Converting Organic Waste To Energy

Biological Dryers vs. Anaerobic Digestion

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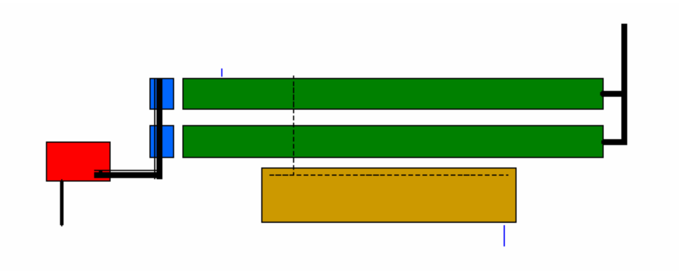
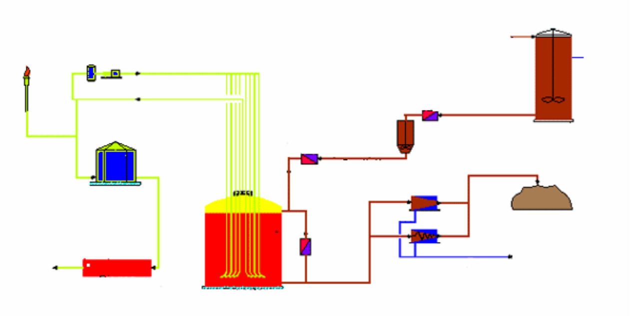


Biological Dryer



Anaerobic Digestion

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White Paper

Background

Mention converting organic waste or biomass resources such as manures, yard, kitchen or food waste, sewage sludge (biosolids), paper mill sludge, brewery waste, animal renderings and so on to renewable energy and the first thing that normally pops into people's mind is "anaerobic digestion" (AD for short).

AD is a well known process that has been around for some time whereby the above organic wastes are converted to a methane gas for heat, steam or power based energy applications.

However, is AD always the most cost effective and efficient way of converting this organic material or biomass resources into renewable energy and what about the various by-products (especially the digestate) of the AD process?

The public, government, utilities and the engineering community are starting to ask these questions and in the process are discovering that in many cases there is indeed a better way of converting organic material into renewable energy.

For example, a Biological Dryer (BD) utilizes the "biological oxidation" process to effectively dry these wet organic materials to create a higher value solid biomass fuel (13000-17000 kJ/kg) instead of producing a methane gas. This biomass fuel can then be used in such conventional energy conversion processes as direct combustion, gasification, cofiring, calcination (cement kilns) and gas turbine steam injection applications.

Therefore, this White Paper looks at the engineering fundamentals of these two technologies (BD vs. AD) and then compares their performance in terms of typical energy conversion efficiency, power output and the by-products of the processes themselves.

This report should then help the reader make a more informed and educated decision on what technology best suits their particular application.

Anaerobic Digestion (AD)

Let's start with the technology that most people are somewhat familiar with. Anaerobic Digestion (AD) is the biological breakdown of organic materials in the absence of oxygen.

The process is carried out by anaerobic micro-organisms that convert carbon-containing compounds to methane ($CH4$) and carbon dioxide ($CO2$), with a partially stabilized organic material (digestate) as a byproduct. The AD process is relatively slow, complex and produces other less known byproducts such as ammonia, acids, hydrogen sulphide, mercaptans and odors as well.

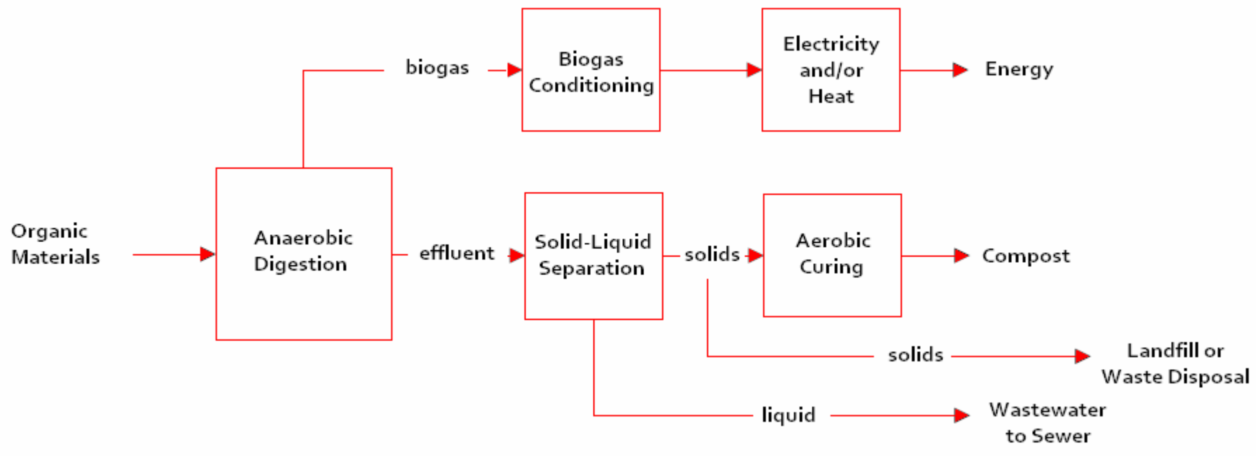
Anaerobic Digestion can be represented by the following generalized chemical reaction:

$$(C_6H_{10}O_4)_x + 1.5H_2O = (C_6H_{10}O_4)_{x-1} + 3.25CH_4 + 2.75CO_2 \quad \textbf{(Endothermic)}$$

Organic material Water Digestate Methane Carbon Dioxide (Requires Heat)

In most cases, the AD process is an endothermic reaction and therefore requires heat (energy) in order for the AD process to occur in a controlled environment. Figure 1 shows a simplified Anaerobic Digestion Process.

Figure 1: Simplified Anaerobic Digestion (AD) Process



The methane and carbon dioxide gases (biogas) can be used to provide fuel or energy but first must be conditioned (compressed, dehumidified, scrubbed, etc) due to contaminants (hydrogen sulphide, chlorine, fluorine, etc), moisture and pressure conditions and to prevent system corrosion.

Although the basic biological process is the same, there are different technologies for achieving the conversion of organic carbon to methane by providing environments which are favourable to different populations of micro-organisms. They can be grouped into general categories according to three variables: process temperature, moisture content of the material being digested, and the number of stages in the process.

The main temperature categories are thermophilic and mesophilic digestion. The moisture categories are wet (low solids) and dry (high solids) digestion. The number-of-step categories consist of single-stage and dual-stage digestion.

For this White Paper, we will look at a typical dry thermophilic single stage digestion system that processes 100,000 tonnes/yr of source separated organics (SSO). The selection of thermophilic digestion is based on maximizing the gas production from the feedstock, as thermophilic digestion generally has a higher gas yield than mesophilic digestion.

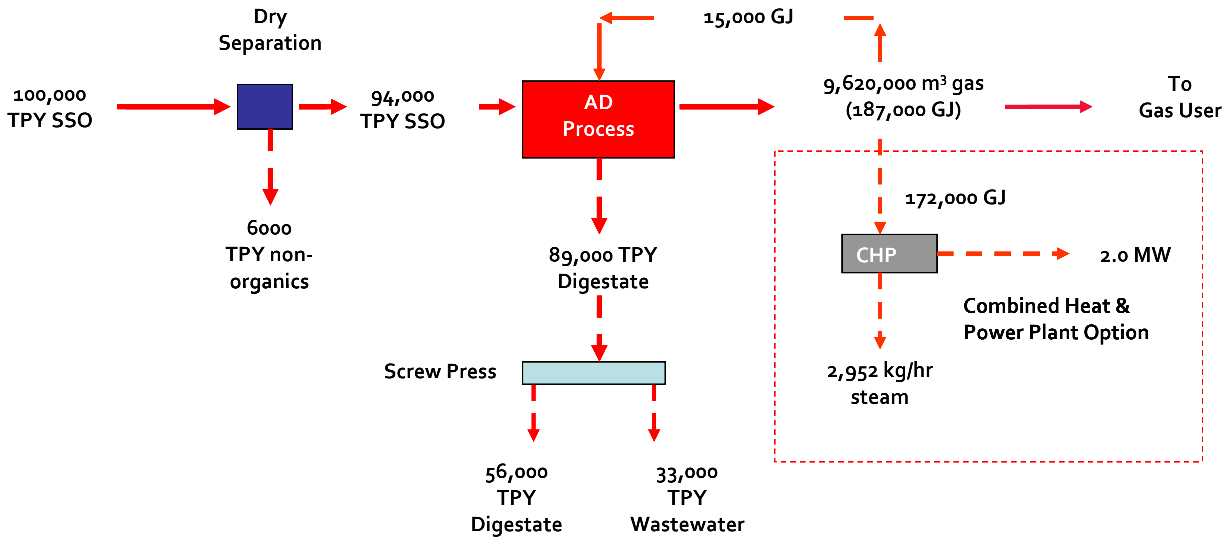
The selection of dry digestion is based on the fact that SSO is a fairly clean feedstock (only 6000 tonnes per year of non-organics such as plastics, glass, etc) for which extensive front-end processing is not necessary, and dry digestion uses less operationally complex front-end processing than wet digestion.

The selection of single-stage digestion is also based on the prevalence of successful single-stage systems (90% of digestion capacity in Europe is single-stage, while only 10% is dual-stage), and the fact that the increased complexity and expense of two digestion systems has not proven to have a corresponding payoff in gas production or end-product quality for two stage systems currently operating.

Figure 2 shows a typical mass-energy balance for a dry thermophilic single stage digestion process.

In addition to the amount of energy (biogas or electricity) produced from this AD process it is just as equally important for the reader to understand just how much digestate byproduct is also produced in the process.

Figure 2: Typical Anaerobic Digestion Mass – Energy Balance



In the above example, the 100000 tpy of SSO is converted to about 9.6 million m^3 of biogas (187,000 GJ). The remaining 8.8 million m^3 of biogas (172000 GJ) that is not used to heat the AD process itself can either be piped to a local natural gas host (steam plant, etc) or used onsite to produce electricity (2000 kW gross) and steam (2952 kg/hr) from a gas reciprocating engine.

However, in addition to the above valuable renewable energy products, the AD process also produces 89000 tonnes/yr of a digestate byproduct that must dewatered, composted or landfilled and the wastewater treated at a WWTP plant.

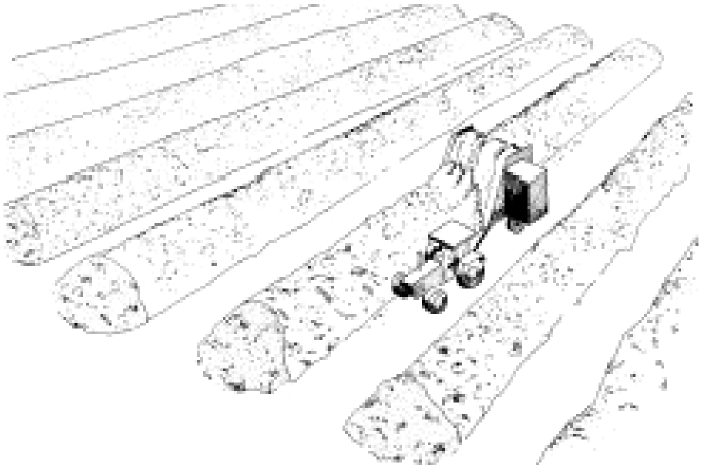
It is the cost and additional processing of this digestate and wastewater that is often overlooked when evaluating the true economics of AD systems. In addition, a lot of potential energy (kJ) is lost in the organic fraction of the digestate and wastewater (BOD).

For example, even though the digestate is still fairly wet (65% MC) after dewatering it also contains a high organic content.

The typical post treatment for the digestate is to produce compost after blending this AD byproduct with a bulking agent such as wood chips and then curing the material for 2-4 months in a windrow (Figure 3).

The composting process is usually carried out at an offsite location either by the client or a third party. In any event, there is the transportation cost and the capital, land and operating costs of the composting process that must be factored into the economic equation.

Figure 3: Typical Windrowing Process for AD Digestate



Finally, odor control and marketability of the compost product are also important issues to consider. Many composting facilities have been forced to shut down due to either odor problems or when there is no long term market for the product.

If the composting post-treatment process becomes too expensive or closes down then the client may be forced to find other more costly digestate management solutions such as landfill (pay tipping fees).

Currently here in Ontario, the cost for a third party to compost the digestate is about $60-$100/tonne.

Based on 56000 tpy of digestate from the above AD process, this equates to \$3.4 - \$5.6 million per year in digestate management costs that must be factored into the AD economic model. In running their economic models, many clients often overlook this cost aspect of the project or have been convinced by the technology provider that it is not an issue.

It should also be noted that most of the AD technology (mesophilic and thermophilic) vendors do not claim to meet the EPA's rule for pathogen reduction during the digestion process, and all depend on the post-digestion curing of the material, during which temperatures rise above 55°C for an extended period of time, to guarantee pathogen kill.

This is a very important issue that is often overlooked in the evaluation of this technology and is extremely important when dealing with such feedstocks as biosolids and paper mill sludge.

Biological Dryers (BD)

Now let's look at another technology for converting organic materials to renewable energy based on the "Biological Oxidation" process.

In the presence of an adequate supply of oxygen, moisture, and aerobic bacteria, the hydrocarbons contained in organic wastes undergo partial oxidation to smaller molecules. This results in the destruction of odour- forming compounds and the formation of carbon dioxide, water vapor and organic material (biomass).

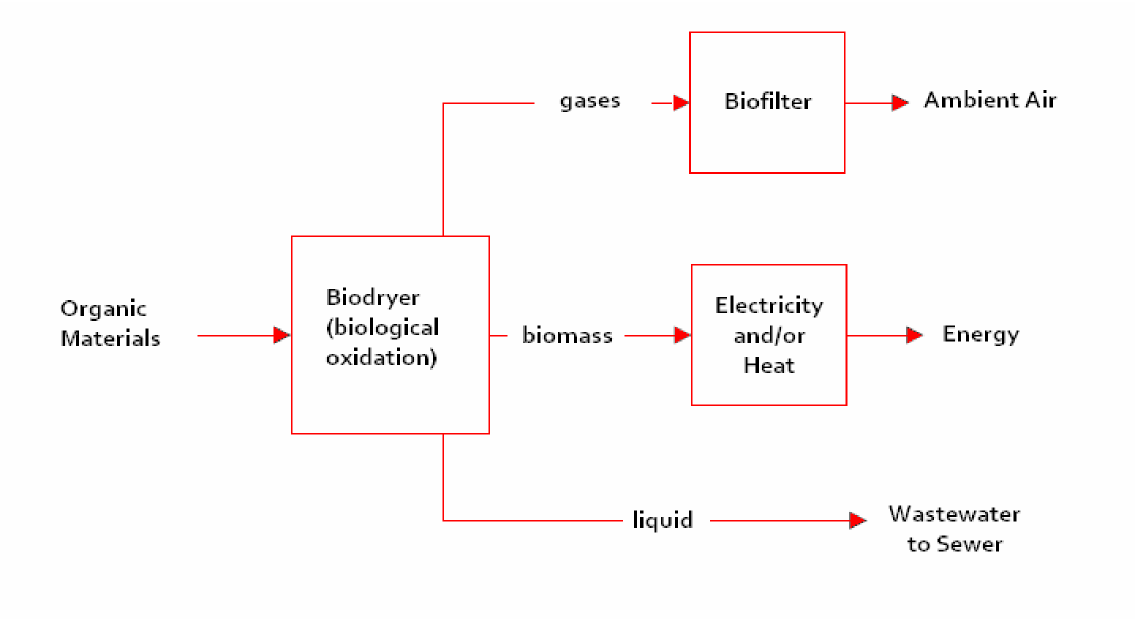
By representing organic wastes by the simplified chemical formula presented earlier, the aerobic bioconversion reaction can be expressed as follows:

$$\mathbf{(C_6H_{10}O_4)_x \quad + \quad 6.5O_2 \quad = \quad (C_6H_{10}O_4)_{x-1} \ + \ 6CO_2 \quad + \quad 5H_2O \quad (Exothermic)}$$

Organic Waste Oxygen Biomass Carbon Dioxide Water (Produces Heat)

In contrast to anaerobic bioconversion, this reaction is strongly exothermic (17500 kJ/mol) and therefore a Biological Drying (BD) process could utilize this "free" heat to help dry the wet biomass or organic waste (Figure 4).

Figure 4: Simplified Biological Drying (BD) Process



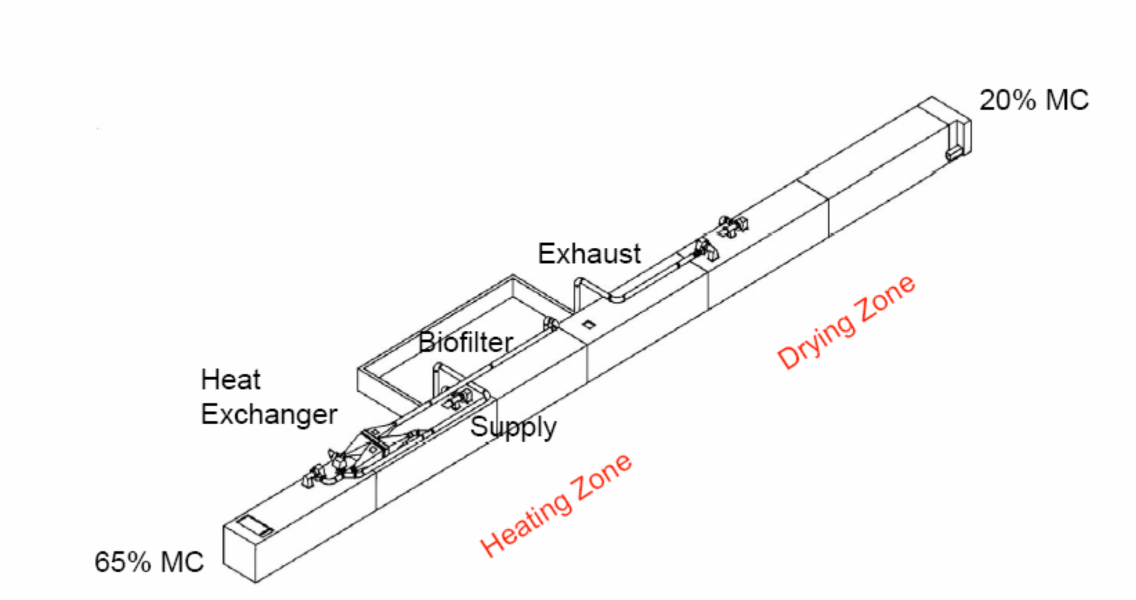
Wright Tech Systems Inc has patented such a biological drying process under the trademark name Biodryer®. The Biodryer® is a double-walled insulated tunnel (stainless steel interior, pre-engineered building siding exterior) with an integral heat recovery system and computer processor to control the heat produced when the organic material decomposes. With this accelerated aerobic drying process, moisture, temperature, oxygen, carbon to nitrogen (C:N) ratios and porosity are controlled within ideal ranges for maximum microbial and drying activity.

The Biodryer® (Figure 5) is divided into two distinct zones (Heat, Drying), which are separated by spinners. The Heating Zone is where the biological oxidation and resulting exothermic reaction takes place.

In the Heating Zone, typical biomass temperatures will increase from 55°C after 24 hours to 80°C after 7 days.

In addition, the moisture content of the biomass will decrease from about 65% to 40%. At 40% MC, the biological oxidation process drastically slows down as moisture is necessary to support the metabolic processes of the microbes.

Figure 5: Biodryer Process for Drying Wet Biomass or Organic Waste



A heat recovery system captures the heat produced in the Heating Zone and transfers this heat into the air stream of the Drying Zone for improved drying performance.

The biomass moisture content is reduced from 40% to about 20% (or setpoint condition) during the next 7 days in the Drying Zone to meet the client's specific biofuel requirements. Due to the low moisture levels in the Drying Zone, the biological oxidation process has practically stopped.

The biomass material is further aerated by mechanical means (spinners) before entering the Drying Zone to ensure that there are no anaerobic pockets in the biomass and more uniform drying is provided.

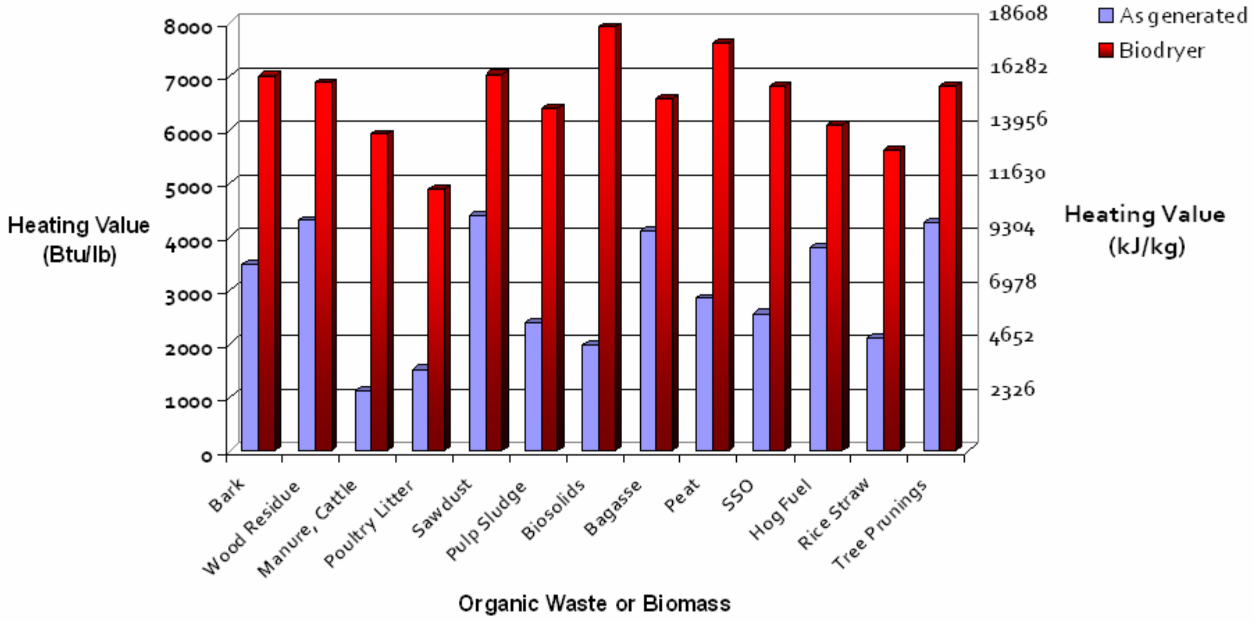
Therefore, the Biodryer® is able to precisely control temperatures and moisture levels within the biomass while limiting the biological oxidation process to only 7 days.

This unique design results in minimal carbon loss (CO_2) and ash production, which translates into improved biofuel quality and calorific value.

Much of the organic waste or biomass that is produced today is a wet material (40%-80% moisture content). Therefore, this material has low calorific value (kJ/kg, Btu/lb), is costly to transport (due to weight of water) and reduces the efficiency of the energy conversion process in which it is used.

Figure 6 shows the heating value of various organic wastes and biomass resources as they are typically generated and after being biologically dried to 20% moisture content (%MC).

Figure 6: Affect of moisture content on heating values of organic waste and biomass

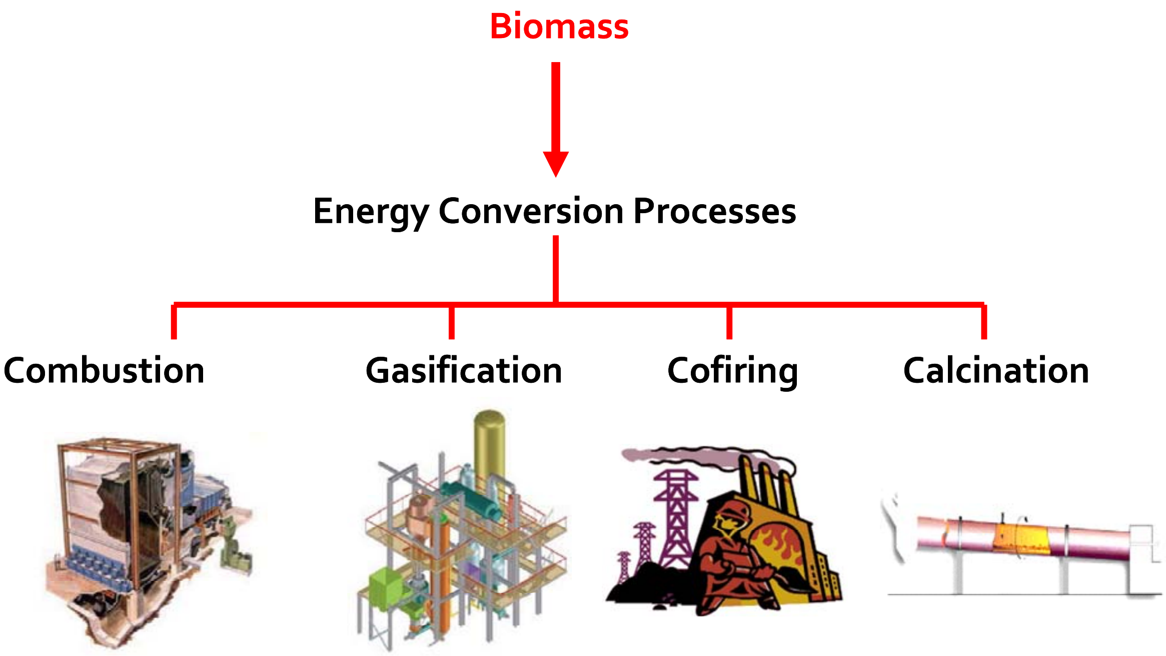


For example, sewage sludge or biosolids typically contains about 80% moisture and therefore has a heating value of around 4605 kJ/kg (1980 Btu/lb). In comparison, drying the biosolids to 20% MC would increase the heating value of the biosolids to 18421 kJ/kg (7920 Btu/lb).

Biomass can effectively be used to replace fossil fuels for most applications (direct combustion, gasification, cofiring and calcination) if a suitable feedstock can be found at reasonable cost.

The critical issues for most industrial requirements are the cost of fuel, quality of heat needed to perform the process task and the state (solid, liquid or gas) of the biomass fuel (Figure 7).

Figure 7: Biomass To Energy Processes



If biomass can be produced from organic waste feedstock that would otherwise go to landfill, then the tipping fees ($30-$100/tonne) generated from processing this waste into a fuel can help to keep the cost of the biomass end product competitive to traditional fossil fuels.

Biomass at 50-percent moisture typically has an adiabatic flame temperature of about 1350–1400°C compared with about 1950°C for natural gas and over 2000°C for fuel oil. Under these conditions, biomass may have difficulty in completely replacing fossil fuel use.

However, if dried to 20-percent moisture, biomass has an adiabatic flame temperature of approximately 1830°C, making it suitable for a wider range of applications.

High moisture content of the biomass also affects boiler efficiency and power plant heat rates as much of the energy contained in the dry fraction is simply used to evaporate (970 Btu/lb, 2257 kJ/kg) the water present in the fuel and provides no useful work in the energy conversion process.

The Biodryer® can dry high moisture content organic waste streams like those found in pulp or fibre sludge, MSW, Source Separated Organics (SSO), manures, bagasse, peat or biosolids to 80% solids (i.e. 20% MC) or better, without the combustion of fossil fuels and at a fraction of the energy and O&M costs associated with conventional thermal dryers (rotary, flash, steam).

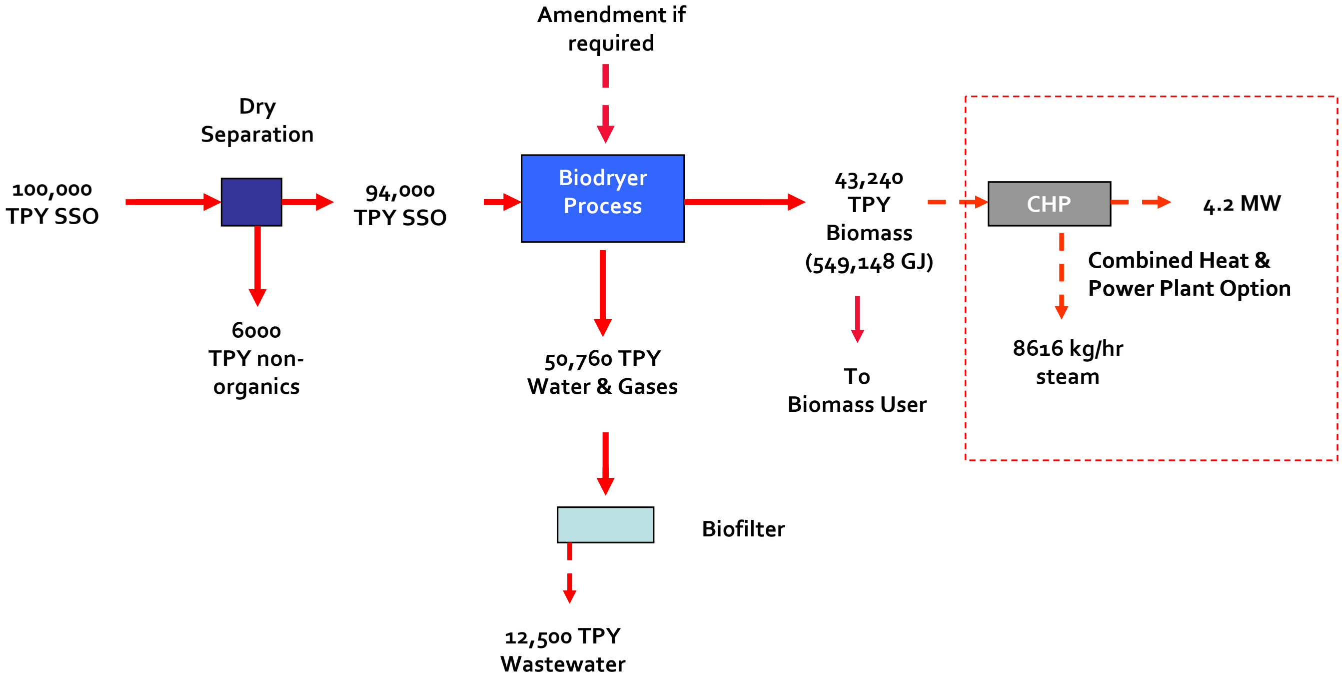

Biodryer Tunnels


Heat Exchanger


Unloading Trays

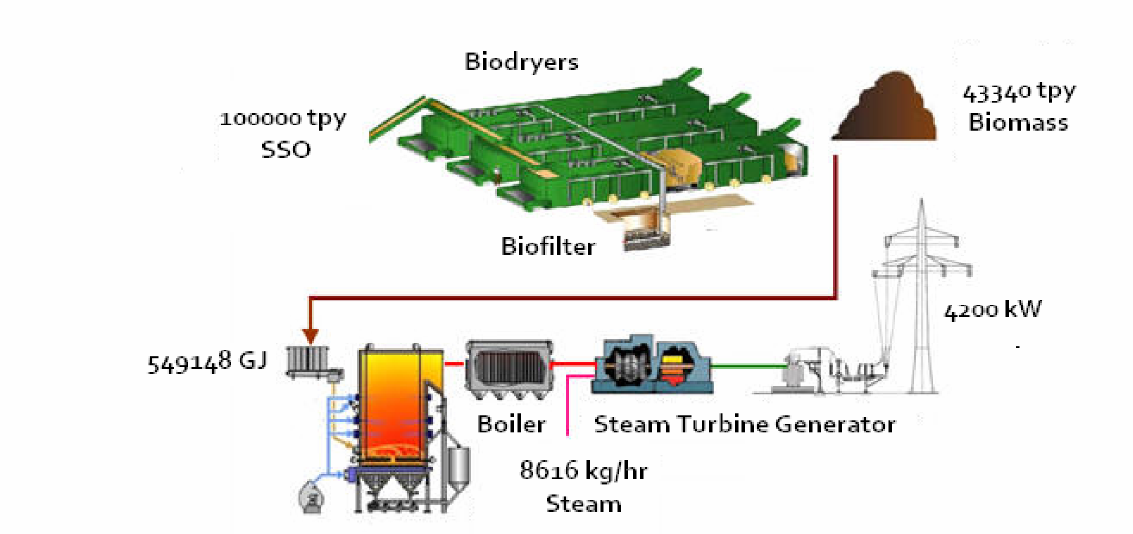
Now let's look at a typical mass-energy balance for a Biodryer® plant that processes 100000 tonnes/yr of SSO into biomass fuel, steam or power (Figure 8) using the biological oxidation process.

Figure 8: Typical Biological Dryer (BD) Mass – Energy Balance



In this example, the 100000 tpy of SSO is converted to about 43240 tonnes of biomass fuel (549148 GJ) in the Biodryer® process. The biomass fuel can then be sold to the local energy market (biomass steam or power plants, coal plants, cement kilns, district heating systems, greenhouses, etc) or converted to power (4200 kW gross) and steam (8616 kg/hr) on site (Figure 9) in a standard Biomass Power Plant (Rankine Cycle).

Figure 9: Biodryer Processing and Biomass Power Plant



In this case, water vapour and any off-gases (ammonia, VOC's, CO2, etc) produced during the biological drying process are effectively managed in the biofilter and the only byproduct left to deal with is the small amount of wastewater.

Therefore, there is no additional processing or windrowing requirements or costs that must be factored into the financial model. In addition, the loss of organic matter has been minimized to increase the energy production capability.

Finally, with BD the client does not have to rely on a third party to further process any of their byproducts (as was the case with digestate from the AD process) which translates into a more sustainable and predictable business model than AD.

Additional information on Wright Tech's patented Biodryer technology can be found on their website at: www.wrighttech.ca

BD vs. AD Energy Performance

Based on processing 100000 tpy of SSO into various forms of energy (biomass, biogas, power and steam), let's now compare the performance of the BD and AD facilities in regards to typical energy production and the related organic processing capital and operating costs.

Table 1 compares the annualized energy equivalency (GJ_e) for the biomass fuel produced by the BD process compared to the biogas production from the AD process. Due to the nature of the BD process itself and the fact that more volatile solids and organic matter are preserved during the conversion process (organic waste to energy), the biomass fuel contains over 3 times as much energy as the biogas.

Table 1: Energy Production Comparison

Technology	Biological Dryer (BD)	Anaerobic Digestion (AD)
1. Selling Fuel Option:	-	-
Fuel Type	Biomass	Biogas
Fuel Production	43340 tonnes/yr	8.8 million m^3
Fuel Output (GJ_e)	549148	172000
Value of Fuel	$1.92 million[1]	$1.03 million[2]
2. Selling Power & Steam Option	-	-
Power (kW gross)	4200[3]	2000[4]
Power Value	$2.35 million[5]	$1.26 million[6]
Steam (kg/hr)	8616[3]	2952[4]
Steam Value	$483,000[7]	$186,000[7]

Assumptions:

1. Biomass having a market value of $3.50/GJ
2. Biogas having a market value of $6.00/GJ
3. A typical biomass CHP power plant operating at a 15000 kJ/kWh heat rate
4. A typical biogas engine CHP power plant operating at a 9800 kJ/kWh heat rate
5. Biomass CHP plant operating at 80% service factor and $0.08/kWh
6. Biogas CHP plant operating at 90% service factor and $0.08/kWh
7. CHP plants can both sell steam to local host at $8.00/tonne

Depending on local market conditions, the value of the biomass fuel will be considerably higher than the value of the biogas. In the above analysis, even with biomass selling for only $3.50/GJ versus $6.00/GJ for biogas, the biomass fuel still creates a greater revenue stream for the client.

Instead of selling the various fuels to the local energy markets (Option 1), the other option (Option 2) available to the client is to use the fuels themselves and produce power (renewable energy, Standard Offer Contract, etc) for the grid and steam to a local steam host (paper mill, district heating, food processing plant, etc).

Therefore, in the above BD example, we have assumed that the biomass fuel will be converted into power in a typical direct fired biomass Combined Heat and Power (CHP) plant operating in a standard Rankine cycle fashion (15000 kJ/kWh).

Unfortunately, most conventional biomass power plants are a relatively inefficient process for converting stored chemical energy into electrical energy (kJ/kWh). For example, we have seen from the above AD analysis that a gas engine is a much more efficient way of converting the biogas into power (9800 kJ/kWh).

However, there are opportunities (cofiring, gasification and gas turbine steam injection) to further improve the heat rate, power output and economics of converting biomass fuel into power. For example, the biomass can be cofired in an existing coal plant. In this case the client would not have to build a new biomass power plant and coal power plants typically operate at lower heat rates (9500 – 12500 kJ/kWh) than conventional biomass power plants. Cofiring the biomass at the coal plant would also produce valuable environmental credits (CO2, NOx, SO2 and mercury) as a result of displacing some of the coal with biomass fuel.

Hopefully by now the reader has a clearer understanding that Anaerobic Digestion (AD) is not the only way to solve the organic waste to energy problem. In many cases, the Biological Dryer (BD) is a much more efficient, cost effective and sustainable solution.