NORTHWEST CHP APPLICATION CENTER

Northwest CHP Application Center

Combined Heat and Power for the states of
Alaska, Idaho, Montana, Oregon and Washington
in cooperation with the U.S. Department of Energy

recycling energy™ CHP It's time

Biomass Drying and Dewatering for Clean Heat & Power

September 2008

Prepared by:
Carolyn J. Roos, Ph.D.
WSU Extension Energy Program

P.O. Box 43165 • Olympia, WA 98504-3165
(360) 956-2004 • Fax (360) 236-2004 • TDD (360) 956-2218

WSUEEP08-015

Cooperating agencies: Washington State University Extension Energy Program, U.S. Department of Energy, Alaska Energy Authority, Idaho Department of Water Resources Energy Division, Montana Department of Environmental Quality Energy Program and Oregon Department of Energy

About the Author

Carolyn Roos, Ph.D., is a mechanical engineer with experience in building systems energy efficiency, mechanical design in hydroelectric facilities, and solar thermal applications. Currently she provides technical support to the Northwest Combined Heat and Power Application Center with a focus in biopower. With the Washington State University Extension Energy Program, she provides technical assistance to commercial and industrial clients on energy system efficiency topics. Carolyn can be contacted by email at roosc@energy.wsu.edu.

Acknowledgements

Development of this guide was funded by the Northwest CHP Application Center with support funding from the U.S. Department of Energy's Industrial Technologies Program and from the State of Washington.

Disclaimer

While the information included in this guide may be used to begin a preliminary analysis, a professional engineer and other professionals with experience in biomass drying should be consulted for the design of a particular project.

Neither the Northwest CHP Application Center nor its cooperating agencies, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Northwest CHP Application Center or its cooperating agencies.

Executive Summary

As prices for biomass fuels increase, it is especially important to use them efficiently. In both incineration and gasification, biomass drying increases efficiency, improves operation, and can increase steam generation by up to 60%. This guide provides general information about drying biomass fuels, one element of getting the most out of biomass-fired combined heat and power projects.

Even maintaining a flame in a boiler can be difficult if the fuel is too wet. Gasifiers, too, cannot tolerate high moisture contents. Some types of gasifiers require less than 55% to 60% moisture content and other require less than 20% moisture content for operation. In addition, biomass often requires pelletization, which may require even lower moisture contents than are required by gasifiers and boilers.

Dryer types used in drying biomass fuels include rotary, conveyor, cascade, and flash dryers. When selecting a dryer and designing a system, it is important to consider many factors in addition to energy efficiency, such as environmental emissions, operation and maintenance concerns, and recovery of marketable co-products.

Overall efficiency may be improved by sizing the boiler and dryer together, incorporating other energy efficiency measures, taking advantage of heat recovery from the boiler or gasifier and other waste heat sources in the facility. Dryers and boiler stack economizers can be used in conjunction with each other in some systems to take maximum advantage of recovered heat from the boiler. Heat may also be recovered from the dryer for use in the facility.

Wet feedstocks can be dewatered prior to drying by using drying beds, filters and screens, presses, and centrifuges. Alternatives to thermal drying and dewatering should also be considered. Moist feedstocks might be mixed with drier materials to achieve an acceptable moisture content of the mixture. Some lower moisture feedstocks can be sufficiently dried simply by storing in a covered area and turning periodically. Others, such as rice stalks or sawdust from cabinet shops, do not need drying at all.

Fuel drying generally results in reduced net air emissions of particulates and volatile organic compounds (VOCs) from the boiler and dryer. Improving the efficiency of a renewable energy project also benefits the environment by reducing carbon emissions.

Contents

List of Tables

Introduction

Biomass feedstocks are becoming increasingly valuable as the demand for renewable fuels has increased and the supply of wood fuels has diminished with the decline in the housing market. Bark, wood chips, and shavings, once considered waste and disposal problems, are now commodities with demand coming from domestic forest products companies, as well as European markets. Other biomass residuals, such as food processing and agricultural wastes, are increasingly being looked upon as fuel sources. As cellulosic ethanol production emerges into commercialization, demand for wood and agricultural residuals will only increase. These trends will likely continue as a whole range of new technologies and uses, summarized in Table 1, are added to traditional technologies and uses.

Rising prices for conventional energy sources have significantly changed the economics of efficiently using our biomass resources. With rising electricity prices and increasing demand for renewable energy, base load biomass-fired combined heat and power (CHP) systems become more attractive. It is now more important than ever that we use our biomass resources efficiently. While CHP itself represents a significant efficiency gain, there are a number of other steps that can be taken to improve the efficiency of existing and new steam CHP systems. These include steam system and boiler measures[1], waste heat recovery, and biomass drying and dewatering. This publication focuses on biomass drying and dewatering, an important and effective part of improving the efficiency of biomass combustion and gasification systems.

---

[1] For more information on steam system and boiler improvements, refer to the steam tip sheets on the website of the U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy Office at http://www.eere.energy.gov/industry/bestpractices/tip_sheets_steam.html.
To assess steam system improvements, including combined heat and power, download the DOE's Steam System Assessment Tool at http://www.eere.energy.gov/industry/bestpractices/software.html#ssat.

Table 1. Summary of Bioenergy Conversion Technologies

Technology	Technology Status	Possible Products	Facility type
Anaerobic digestion	Mature	Power, heat, soil amendments, and other co-products	Dairies, food processors, confined animal feedlots, wastewater treatment facilities
Ethanol Fermentation	Mature	Ethanol	Agricultural and food processing industries
Incineration	Mature	Power, heat, soil amendments, and other co-products	Wide range of facility types, including forest products, agricultural and food industries.
Biomass Gasification	Demonstration emerging into commercialization	Power, heat, combustible syngas, chemical feedstocks, hydrogen, biochar, soil amendments	Wide range of facility types, including forest products, agricultural and food processing industries
Biomass Pyrolysis	Demonstration emerging into commercialization	Power, heat, liquid fuel bio-oil, combustible syngas, chemical feedstocks, soil amendments, biochar	Forest products industries
Lignocellulosic Conversion	R&D and Demonstration	Cellulosic ethanol, chemical feedstocks, hydrogen, other co-products	Biorefineries, especially in the forest products industry.

Why Dry Biomass?

Drying biomass fuel improves combustion efficiency, increases steam production, usually reduces net air emissions, and improves boiler operation. In a boiler or gasifier, moisture in the fuel must first be heated and evaporated, carrying with it a large quantity of heat up the stack. While a fuel dryer also consumes energy in heating and evaporating moisture, the drying is more efficient in equipment designed especially for this purpose. If heat for the dryer is recovered from the boiler flue gas or gasifier—or from other waste heat sources—efficiency is further increased.

For wood chips with a moisture content (MC) of 45%, the maximum boiler efficiency with standard equipment is about 74%. If the same standard equipment is burning dry wood (~10% to 15% MC), the efficiency can be as high as about 80%. These efficiency improvements have corresponding steam production increases of 50% to 60%.[2]

A biomass-fired boiler will perform better when fuel has an optimum dryness. If the fuel is too wet, it may be impossible to even keep the flame lit without supplementary use of fossil fuels. With dry fuel, the flame burns hotter and more evenly, facilitating complete combustion.[3] Boiler air emissions are reduced (although emissions from the dryer must also be considered.) More complete combustion results in lower quantities of volatile organic compounds and ash produced.

Excess air can be reduced significantly, reducing air velocities through the boiler. This reduces entrained particulates in the flue gas, erosion of dryer surfaces, and fan power. Reduced fuel requirements to meet a given thermal requirement also means smaller fuel handling equipment.

If the fuel is to be transported, drying reduces transportation costs. In addition, dry biofuels are less subject to microbiological degradation in storage.

As with any technology, there are drawbacks as well. A dryer increases the complexity of the system and so may reduce overall system availability and operation and maintenance costs. Ash fouling and slagging tend to increase. The first cost of the dryer can be significant, although this may be offset by smaller boiler, air emissions equipment and fuel handling equipment and by reduced energy costs and boiler operation and maintenance costs.

[2] Refer to *Thermal Drying of Wet Fuels: Opportunities and Technology* by Bruce and Sinclair for boiler efficiency, steam generation, flue gas volumes and adiabatic flame temperatures when burning sludge and wood residues over a range of moisture contents.
[3] Dry wood burns at a flame temperature of 2300 to 2500°F, while green wood burns at about 1800°F.

Biomass Fuel Characterization

Biomass characteristics vary widely even for the same type of material, depending on many factors. Because of this, samples of the biomass to be dried will often be required to size and design a dryer for a specific application.

Biomass fuels may be derived from many sources, including forestry products and residue, agriculture residues, food processing wastes, and municipal and urban wastes. The waste produced by our cities, farms and industries represents a vast energy resource that, if tapped, could supply renewable clean heat and power. Waste—or "co-product"—streams that can be incinerated or gasified include:

- Forest products industry wastes such as residue from logging, thinning, lumber milling and furniture manufacturing. Sludges from paper manufacturing. Bark and wood waste are often used as "hog fuel," which refers to wood that has been prepared by processing through a "hog" (a mechanical shredder or grinder).

- Agricultural wastes such as the stalks, chaff, and "stover" (dried husks and leaves) from field crops and weather-damaged crops. Crop residues are primarily derived from grain crops such as corn, wheat and rice. "Bagasse," the residue remaining after sugarcane stalks are crushed to extract their juice, is used as a fuel. Biomass fuels have also been derived from cotton, sugar cane, and fruit and nut crops.

- Food and beverage processing waste such as trimmings, peelings, husks, floor waste, and "pomace" (the pulpy material remaining after the juice has been pressed from fruit, such as apples).

- Municipal and urban wastes such as construction and demolition debris, yard and tree trimmings, solid waste. Wood pallets, packaging materials, and leftover food from restaurants, supermarkets, schools and hospitals.

Table 2 summarizes measured moisture contents of a variety of materials,[4] although we must keep in mind that characteristics of any particular sample will vary. In the forest products industry, freshly harvested hardwoods, softwoods and herbaceous materials typically have moisture contents of 40% to 65%. On the high end, the moisture content of wood products in the temperate rain forests of the Pacific Northwest is commonly 65% for much of the year. The moisture content of pulp and paper mill sludges is also high. Agricultural crop residues that have been exposed to open air drying, such as straws, corn cobs, hulls and shells, often have 15% moisture content or less. Municipal solid waste usually contains 10% to 30% moisture. Biomass with very high moisture content

[4] A database of the characteristics of wood- and agriculturally-derived biomass is available online from the Commonwealth Scientific and Industrial Research Organisation of Australia at http://www.det.csiro.au/science/energyresources/biomass.htm.

includes many food and beverage processing wastes, aquatic biomass such as algae, municipal wastewater sludge, and farm animal wastes.

Moisture Requirements

Moisture content is critical in incineration, gasification and pelletization.

With the exception of suspension-firing furnaces, wood-fired boilers require fuel moisture contents below 55% to 65% in order to sustain combustion.[5] For wood-fired incineration, the *optimum* moisture content is generally much less, between about 10% and 15%.

Maximum moisture contents required for gasification depend on the gasifier type. Most biomass gasifiers are downdraft fixed bed type because these are most suitable for small sizes and produce low quantities of tars. Downdraft fixed bed gasifiers cannot tolerate moisture contents above about 20%. Updraft fixed bed gasifiers and fluidized bed gasifiers can tolerate higher moisture contents of 50% and 65%, respectively. Moisture contents can be as high as 95% in gasifiers using the supercritical water process, but this type of gasifier is still in the research and development phase.

Biomass may require pelletization to facilitate feeding and handling, to reduce transportation costs, to homogenize mixed substrates, and/or to achieve a uniform size to improve gasification or incineration. Pellet mills generally require moisture contents of less than 15% to produce stable and durable pellets.

Wastes with very high moisture contents often cannot be dried cost effectively except perhaps by passive dewatering methods, such as using filter bags, as discussed below. For these wastes, conversion technologies such as anaerobic digestion and fermentation will likely be more cost effective than incineration or gasification.

[5] Refer to *Thermal Drying of Wet Fuels: Opportunities and Technology* by Bruce and Sinclair for moisture requirements of grate-fired and fluidized-bed boilers when burning sludge and wood residues.

Table 2. Moisture Content by Weight of Several Biomass Feedstocks As Received

Feedstock	Moisture Content by Weight (%)
Food wastes: Fruits	
Apple pomace [5]	72
Cherry [2]	37.8
Orange peels [2]	10.8
Melon shell [2]	27.6
Nuts	
Black walnut shell [2]	11.6
Peanut Hulls [5]	9
Peanut Skins [5, 6]	8
Vegetables	
Wet potato wastes [6]	86
Other	
Sugar Cane Bagasse [9]	42-48
Fish waste [3]	76
Fruit & vegetable waste - grocery store [3]	88
Forest Products:	
Fuel Chips [9]	45-55
Pine sawmill waste [1]	11.3
Construction waste [4]	12-17
Bark [9]	30-60
Pulp & Paper Mill Sludges [8]	50-70
Agricultural wastes	
Rice husks [1]	10 (as received); 8.5 (air dried)
Corn cob	43 [2], 10 [6]
Soy hulls [5]	9
Lactating cow manure	88 (as excreted) 98 to 99.7 (from milk house or parlor)
Freshwater and Marine Biomass [7]	>95
Municipal waste	
Sewage sludge – biosolids [4]	90-97
Septage – biosolids [4]	98
Municipal solid waste [4]	12-32

(1) "Biofuel Database," Commonwealth Scientific and Industrial Research Organisation, www.det.csiro.au/science/energyresources/biomass.htm

(2) Jekayinfa1, S.O. and O.S. Omisakin, "The Energy Potentials of Some Agricultural Wastes as Local Fuel Materials in Nigeria" cigr-ejournal.tamu.edu/submissions/volume7/EE%2005%20003%20Jekayinfa%20final%20Oct2005.pdf

(3) Esteban, M.B., et al, "Evaluation of fruit–vegetable and fish wastes as alternative feedstuffs in pig diets," dx.doi.org/doi:10.1016/j.wasman.2006.01.004

(4) "Biomass," Institute for Environmental Research and Education, www.iere.org/documents/biomass.pdf

(5) McCann, Mark A. and Robert Stewart, "Use of Alternate Feeds for Beef Cattle," University of Georgia, 2000, pubs.caes.uga.edu/caespubs/pubcd/l406-w.htm

(6) Stanton, T.L. and S.B. LeValley, "Feed Composition for Cattle and Sheep," Colorado State University Extension. www.ext.colostate.edu/PUBS/livestk/01615.html

(7) Klass, Donald L., *Biomass for Renewable Energy, Fuels, and Chemicals*, Academic Press, 1998.

(8) K. C. Das and E.W. Tollner "Composting Pulp and Paper Industry Solid Wastes: Process Design and Product Evaluations," Proceedings of the 1998 Composting in the Southeast Conference, http://www.p2pays.org/ref/12/11563.pdf

(9) Bruce, D.M. and M.S. Sinclair, *Thermal Drying of Wet Fuels: Opportunities and Technology*, 1996, EPRI TR-107109

Dewatering Equipment

Overall efficiency can often be improved by dewatering wet feedstocks prior to thermal drying. On the downside, mechanical dewatering equipment itself can consume a large amount of energy and have high maintenance requirements, which must be weighed against the reduction in drying energy. Dewatering equipment includes drying beds, filters and screens, presses, and centrifuges. Depending on the material and the specific type of equipment, mechanical dewatering equipment may quickly reduce moisture content to as little as approximately 50%. More commonly, such a low moisture content cannot be achieved with mechanical dewatering equipment. Passive dewatering methods, such as using filter bags that are impervious to rain but allow moisture to seep out, can achieve moisture contents as low as 30% at low cost, but long periods of time – on the order of two to three months – may be required.

Types of mechanical presses include belt filter presses, V-type presses, ring presses, screw presses and drum presses. In a belt filter press, for example, the material is sandwiched between two porous belts, which are passed over and under rollers to squeeze moisture out. Belt presses are used in many industries, including wastewater treatment. A drum press consists of a perforated drum with a revolving press roll inside it that presses material against the perforated drum. This kind of press has been used with many materials, including hog fuel and bark.

In a bowl centrifuge, the material enters a conical, spinning bowl in which solids accumulate on the perimeter. Belt filter presses have lower capital, energy and O&M costs and have longer lives than centrifuges. Depending on the material, centrifuges can achieve lower moisture contents—65% to 85% moisture content compared to 76% to 88% moisture content for belt presses when drying municipal sludge. The savings associated with achieving a lower moisture content can offset the higher first cost of a centrifuge.

Biomass Dryers

There are many types of dryers used in drying biomass, including direct- and indirect-fired rotary dryers, conveyor dryers, cascade dryers, flash or pneumatic dryers, superheated steam dryers,[6] and microwave dryers. Selecting the appropriate dryer depends on many factors including the size and characteristics of the feedstock, capital cost, operation and maintenance requirements, environmental emissions, energy efficiency, waste heat sources available, available space, and potential fire hazard. See Table 3 (Dryer Classifications) and Table 4 (Dryer Type Comparison).

Fuel dryers can be generally classified according to their drying media, i.e. the stream that passes through the material to be dried. Drying media are superheated steam, hot air or flue gas. Air and flue gas dryers have air emissions and fire risk, while superheated steam dryers do not. Superheated steam dryers instead have condensate that must be treated, although it is possible to recover some compounds from the condensate as marketable products, such as wood oils. Superheated steam dryers vent moisture evaporated from the material, and so are best suited in facilities that have a use for the excess low pressure steam that must be purged from the drying cycle.

Dryers can be also classified as either direct- or indirect-fired. In direct-fired dryers, the heat transfer medium – flue gas, hot air or superheated steam – is passed directly through the material to be dried. In indirect-fired dryers, the heat transfer medium – usually steam or hot water – is passed through tubes or other heat exchangers inside the dryer, heating the material indirectly. In classifying dryers, notice that the heat transfer media is also the drying media for direct-fired dryers, but not for indirect-fired dryers. Direct-fired dryers are generally more efficient. The exception is when no air is let into an indirect-fired dryer and the moisture vented from the dryer as steam is recovered to serve process heating needs. Direct-fired dryers are not suitable for all materials. In particular, indirect dryers are better suited for drying fine and dusty materials.

Dryers may be designed to operate at atmospheric pressure or vacuum pressure. Drying of biomass under vacuum reduces the boiling point of water and so reduces the temperature required for drying, increasing opportunities to take advantage of waste heat in the facility. Vacuum dryers typically have high capital cost. This and the operating expense of the vacuum system must be weighed against energy savings due to increased use of heat recovery. Superheated steam dryers can be operated at pressures above atmospheric to allow heat recovery at a more useable, higher temperature.

[6] Terminology note: As will be discussed later, superheated steam dryers pass superheated steam directly through the material, evaporating its moisture as the steam approaches saturation. This is in contrast to indirect-fired steam dryers, which pass steam through a heat exchanger in the dryer, heating the material indirectly. In many references, a clear distinction is not made between these two dryer types, calling both "steam dryers." In this document, we have attempted to make this distinction clear by consistently referring to them as "superheated dryers" and "steam-tube dryers," respectively.

Heat for the dryer may be derived from the dryer's own burners, from boiler flue gas, from waste heat recovered from the exhaust of process heating in the facility, or from steam from the boiler. When recovering heat from process equipment, water can be heated and transferred over longer distances than can air. In pulp and paper mills, for example, waste heat may be recovered from the paper machine, the pulp dryer, the smelt dissolving tank, hot effluent streams, or low pressure steam.

Table 3. Dryer Classifications

Classification	Alternatives
Drying media (i.e. the stream passing through the material to be dried)	Flue gas, hot air or superheated steam
Firing	Direct- or indirect-fired
Heat transfer media	Flue gas, hot air, steam, or hot water
Pressure	Atmospheric, vacuum or high pressure
Heat source	Dryer burners, boiler (flue gas or steam), recovered waste heat from facility processes

Open-Air Drying

Some materials, such as park trimmings or husks and stalks, can be allowed to dry naturally by storing in a covered, open area or by taking advantage of open-air solar drying. The final moisture content of air-dried materials usually varies from about 15% to 35%, depending on the size and characteristics of the material and ambient conditions. Open-air drying is slow and depends on weather conditions. The pile may need stirring or turning to facilitate drying. Open-air drying is generally not suitable for high water content feedstocks since they tend to decompose quickly.

Perforated Floor Bin Dryers

Small biomass projects may only need a perforated floor bin dryer to dry the feedstock in batches. In this simple dryer, hot gases from the dryer's burner or flue gas recovered from boiler or gasifier are passed through the perforated floor into a large bin containing the feedstock. The depth of the feedstock in the dryer should not exceed 1 or 2 feet. The feedstock usually requires mixing after drying to achieve uniform moisture content.

Superheated Steam Dryers

In superheated steam dryers, superheated steam from the boiler is fed directly into the dryer – not through a heat exchanger as in indirect-fired, steam-tube dryers. The temperature of the steam stays above the saturation temperature, so it does not condense, evaporating moisture from the biomass by transferring only sensible heat. A larger quantity of steam at a lower temperature and pressure leaves the dryer than enters it.

Superheated steam dryers can operate in a closed-loop with low-pressure steam from the dryer being reheated and injected back into the dryer. If the excess steam is recovered for use in another process, a large fraction – as high as 70% to 80% – of the energy is recoverable. Steam exhausted from the dryer will be at the same pressure as the dryer. Therefore, maintaining a pressure above atmospheric allows heat recovery at a more useful, higher temperature. The pressure can be selected to match that of process heating requirements. If fouling is a concern with steam that is used directly, the steam can be reboiled. Atmospheric steam can be used to meet hot water needs. If there is no use for the vented steam, the energy savings potential is due only to the absence of hot air vented in other dryers and so are much less. The material must be fed into the dryer by a pressure tight feeder, such as a rotary valve or plug-screw feeder.

Superheated steam dryers have no air emissions, no fire hazard and a small footprint. However, when drying wood and wood-derived residues, the condensate will contain VOCs, have a high biochemical oxygen demand and will be corrosive, making some type of treatment mandatory. Depending on the material being dried, it may be possible to recover marketable products, such as wood oils, from the condensate.

Superheated steam dryers extract steam from the boiler, rather than recovering heat from boiler flue gas or from other process heat in the facility. Nevertheless, if the excess steam from the dryer can be recovered they are typically more cost effective than rotary dryers.

Rotary Dryers

In a rotary dryer, material is fed into a slowly rotating cylinder. Longitudinal flights inside the cylinder lift the feedstock and allow it to cascade down through the drying medium. Rotary dryers are in wide use and have a long, proven history in many industries and are the most commonly used dryer in drying hog fuel. On the other hand, high clay content paper sludges tend to ball up in a rotary dryer. Coarse bark has also been found to be problematic in rotary dryers.

- **Direct-Fired Rotary Dryers**

  Continuous-feed, direct-fired rotary dryers are the most common type of dryer for hog fuel, sawdust and bark, and many other materials. In general, the highest temperature possible without scorching the fuel results in greater dryer efficiency. An inlet temperature of around 800^{o}F is optimum for hog fuels dried in a rotary drum direct dryer. Moister fuels will require somewhat higher temperatures than drier fuels. But temperatures as low as 500^{o}F can be used with acceptable efficiencies in these dryers. Exhaust temperatures of about 150^{o}F are typical.

  Compared to rotary steam-tube indirect-fired dryers (see below), direct-fired dryers have lower operation and maintenance costs and higher availability (i.e. less down time for maintenance.) Lower temperature dryers such as conveyor dryers and cascade dryers have several advantages over direct-fired rotary dryers. In comparison, direct-fired rotary dryers have greater emission of VOCs and particulates, lower opportunity to recover waste heat, and have greater fire hazard especially after the dryer and in shutdown. Exhaust from the dryer may need to be passed through a cyclone, baghouse filter, scrubber or electrostatic precipitator to remove particulates.

- **Indirect-Fired Rotary Dryers**

  Steam-tube dryers use steam from the power boiler to dry the fuel, passing the steam through tubes or other heat exchanger type located inside the drum. Since this steam would otherwise be used to generate electricity, it represents an energy cost.

  Indirect-fired dryers are generally less efficient than direct-fired dryers because they introduce an inefficiency associated with transferring heat from the steam tubes to the material.

Conveyor Dryers

In conveyor dryers, the feedstock is spread onto a moving perforated conveyor to dry the material in a continuous process. Fans blow the drying medium through the conveyor and feedstock, either upward or downward. If multiple conveyors are used they can be in series or stacked (i.e. “multi-pass). Conveyor dryers are very versatile and can handle a wide range of materials. They are not as commonly used in drying hog fuel but have several advantages, along with some disadvantages, compared to the more commonly used rotary dryers.

Conveyor dryers are better suited to take advantage of waste heat recovery opportunities because they operate at lower temperatures than rotary dryers used in hog fuel drying. Rotary dryers, for example, typically require inlet temperatures of at least 500°F for drying hog fuel, but more optimally operate around 800°F. In contrast, the inlet temperature of at least one commercially available vacuum conveyor dryer can be as low as 10°F above ambient, although more typically conveyor dryers operate at higher temperatures between about 200°F and 400°F. Because of their lower temperatures, conveyor dryers can even be used in conjunction with a boiler stack economizer to take maximum advantage of heat recovery from boiler flue gas. In this scenario, an economizer first recovers heat from the boiler flue gas. Then exhaust from the economizer is used for fuel drying.

Their lower temperature also means that there is a lower fire hazard. Emissions of volatile organic compounds (VOCs) from the dryer will also be lower. An advantage conveyor dryers have over many other dryer types is that the material is not agitated. This means there may be fewer particulates in its emissions. On the other hand, fines may need to be screened out first and added back into the dryer at a later point, since they can fall through the belt’s perforations.

The footprint of single-pass conveyor dryers is typically larger than a comparably sized rotary dryer. Multi-pass conveyors in which conveyors are arranged one above the other with material cascading down from upper conveyors to lower conveyers, save considerable space. Multi-pass dryers are very common in many industries due to their small footprint and lower cost.

The capital cost of conveyor dryers and rotary dryers is often comparable. However, a conveyor dryer may require less ancillary equipment for treatment of emissions; so for new installations the overall cost may be less. Operation and maintenance (O&M) costs are higher than for rotary dryers. Multi-pass dryers are more complex than single-pass dryers and so have greater O&M costs than single-pass dryers.

Cascade Dryers

Cascade dryers have been widely used for biomass drying in Europe, especially in Sweden. They can be thought of as a type of fluidized bed dryer. The material is introduced into a flowing stream of hot air in an enclosed chamber. It is carried upward by the air and then cascades back to the bottom to be lifted again. Material is drawn out through openings in the side of the chamber.

Cascade dryers operate at intermediate temperatures between those of conveyor and rotary dryers. They have a smaller footprint than rotary and conveyor dryers. A disadvantage is that they are more prone to corrosion and erosion of dryer surfaces and so have higher maintenance costs.

Flash Dryers

In flash dryers (a.k.a. pneumatic dryers), the feedstock is suspended in an upward flow of the drying medium, usually flue gas. Flash dryers are appropriate for drying a wide variety of materials.

Flash dryers are generally cost effective only at larger scales. Electricity use by flash dryers is greater than that of other dryer types because high air flows are required to keep the material suspended. Flash dryers require a small particle size and so shredders may be required, also increasing electrical use.

Flash dryers have a small footprint. On the downside, they are subject to corrosion and erosion problems and have a fire risk after the dryer and in shutdown.

Microwave Drying

Industrial microwave drying is used in many industries, primarily in applications where the product quality, drying speed and efficient removal of the final traces of moisture are advantageous. Advantages include faster drying, more uniform heating, energy efficiency, better process control, and often a smaller footprint. On the other hand, capital cost is greater.

In biopower applications at facilities such as pulp and paper mills, often ample waste heat is available to cost effectively dry biomass by conventional methods. Microwave drying would not take advantage of this.

Table 4. Dryer Type Comparison

Dryer Type	Feedstock Requirements	Capital & Operating Cost	O&M Requirements	Environmental Emissions	Energy Efficiency & Heat Recovery	Footprint	Fire Hazard
Rotary	Less sensitive to particle size. High content paper sludges tend to ball up. Coarse bark can be problematic.		Low	More VOC emissions compared to lower temp dryers	Less opportunity to recover waste heat		Greater than lower temperature dryers
Conveyor	Fines may need to be screened out first and added back.	Comparable to rotary dryer, but may require less ancillary equipment for treatment of emissions reducing overall cost.	Greater than for rotary dryer.	Lower emissions of VOCs and particulates	High opportunity for heat recovery due to lower temperature.	Larger than comparably-sized rotary dryer. Multi-pass conveyors save space and can have comparable footprint to rotary dryer.	Low.
Cascade	Requires fairly uniform particle size. Can handle large particle size.	Higher than rotary dryers.	Subject to corrosion and erosion		Heat recovery is difficult. High blower costs.	Smaller footprint than rotary and conveyor dryers.	Medium. Risk after the dryer and in shut down
Flash	Requires small particle size.	Higher than rotary dryers.	Subject to corrosion and erosion		Heat recovery is difficult. High blower costs.	Smaller footprint than rotary and conveyor dryers.	Medium
Superheated Steam	Requires small particle size.	High.	High. Subject to corrosion.	No air emissions. Condensate requires treatment.	Very efficient if low-pressure steam is recovered. No heat losses from heating air.	Smaller footprint than rotary and conveyor dryers.	No fire hazard.

Considerations in System Design

For optimum efficiency and operation, how a fuel dryer operates in conjunction with other equipment in the facility must be considered. Considerations include heat recovery from the boiler or gasifier and process equipment in the facility, interactions between a fuel dryer and economizer, sizing a boiler for drier fuel, and the need for a back-up boiler in the case of a dryer outage.

Heat Recovery

Drying requires a large energy input to produce the necessary heat, so design of a system should consider opportunities to recover process heat. In both incineration and gasification, heat may be recovered from the boiler's flue gas or the gasifier's hot product gas. Heat may also be recovered from the turbine exhaust. In a pulp and paper mill, heat may be recovered from the paper machine, the pulp dryer, the smelt dissolving tank, hot effluent streams, and from waste low-pressure steam. Even if this equipment is located some distance from the dryer, a pipe loop can be used to transfer steam or water from 1000 feet or so.

When recovering boiler flue gas for a low temperature dryer, the possibility of high saturation must be considered since flue gas contains moisture and lowering the temperature increases relative humidity.

Dryers and Boiler Economizers

The energy contained in the boiler flue gas can be recovered to dry fuel in a flue gas dryer, but can also be recovered by an economizer to preheat boiler feedwater. Of the two, an economizer has a lower first cost and is generally more cost effective than a fuel dryer and so should be installed as a first step. Nevertheless, both can be used in conjunction with each other when using a lower temperature dryer. Vacuum dryers and low temperature conveyor dryers can effectively use waste heat at the lower temperatures exhausted after a stack economizer. This means both measures can take advantage of boiler flue gas, optimizing heat recovery.

Interactions between the dryer and economizer must be considered in an energy analysis. Boiler flue gas temperature is lower when using drier fuels: about 350°F or more without a fuel dryer versus about 220°F with a fuel dryer. Therefore, the energy available for recovery by an economizer is reduced if a fuel dryer is used.

Sizing the Dryer and Boiler or Gasifier Together

A fuel dryer should be sized so it is well matched with the boiler or gasifier. When burning dry fuel, less boiler heat transfer surface area is required for the same amount of heat transfer due to increased flame temperature. For an existing boiler, steam production will be increased. In a new installation, a smaller boiler will be required.

In addition to smaller heat transfer surfaces, the boiler fire box can be smaller due to more complete combustion. Since less ash is produced, the downstream ash handling system can be smaller. The reduced first cost of a smaller boiler will offset some of the first cost of the dryer.

Boiler Operation in a Dryer Outage

A boiler sized to burn dry fuel will be undersized when burning wet fuel. If there is a dryer outage, a fossil-fuel-fired back-up boiler may be required to make up for the reduced capacity of the biomass boiler.

Incorporating Other Energy Efficiency Measures

Using a fuel dryer is an energy efficiency measure in itself. There are further measures that can be taken to improve the efficiency of the drying process. As examples, in direct-fired dryers, the dryer's exhaust can be recirculated to ensure high saturation. Latent heat can be recovered from the moist exhaust using flue-gas condensers or industrial heat pumps. In superheated steam dryers, low pressure steam can be recovered. Low-pressure steam can be recompressed to a higher pressure if there is not a need for low-pressure steam in the facility. Volatile organic compounds (VOCs) can be recovered from the exhaust condensate of superheated steam dryers. These VOCs can then be burned in the boiler as fuel.

Improving operation and reducing energy use of dryers in general is discussed in *Process Drying Practice* by Edward M. Cook and Harman DuMont (1991). Measures discussed include using two-stage drying, preheating supply air, recycling exhaust air, and preheating the feed.

Considerations in Selecting a Fuel Dryer

In selecting a fuel dryer, factors to consider include energy efficiency, environmental emissions, feed and discharge systems, fire hazard and the potential for marketable byproducts.

Energy Efficiency and Heat Recovery

Low temperature dryers, such as conveyor dryers, can best take advantage of heat recovery opportunities. Drying of biomass under vacuum reduces the boiling point of the water in the wet material and so reduces the temperature required for drying, increasing opportunities for heat recovery. Vacuum dryers generally use hot water as the heat source and so heat can be more easily transferred to the dryer from process equipment.

If excess steam can be put to good use, superheated steam dryers are very energy efficient.

Feed and Discharge Systems

Superheated steam dryers have more problems with leakage from the feeding and discharge systems compared to flue-gas dryers. This results in superheated steam dyers having lower availability; that is, more down time for maintenance. Rotary valve and plug-screw feeders have worked better than other types of feeders but need to be replaced frequently due to wearing.

Fire Hazard

Superheated steam dryers have no fire hazard. In other types of dryers, fire hazard is lower in dryers that operate at lower temperatures, such as conveyor dryers. Fires result from ignition of dust or combustible gases, either inside the dryer or after the dryer. To reduce the potential for fire with hog fuel, the drying medium should not have an oxygen concentration greater than 10%.

Corrosion and Erosion

Corrosion and erosion are more problematic in flash, cascade and superheated steam dryers than in rotary and conveyor dryers. Paper sludges can have very high ash content, which contributes to erosion especially in dryers with high velocities.

Marketable Coproducts

VOCs may be recovered and burned in the boiler to increase energy efficiency or alternatively may be sold as raw materials for many high-value products. In superheated steam dryers and indirect-fired steam-tube dryers in which no air is added, steam vented from the dryer is condensed and the condensate is collected in a separator where oils and terpenes are extracted. In fact, superheated steam drying is essentially the same process (steam distillation) that is used to extract essential oils from wood and many food products. VOCs can also be recovered in flue gas dryers if the flue gas is scrubbed with water. High steam temperatures result in greater extraction of VOCs from the material at the expense of fuel heat content, however.

The wood oils and terpenes extracted from wood chips, bark and sawdust of trees in the pinus family (cedar, firs, hemlock, larches, pines and spruces) are used in the manufacture of fragrances, cosmetics and other personal care products, cleaning products, paint thinners, surfactants, emulsifiers, textile penetrants, disinfectants, and pharmaceuticals.

Environmental Emissions

Environmental emissions result from both the drying process and combustion in the boiler. Net emissions must be considered.

In the case of flue gas dryers, emissions from combustion and drying are both emitted in the exhaust from the dryer. Environmental air emissions from flue gas dryers primarily consist of volatile organic compounds and particulates, but other compounds of concern may also be emitted.

Direct-fired rotary dryers have greater emission of VOCs and particulates than indirect-fired dryers. Conveyor dryers have lower emissions of VOCs and particulates than rotary dryers. Superheated steam dryers by nature do not have air emissions but may have contaminated condensate that must be treated. Since flue gas from the boiler does not enter the dryer, emissions from the boiler are not affected by superheated steam dryers.

Burning drier fuel impacts emissions from the boiler, which may include VOCs and particulates, in addition to nitrogen oxides.

- **Particulates**

  The amount of particulates in the exhaust of a flue gas dryer is typically less than that of a biomass boiler alone. This is because fine materials in boiler flue gas adhere on coarse, wet fuel particles. If the wet fuel is composed principally of fine material, however, this will not be the case and there may be an increase in particulates. Reducing the fines contained in the feed to the dryer reduces particulate emission.

  With grate-firing, drier fuel results in improved combustion, reducing particulates in the flue gas. Moisture content of the fuel does not impact the quantity of particulates from fluidized-bed boilers or suspension-fired boilers.

  Particulate emissions may need to be reduced by utilizing filtration or other type of particulate removal system.

- **Volatile Organic Compounds**

  Wood, bark and wood-derived residues contain a larger portion of volatile organic compounds than agricultural and food wastes. VOC emissions from wood and wood-residue drying primarily consist of terpenes and wood oils, which must be monitored for air quality reasons. VOCs can also cause tar build up on lower temperature surfaces in flue gas ducts.

  VOCs begin to be released when the temperature of the feedstock rises above the boiling point of water and become more significant as temperature rises. A tell-tale sign of VOCs is blue haze being emitted from the dryer. VOCs may also be odorous.

  Reduction in emission of VOCs can be achieved by reducing temperature, recycling part of the dryer exhaust through the dryer, reducing the quantity of fine material in the feed, and reducing its residence time in the dryer.

  Note that *over*-drying not only reduces dryer efficiency but also increases the release of VOCs. Smaller particles may be over dried and larger particles under dried in some dryers. Look for dryers where particles are naturally entrained in the air flow when they reach the optimum dryness.

  VOCs are also released when wood is combusted in the boiler, although to a lesser extent typically than in a dryer. Drier fuel results in more complete combustion, reducing VOC emissions from the boiler.

- **Nitrogen Oxides**

  Burning drier fuel increases combustion temperature, which increases the formation of nitrogen oxides in the boiler flue gas. Even so, NOx emissions when burning biomass is typically less than when burning natural gas, oil or coal using conventional burners. Low NOx burners reduce these emissions.

- **Other Air Emissions**

  Wood may also undergo thermal degradation in the drying process and release other compounds, such as acetic and formic acids, alcohols, aldehydes, and furfurals. As with VOCs, these compounds are released when the temperature of the fuel rises above the boiling point of water and become significant as temperature rises above about 400^{o}F.

- **Contaminants in Condensate**

  The condensates from the drying process of forest residues, especially bark and needles, are toxic and require treatment. Condensate results from steam dryers, water scrubbers of flue gas dryers, and any dewatering steps preceding drying, such as pressing. Conventionally, wastewater treatment involves neutralization, decantation, filtration of suspended solids, and biological treatment. Alternatively, VOCs can be removed by steam stripping, which is a distillation process. Steam stripping allows recovery of VOCs for burning in the boiler or as raw materials for marketable byproducts.

Boiler Operation & Maintenance Considerations

Burning drier fuel in a boiler can impact boiler operation and maintenance. Considerations include excess air requirements, sulfuric acid formation and ash fusion temperature.

Excess Air

Excess air can be dramatically reduced with drier fuels due to more complete combustion. Since excess air impacts boiler efficiency, be sure to adjust excess air to the lowest practical volume. With moist fuels, 80% excess air may be required to prevent smoke formation in wood-fired boilers. Excess air can be reduced to about 30% with dry fuel.

Sulfuric Acid Formation

If flue gas cools below the dew point, sulfur trioxide can condense and form sulfuric acid. This can seriously corrode equipment and ductwork downstream of the boiler. Sulfuric acid formation increases maintenance costs unless more expensive, corrosion-resistant materials are used. If heat is recovered from the boiler's flue gas for drying fuel, the flue gas will be cooler, increasing the potential for sulfuric acid formation.

Ash Fusion Temperature

When burning drier fuels, the flame burns hotter. Some material components turn to glass and build up as slag on surfaces when temperatures rise above their fusion temperature. In particular, the fusion temperature of ash may be approached with the higher flame temperatures. Generally the ash fusion temperature of wood fuels will be safely above the flame temperature. But ash from contaminants of construction debris may have a lower fusion temperature. In addition, high silicon content biomass, such as some straws, may have lower fusion temperatures.

Cost Effectiveness

Fuel drying can be cost effective even at a small facility, provided heat recovery is used to capture waste heat generated in the facility and from the dryer. Other design factors will also influence cost effectiveness, so a complete analysis must be performed for each case. Manufacturers' representatives will often perform such analyses for a plant, or at least provide a ballpark figure.

Scenarios that improve the cost effectiveness of a fuel dryer include the following:

- *If drying reduces consumption of expensive fossil fuels.*
  For example, a fuel dryer may eliminate use of natural gas as a supplementary fuel to improve boiler operation when the fuel is too wet. If a dryer reduces the use of fossil fuels, it is generally more cost effective than if it reduces biomass fuel consumption.

- *If the wet fuel creates a bottleneck that drying can eliminate.*
  For example, boiler capacity may be limited by a fan that is not large enough to handle wet fuel. As another example, a turbine that is sized to match a boiler burning dry fuel will have unused capacity when burning wet fuel, possibly reducing electricity sales.

- *If boiler stack emissions of VOCs and particulates must be reduced to correct permitting problems.*

- *If low temperature heat from the dryer is recovered and used in the facility.*
  Cost effectiveness is improved if the sensible and latent heat in the dryer exhaust is recovered and put to good use in the facility. If so, a superheated steam dryer will often be more economical than a flue gas dryer.

- *If drying reduces disposal of materials.*
  A dryer may reduce disposal costs of, for example, waste wood and ash (assuming these are not already marketed as co-products.)

- *If green power can be sold at a premium price.*
  "Green power" generated from renewable resources such as biomass may be sold on the wholesale market to local or non-local utilities, fetching premium prices. In some cases, rate differences between utilities can be taken advantage of. For example, a mill may sell 100% of the power it generates at a premium price to a non-local utility, while purchasing less expensive power from the local utility to meet its own electricity requirements. The local utility charges a percentage of the sale of the wheeled power in these cases.

- *If carbon offsets or Renewable Energy Credits (RECs) are sold.*
  Carbon offsets associated with carbon emission reductions can be sold in the U.S. to cap-and-trade system members, such as the Chicago Climate Exchange, or on over-

the-counter retail markets. Similarly, the RECs associated with increasing the quantity of renewably generated power can be sold.[7]

Assistance in selling carbon offsets and environmental attributes can be obtained through brokers and marketers. Refer to the following websites to find contact information:

- Chicago Climate Exchange, Offset Aggregators: http://www.chicagoclimateexchange.com/content.jsf?id=64.
- U.S. Department of Energy's list of wholesale and retail renewable energy certificate marketers and brokers: http://www.eere.energy.gov/greenpower/markets/certificates.shtml?page=2.
- Carbon Offset Providers Coalition: http://www.carbonoffsetproviders.org.

The financial benefit of reducing carbon emissions can be expected to increase in the future, as either mandatory cap-and-trade systems or carbon taxes are implemented.

Other Information Resources

The following resources are available for more information on biomass-fired combined heat and power systems.

CHP Application Centers

The U.S. Combined Heat and Power (CHP) Association and the eight regional CHP application centers provide assistance to facilities considering CHP. These centers can offer technology, application and project development information, case studies and other publications, workshops and other educational opportunities, and contacts for local resources.

- U.S. Clean Heat and Power Association
  http://uschpa.admgt.com

- Gulf Coast CHP Application Center
  Texas, Louisiana and Oklahoma
  http://www.gulfcoastchp.org

- Intermountain CHP Application Center
  Arizona, Colorado, New Mexico, Utah, and Wyoming.
  http://www.intermountainchp.org/

[7] The environmental benefits of efficiency and renewable energy projects cannot be double counted when selling green power, carbon offsets or RECs. If power is sold as green, its environmental benefits cannot also be sold as RECs or as carbon offsets, and vice versa.

- Mid-Atlantic CHP Application Center
  Delaware, Maryland, New Jersey, Pennsylvania, Virginia, West Virginia and Washington D.C.
  http://www.chpcenterma.org

- Midwest CHP Application Center
  Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, Wisconsin
  http://www.chpcentermw.org

- Northeast CHP Application Center
  Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont
  http://www.northeastchp.org

- Northwest CHP Application Center
  Alaska, Idaho, Montana, Oregon and Washington
  http://www.chpcenternw.org

- Pacific Region CHP Application Center
  California, Hawaii and Nevada
  http://www.chpcenterpr.org/

- Southeast CHP Application Center
  Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, South Carolina, North Carolina, Tennessee
  http://www.chpcenterse.org

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency's CHP Partnership (http://www.epa.gov/chp/index.html) works to support the development of new CHP projects and promote their energy, environmental, and economic benefits.

References

Anderson, Eva, Simon Harvey, and Thore Berntsson**,** "Energy efficient upgrading of biofuel integrated with a pulp mill," *Energy*, Volume 31, Issues 10-11, August 2006, pages 1384-1394. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2S-4GGWG82-2&_user=137179&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000011439&_version=1&_urlVersion=0&_userid=137179&md5=3ce884a6227def61931b952e52d820e9

Bishop, Jim, "Dewatering Technologies: Municipalities can choose from a variety of options," Water Environment Federation website, July 2006. http://www.wef.org/NR/rdonlyres/6ECA6AB7-F3E7-4238-880B-92E6B8D82E95/0/SpecialSection_July06.pdf

Bruce, D.M. and M.S. Sinclair, *Thermal Drying of Wet Fuels: Opportunities and Technology*. H.A. Simons, LTD, prepared for Imatran Voima Oy, Finland, and Electric Power Research Institute, Palo Alto, CA, EPRI TR-107109, December 1996. www.epriweb.com/public/TR-107109.pdf

Cook, Edward M. and Harman D. DuMont, *Process Drying Practice*, McGraw-Hill, Inc., New York, NY 1991.

Cummer, Keith R., and Robert C. Brown, "Ancillary equipment for biomass gasification," *Biomass and Bioenergy,* Volume 23, Issue 2, August 2002, pages 113-128.

Hanson, Sheila K., Tera D. Buckley, Darren D. Schmidt, and Kerryanne M. Leroux, *Guide to Commercial Biomass Energy Conversion Systems*, North Dakota Forest Service, June 2006. http://www.ndsu.nodak.edu/forestservice/comm_forestry/doc/biomass_buyers_guide.pdf

Holberg, Henrik, *Biofuel Drying as a Concept to Improve the Energy Efficiency of an Industrial CHP Plant*, doctoral dissertation, Helsinki University of Technology, April 2007. http://lib.tkk.fi/Diss/2007/isbn9789512286492/isbn9789512286492.pdf (The first section of this dissertation provides background on biofuel drying. This dissertation lists manufacturers of various dryers that have been used in hog fuel drying.)

International Energy Agency, Organisation for Economic Co-operation and Development, *Drying wood waste with flue gas in a wood fuel dryer*, Caddet Energy Efficiency, 1997. http://lib.kier.re.kr/caddet/ee/R273.pdf

Klass, Donald L., *Biomass for Renewable Energy, Fuels, and Chemicals,* Academic Press, San Diego, California, 1998.

Mujumdar, Arun S., *Handbook of Industrial Drying*, CRC/Taylor & Francis, Boca Raton, FL, 2007.

National Renewable Energy Laboratory (NREL), *Report on Biomass Drying Technology*, November 1998. http://www.nrel.gov/docs/fy99osti/25885.pdf

TNO Environment, Energy and Process Innovation, "Industrial Superheated Steam Drying," Apeldoorn, Netherlands, 2004.

U.S. Department of Energy and U.S. Department of Agriculture, *Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005. http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Wimmerstedt, Roland, "Recent advances in biofuel drying," *Chemical Engineering and Processing*, Issue 38, pp. 441-447, 1999.

Appendix A: Dryer Manufacturers and Suppliers

Several manufacturers and suppliers of dryers are listed below, with excerpts from their webpages illustrating their experience in the forest products industry.

The Northwest CHP Application Center and its cooperating agencies do not endorse, recommend or favor these manufacturers and suppliers and do not guarantee the accuracy of information obtained from them summarized below. This list of manufacturers and suppliers may not be all inclusive.

Alstom Power, Air Preheater Co. (acquired ABB Raymond)
Distributor: Krupa Sales Company
1416 Whitecliff Way
Walnut Creek, CA 94596
http://www.airpreheatercompany.com/Products/Category.aspx?cat=6

Air Preheater Co. manufactures flash dryers.

Aeroglide
100 Aeroglide Drive
Cary, NC 27511
www.aeroglide.com/wood.html
Aeroglide manufactures both rotary and conveyor dryers for wood products. Aeroglide acquired National Drying Machinery Co.

Andritz Inc. (Austrian)
1115 Northmeadow Parkway
Roswell, GA 30076-3857
Phone: +1 770 640 2500
www.andritz.com
For a list of other North American offices, including several in the U.S., refer to http://www.andritz.com/ANONIDZ3937C8542CD9BCA8/ppp/ppp-service-2004/ppp-service-locations/ppp-service-contacts-adresses-na.htm.
Their "major customer segments are: wood processors, mechanical pulp producers, chemical pulp producers (including chemical recovery applications), market pulp producers (baling and handling applications), recycled fiber producers, tissue producers, paper/board producers (stock preparation applications), and the panelboard industry."

Andritz's webpage does not include hog fuel as a material they dry, but their dryers are listed as being used for hog fuel in the dissertation available at http://lib.tkk.fi/Diss/2007/isbn9789512286492/isbn9789512286492.pdf.

Barr-Rosin Inc. (Canadian)
255 38th Avenue, Suite G
St. Charles, Illinois 60174 • USA
Tel: 630-659-3980 • Fax: 630-584-4406
E-mail: bri@barr-rosin.ca
http://www.barr-rosin.com
"Barr-Rosin is a leading supplier of industrial drying systems and offers numerous systems and technologies to dry wet materials, ranging from granules, cakes, and powders to sludges, slurries, and solutions." For forest industries, refer to http://www.barr-rosin.com/applications/pulp_paper_sawmill_plant.asp

Barr-Rosin (www.barr-rosin.com) manufactures direct and indirect rotary dryers, superheated steam dryers.

Berlie-Falco Technologies Inc. (Canadian)
Distributor for Swiss-Combi: www.swisscombi.com (Swiss)
1245, Industrielle Street
La Prairie (Quebec)
Canada, J5R 2E4
Tel. (450) 444-0566
Fax (450) 444-2227
www.berlie-falco.com/
Swiss Combi's webpage does not include hog fuel as a material they dry, but their dryers are listed as being used for hog fuel in the dissertation available at http://lib.tkk.fi/Diss/2007/isbn9789512286492/isbn9789512286492.pdf.

Swiss Combi manufacturers low temperature belt dryers and rotary dryers.

Bruks-Klöckner Inc. (Swedish)
5975 Shiloh Road, Suite 109
Alpharetta, GA 30005
http://www.bruks-klockner.com
"The Bruks Klöckner bed dryer is an environmentally friendly low-temperature dryer for chips, sawdust, bark and the like."

Bruks-Klöckner is a subsidiary of FTG Forest Technology Group, which specializes in technologies for the forest industry. Bruks Klöckner is Swedish owned with an office in the U.S. They have a low-temperature bed dryer for chips, sawdust, and bark that operates at temperatures of 80 to 110°C.

Charles Brown (U.S.)
4465 Rea's Bridge Rd.
Decatur, IL 62521
(217)422-8608
http://www.charlesbrowncompany.com/index.html
"We offer a broad product line of continuous rotary dryers for a variety of industries such as aggregates, grain, food processing, and petro-chemical, to name a few. All of our

rotary equipment can be expertly designed and sized for any requirement no matter what the application."

ESI Inc. of Tennessee
1250 Roberts Boulevard
Kennesaw, GA 30144
Phone: 770-427-6200
Fax: 770-425-3660
Email: info@esitenn.com
Web Site: www.esitenn.com
"ESI's Steam & Power *SPECIAL FORCES*® own a proprietary biomass drying technology that is used to dry biomass and paper mill sludge. ESI has installed this technology in several biomass and paper mill sludge-fired projects, resulting in significant increases in boiler steam flow capacity and load following capability while simultaneously reducing air emissions and the use of support fossil fuels. Many times, the installation of a biomass dryer is a significantly less expensive alternative to the installation of new boiler capacity."

ESI supplies cascade dryers.

International Applied Engineering Inc.
1165 Allgood Road, Suite 6,
Marietta, GA 30062
Tel: (770) 977-4248
Fax: (770) 977-2832
http://www.iaeinc.com/
"IAE personnel have worked on every aspect of operations and maintenance of biomass-fueled power plants from the most basic and standard programs to complex legal and performance issues concerning the plant-wide performance of contracted operations and maintenance providers."

International Applied Engineering supplies cascade dryers.

M-E-C Company (U.S.)
P.O. Box 330
1400 West Main Street
Neodesha, Kansas 66757 USA
Phone: 1 (620) 325-2673, Fax: 1 (620) 325-2678
http://www.m-e-c.com
"M-E-C Company designs, manufactures, installs and maintains industrial drying systems for a wide range of wet materials." Industries served include the forest products industry and biomass energy industry.

M-E-C manufactures direct-fired rotary dryers.

The Onix Corporation (U.S.)
4140 Tuller Road
Suite 101
Dublin, Ohio 43017
614-798-1740
Fax: 614-798-1748
http://www.theonixcorp.com/index.html
"The Onix Corporation is a manufacturer of industrial wood combustion, rotary drum drying, wood-fired boilers, wood-fired industrial air heating and pollution-control equipment. The Onix Corporation designs recycling solutions for many industrial problems. This equipment is currently employed by the agricultural, pharmaceutical, pulp and paper, feed, and forest related industries."

The Onix Corporation manufactures direct-fired rotary dryers.

Thermal Energy International (Canadian)
36 Bentley Avenue
Ottawa, Ontario Canada
K2E 6T8
Phone: 613-723-6776, Fax 613-723-7286
www.thermalenergy.com
"Our bioenergy solutions help industries displace the use of expensive fossil fuels and achieve even greater energy cost savings by improving the value of the biomass fuels, converting waste products into valuable biomass fuels and increasing steam production and throughput of biomass plant operations by up to 35%."

Thermal Energy International is the distributor for "Dry-Rex" dryers, which are low-temperature vacuum belt dryers. (The Dry-Rex dryer was formerly available from Mabarex.) Both Mabarex (www.mabarex.com) and Thermal Energy International (www.thermalenergy.com) have experience with heat recovery and drying bark and hog fuel. Thermal Energy International specializes in heat recovery in general and so would be able to assist you in implementing other conservation measures as well. See the article about the Dry-Rex dryer in the *Bioenergy Update* (July 2003), available at http://www.bioenergyupdate.com/magazine/security/Bioenergy%20Update%2007-03/bioenergy_update_July_2003.htm.

Williams Patent Crusher and Pulverizer Co.
2701 North Broadway
St. Louis, MO 63102
http://www.williamscrusher.com/impdrymill/impdryR01.asp

Williams Patent Crush and Pulverizer has impact dryer mills that have been used with wood waste. Their mills simultaneously grind, dry, classify and convey material.