, where a fluidized bed dryer is implemented, is the most expensive.

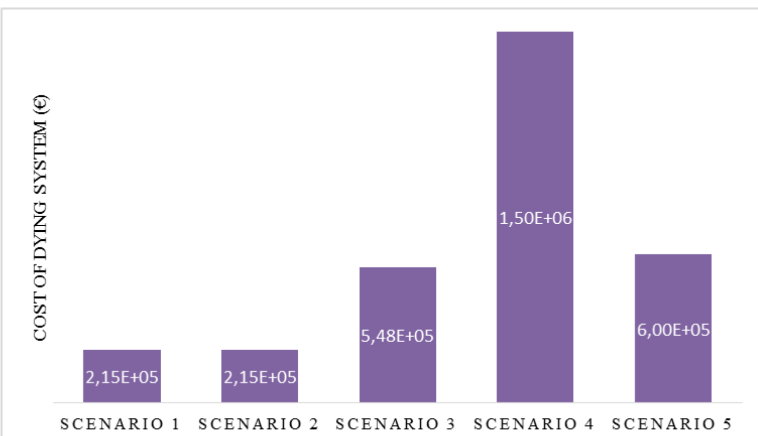


**FIGURE 2 – Construction cost of alternative scenaria**

The operation cost depends largely on the way the drying systems are operated, the technical characteristics of the equipment such as the capacity, the flow rate and the daily operation hours and the consumption of energy during the operation phase. Proper maintenance also plays a vital role in the operation cost. In particular, according to the technical data of the equipment, the flow rate for the rolling bed dryer (scenario 5) is 2.4 t/h, while the flow rate for the flash dryer (scenario 2), belt dryer (scenario 3) and fluidized bed dryer (scenario 4) is 7.5 t/h.

Similarly the retention time for the process of the flash dryer (scenario 2) is 0.33 min, which is short, compared to retention time for the process of the rolling bed dryer (scenario 5) which is 35 min.

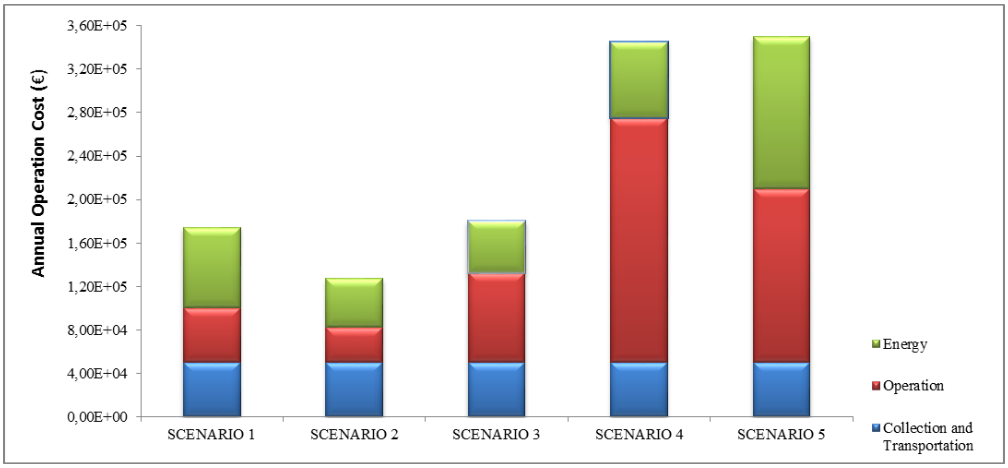


**FIGURE 3 – Annual operation cost of alternative scenaria**

The production rate is about 4.1 t/h in scenario 2 (implementation of flash dryer) and 2.3 t/h, 3.83t/h, 3.82t/h and 1.5 t/h in scenaria 1 (implementation of rotary dryer), 3 (implementation of belt dryer) 4 (implementation of fluidized bed dryer) and 5 (implementation of rolling bed dryer) respectively.

Another important factor during the operation phase is the consumption of energy (electric power and heating energy). The demands during the operation phase for energy are about 910 kWh/tevap, 856 kWh/tevap, 1,280 kWh/tevap, 1,630 kWh/tevap and 1,382 kWh/tevap in scenaria 1, 2, 3, 4 and 5 respectively.

The percent of moisture in the product plays an important role in the choice of the drying process. For instance, the percent of moisture in the product of drying is 10-12% according to the process in scenaria 1, 2, 3 and 4, while in scenaria 5 the percent of moisture in the product is 20%. This means that the dried product is unsuitable for prolonged storage and may be inappropriate as alternative fuel.

The evaporation rate is 4.1t/h in scenario 2, compared to evaporation rates of 2.3t/h, 3.83 t/h, 3.82 t/h and 1.5 t/h for scenaria 1, 3, 4 and 5 respectively.

The air emission, during the operation phase of the rotary drum dryer (scenario 1) and the rolling bed dryer (scenario 5), has a high concentration of dust and volatile organic compounds (VOCs). Moreover, it should be noted that the space demanded for construction of scenaria 1, 4 and 5 is extensive. What is more, the fire hazard in scenario 1 is appreciable.

Comparing the results of all the assessed scenaria, it turns out that scenario 2 (implementation of flash dryer) is more cost effective than the others. Moreover, the lower consumption of energy during the operation phase results in the impacts on the environment being less than in the other scenaria.

## 5 Conclusion

A methodology for the evaluation of different management scenaria of municipal solid waste generated in a municipality of 100.000 inhabitants, taking into account a techno-economic assessment, was developed. Five integrated alternative scenaria of drying were considered. A spreadsheet model was developed and used to estimate the design inventory data from both the construction and the operation phases of all alternative scenaria.

The interpretation of the results leads to the conclusion that the most economicprospect is scenario 2, which is based on the drying process of biowastes by flash dryer.

The local treatment of biowastes achieves a reasonable management at a low cost and leads simultaneously to the reduction of the potential impacts on the environment from transportation and treatment of MSW. Furthermore, the dying process of biowaste at a location within the municipality reduces the transportation cost and the total cost of their treatment. In addition, it leads to the production of a product of lower volume with low concentration of moisture, which can be converted to a fertilizer or an alternative fuel due to its high calorific value. The dried product can be stored for a prolonged period without any significant change in its composition. Finally, scenario 2 (use of a flash dryer) is more environmentally friendly as it leaves a limited environmental footprint. This scenario offers a valuable aspect for treatment of biowaste within the municipality and at the same time converts a waste to a valuable biomass product.

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