Moisture Content and Temperature Changes of Wood Fuel During Outside Storage
Michigan State University Extension Service
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Issued April 1992
10 pages

Michigan Energy Conservation Program for Agriculture and Forestry

Extension Bulletin E-2374 May 1992

Case Study in Wood Energy: Custom Forest Products, Grayling, Michigan

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Overview

Custom Forest Products, Inc. of Grayling, Michigan, participated as a demonstration site for the Michigan Energy Conservation Program (MECP) Wood Energy Demonstration Project. The Michigan firm was established in 1981, and has developed hardwood specialty product lines using maple, beech, red oak, and basswood species. Custom's drying and lumber processing facility produces door and window components for the residential housing industry. It also produces dimensioned wood parts.

Custom's original wood energy system was installed in 1982 and has been used to dry lumber as well as provide space heat for their manufacturing operations. A new 300 HP boiler system was installed in December 1988. The new boiler requires far less maintenance and repair than the previous boiler and operates more efficiently.

Custom Forest Products received a $10,000 MECP grant to install an electronic dry kiln control system to improve energy efficiency. Several MECP Wood Energy Demonstration Project facility tours were conducted at Custom Forest Products and the operating characteristics of their wood energy system have been evaluated. This bulletin includes a case study overview of the wood energy system and of the energy savings resulting from MECP grant funding.

MECP Wood Energy Demonstration Project

The Michigan Energy Conservation Program (MECP) was established to help farmers and wood energy users reduce their costs by several different energy conservation methods. Funding for the program was approved by Michigan's legislature and is the result of two federal court decisions from oil overcharges during the 1970s. The Wood Energy Demonstration Project is one of six areas within MECP and is designed to help wood fuel users establish energy systems, providing model demonstration sites for other organizations. The Wood Energy Demonstration Project was administered by Michigan State University through the Department of Forestry and by the State of Michigan Department of Agriculture. All Michigan businesses, governmental units, and not-for-profit organizations were eligible for the grant program. A total of $300,000 in funding was provided to 8 demonstration sites for either upgrading existing systems or developing new systems.

Custom F.P.- Wood Energy System

Custom Forest Product's wood-fired boiler system has a capacity of about 300 horsepower (about 9 million BTUs per hour) and utilizes dry sawdust and manufacturing residues from their dimension sawmill facility. Energy is provided to heat 200 thousand board feet (MBF) capacity of dry kilns, 1,000 MBF capacity of lumber predriers, and 45,000 sq. ft. of factory floor space. Custom's dry kilns process 13-14 million board ft. of lumber each year.

- Fuel Handling and Storage

An air-driven system deposits wood residues from the dimension shop into a covered concrete storage silo with a capacity of approximately 21,000 cubic ft. A pneumatic system also transports fuel to the adjacent boiler/burner. During summer months, when fuel consumption is low, the excess manufacturing residue is sold as bedding material to local dairy farmers for about $10 per ton.

- Boiler/Burner

The boiler system at Custom Forest Products includes both fire tube and water tube features to transfer heat from hot combustion gasses to the boiler water. Primary combustion gasses travel 3 passes through the boiler in fire tubes which are surrounded by boiler water. A water tube system transports cooler water at the base of the boiler to a steam drum at the top of the unit. Water tube systems may be more economical than fire tube systems when higher steam pressures and greater boiler capacities are needed.

Boiler steam pressures typically range from 75-80 psi, depending on the steam demand for drying lumber and space heat for factory buildings. Wood is injected into the burner intermittently - steam pressures tend to rise during fuel injection and subside when wood is not being fed into the burner. Fuel feed rate may be adjusted manually, further increasing the flexibility of the system. Natural gas is used as a stand-by fuel source and is also co-fired with wood for short periods during start-ups.

- Wood Ash

The burner has a fixed grate which is a combination of firebrick supported by a metal frame. Bottom ash is collected as uncombustibles accumulate on the grate of the burner. The bottom ash is removed manually about once per week. During the procedure, natural gas is used for energy for about 5 minutes while ash is removed from the grate area. Wood energy then resumes after a brief period of co-firing with wood and natural gas. About 4 cubic ft. of bottom ash is generated each week. Fly ash passes through the burner/boiler and is collected by the multicyclone in volumes ranging from 45-50 cubic ft. per week. Both bottom ash and fly ash are landfilled soon after collection.

- Labor and Periodic Maintenance

Labor requirements for normal operation of the wood energy system involves removing bottom ash and fly ash in 55-gallon drums. Additional maintenance work on the boiler water takes about 15 minutes each day. Once each year, the boiler is shut down, inspected, and the fire tubes and water tubes are cleaned. On a day-to-day basis the system is monitored for boiler steam pressure and for the level of wood inventory in the storage silo.

Kiln Drying of Lumber

Lumber is dried in enclosed, heated kiln buildings with fans to increase air movement. Heated air gains moisture as it passes through stacks of lumber, then is released to the atmosphere through vents. Careful control over temperature and relative humidity conditions is required throughout the kiln cycle to prevent defects such as warp and checking. Longer drying times are needed for thicker lumber and for wood with higher moisture contents. More than four weeks may be needed to dry 1-inch thick red oak lumber from the green condition to a final moisture content of less than 7 percent.

Hardwood kiln schedules typically include several changes in drying conditions with warmer and less humid conditions occurring later in the kiln cycle. Early in the kiln cycle, relatively low temperatures are used to prevent wood drying defects such as surface checking, collapse, and honeycomb. Relative humidity is maintained at a high level to prevent checking at the surfaces and ends of boards. When the average wood moisture content has been reduced to less than 30 percent, drying temperatures may be raised sharply for the rest of the kiln cycle. Secondary treatments such as lumber conditioning and drying stress equalization are included during the final stages of drying.

Kiln drying of lumber is an energy intensive process. Complete drying of 1000 board ft. of 1-inch red oak lumber may consume up to 6 million BTUs of energy. Kiln drying times and energy requirements may be reduced considerably if lumber is first air-dried or pre-dried.

Lumber Drying at Custom Forest Products

-Predrying

Predrying is used to reduce moisture content before lumber is kiln dried. Outside air drying may be considered a form of predrying, but is effective only during summer months, whereas predriers may be operated all year.

Green lumber is pre-dried to a wood moisture content of about 12 percent. The predrier facility is a large structure with approximately 500 MBF lumber capacity and a limited degree of temperature and relative humidity control. Custom Forest Products maintains two lumber predriers with a combined capacity of 1000 MBF.

Predrying times depend on species and lumber thickness, ranging from about 8-9 days for thinner basswood boards to 2 months or more for 1.5-inch thick red oak boards. Predrying temperatures range from about 85-95 degrees F and vary with outdoor temperatures. Several different species and thicknesses of lumber may be dried at the same time; however, drying times will vary.

-Kiln Drying

The second drying stage takes place in the dry kilns, where lumber is dried to moisture contents of 6-8 percent. Custom Forest Products maintains 4 compartment-type dry kilns with a total capacity of 200 MBF of lumber (50 MBF each). The dry kiln buildings are smaller than the predriers and are designed for more intense drying conditions with more precise temperature and relative humidity controls.

In the dry kilns, temperatures are gradually increased as the lumber becomes drier. Typically lumber is dried in 3-4 steps or stages which become progressively drier and warmer. For 1-inch thick red oak, temperatures are typically increased from about 130 to 165 degrees F during a 7-day drying cycle (Table 1). For 1-inch thick basswood, temperatures are typically increased from about 160 to 180 degrees F during a 4-day drying cycle (Table 1). Specific drying conditions will vary according to initial moisture content, thickness, and species.

Table 1

Typical drying schedules for basswood and red oak lumber at Custom Forest Products[1]

	basswood	red oak
wood density	0.32	0.56
initial moisture content [2]	95	75
predrying time:	30 days	30 days
kiln drying time:	4 days	7 days
starting dry kiln temp:	160 F	130 F
ending dry kiln temp:	180 F	160-170 F

[1] based on 1" thick lumber
[2] estimated moisture content before predrying (based on oven-dry wood weight)

-Equalizing/Conditioning

The final stage of the kiln cycle includes equalizing and conditioning. This phase is used to ensure uniform moisture content between boards as well as to relieve drying stresses, which occur when lumber is dried.

At Custom Forest Products, the final drying phase includes a steam spray cycle which may last from 10 to 14 hours to reestablish a uniform moisture content gradient between the surface and interior regions of the dried lumber. Without the steam and heat treatment, the lumber would contain residual drying stresses, a condition called casehardening. It is important for drying stresses to be relieved so that boards remain stable when sawn and machined in the dimension mill. Proper drying practices also reduce the likelihood of warpage and other dimension changes in-use.

-Loading and Unloading

Unloading a dried charge of lumber typically takes close to 30 minutes followed by about 1 hour to reload green lumber into the kiln. Dry kilns typically remain idle for less than 2 hours between cycles.

Electronic Kiln Control System

-Project Description

Custom Forest Products is utilizing an MECP grant to make improvements in control equipment, and to record and regulate the dry kiln process. New controls consist of a complete automated electronic system which includes a computer and accessories, wood moisture content probes, relative humidity sensors, and temperature sensors. Currently, the equipment is being used on 1 dry kiln, and moisture content is monitored on 6 boards at selected locations within the kiln. Custom plans to equip its remaining kilns with similar electronic controls.

The equipment records and regulates drying conditions throughout the kiln cycle from the initial loading to the completion of the conditioning treatment. All drying condition changes are programmed into the computer at the beginning of the drying cycle. Changes in temperature and relative humidity are then made automatically without assistance from a kiln operator.

-Features of New Kiln Control Equipment

Kiln cycles can be shortened considerably with the new system because temperature and relative humidity changes can be made as soon as needed. Previously, changes were made only during normal working hours, resulting in unnecessary delays when changes could have been made at night or during weekends.

The new system monitors drying conditions and lumber moisture content continually and provides all relevant information on the computer monitor. Specific error messages are displayed if improper drying conditions occur, reducing the need to interpret the charts and dials used previously with the analog system.

The new system can detect certain errors and equipment malfunctions and make automatic adjustments before a problem arises. For example, if heat or steam valves stay open too long, the computer will discontinue the entire kiln cycle, reducing the possibility of an entire charge of lumber being dried improperly. As a result, lumber degrade can be minimized with the new system. During the first several months of operation, kiln operators have observed a reduced incidence of end checks, cupping, and warpage of lumber.

The new system can detect regions within the kiln that may be drying too slowly. For example, stacks of lumber are sometimes loaded too closely together, reducing air flow between boards. Since moisture content is monitored continuously, slow drying boards can be easily identified during the kiln cycle. Under the previous system, high moisture content boards were sometimes not identified until after unloading, resulting in further drying and rehandling. Previously, wood moisture was determined by regular weighing of lumber kiln samples, a more labor intensive approach than with the computer monitor and electronic controls.

Drying times are further reduced with the new system because lumber is cooled to ambient temperatures more quickly after drying. The new controls automatically shut off the drying system and open the kiln vents, resulting in more rapid cooling.

Case Study Evaluations-Custom Forest Products

-Procedures

Combustion gasses were evaluated to determine the operating efficiency of Custom's wood energy system. The intake probe of an Enerec (Model E 2000) combustion efficiency analyzer was positioned in the exhaust stack, just after the boiler but before the cyclone emission control device.

Gas parameters were analyzed based on changes in overfire air volume and changes in fuel feed rates. Airflow into the burner was regulated by adjusting a damper from open to closed positions (high overfire air and low overfire air were evaluated). Fuel feed rate was also adjusted manually and included low, medium, and high fire. Samples were taken at approximately one minute intervals, and included readings for oxygen, carbon dioxide, carbon monoxide, combustion efficiency, and excess air.

-Wood Combustion

During the combustion process, carbon atoms in wood combine with oxygen atoms in the air in a chemical reaction that releases heat. Normal air is only 21 percent oxygen, with most of the remainder being nitrogen. Wood combustion is complete when 2 oxygen atoms combine with a carbon atom to form carbon dioxide. When only 1 oxygen combines with carbon, carbon monoxide is formed and incomplete combustion results. Less than one third of the energy potential of carbon is realized when carbon monoxide is formed. In wood energy systems it is important to provide necessary air volumes as well as turbulent mixing of air and wood to improve the probability of complete combustion.

-Combustion Air Ratios

Typically both underfire air and overfire air are used together to promote complete combustion in commercial wood energy systems. Overfire air is introduced into the burner above the zone of active combustion, while underfire air is provided from beneath the grate.

Air ratios are important in wood energy systems because they affect the amount of turbulent mixing of gasses with wood in the combustion chamber. For dry wood, such as the fuel at Custom Forest Products, more overfire air than underfire air is needed for most efficient burning and a minimum of pollutants and opacity. For higher moisture content fuel, more underfire air than overfire air is needed. (3).

Under ideal conditions, complete combustion requires 6.17 lbs. of air for each lb. of oven-dry wood (3). Excess air is introduced to compensate for the less than ideal conditions found in real wood energy systems. With insufficient levels of overfire air, emissions would contain incomplete combustion products such as carbon monoxide and high levels of uncombustible ash.

-Combustion Efficiency Results

-overfire air volume

The effect of overfire air on combustion parameters was evaluated at a constant fuel feed rate. High volumes of overfire air resulted in higher excess air and oxygen content than for low overfire air (Table 2). For a fixed level of underfire air, overfire air should be directly related to excess air. High overfire air resulted in relatively high oxygen content and low carbon dioxide content of combustion gasses. Low overfire air had the opposite effect. Uncombustible particle contents were somewhat higher for high overfire air than for low overfire air. Air flow is important not only with respect to wood combustion properties but also for overall power requirements. Proper sizing of the overfire air fans can result in savings of electrical energy.

-fuel feed rate

Fuel feed rate can directly influence energy output and steam pressures. Interaction of fuel feed rate and air volume is important to insure efficient and complete combustion. Three levels of fuel feed rate were evaluated, with air flow being kept constant.

Low fuel feed rate resulted in the highest ratio of air to wood. Oxygen and excess air levels were correspondingly high (Table 3). Carbon dioxide, which varied inversely with oxygen, was at a low level for low feed rate. Carbon monoxide, an incomplete combustion product, was also relatively low, averaging 863 ppm.

At the high fuel feed rate the ratio of air to wood was minimized. Oxygen content and excess air were both at relatively low levels while carbon dioxide and carbon monoxide were both at high levels.

Table 2

The effect of high vs. low levels of overfire air on combustion gas parameters Custom Forest Products.

Overfire Air Volume		Combustion Parameters				
		oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combustibles (%)	excess air (%)
	avg:	6.4	14.1	1670.0	1.6	49.2
LOW	sd:	1.63	1.11	364.1	0.6	18.9
	n:	5	5	5	5	5
	avg:	16.28	4.54	1941.2	2.2	354.6
HIGH	sd:	0.65	0.56	201.7	0.1	55.2
	n:	5	5	5	5	5

(average, standard deviation, and number sampled)

Table 3

The effect of fuel feed rate on combustion gas parameters
Custom Forest Products

Fuel Feed Rate		oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combustibles (%)	excess air (%)
		Combustion Parameters				
LOW	avg:	19.27	2.00	862.7	0.71	*
	sd:	0.21	0.87	79.9	0.10	*
	n:	6	6	6	6	6
MEDIUM	avg	16.10	4.82	1681.3	1.55	333.0
	sd:	0.41	0.21	79.7	0.22	23.1
	n:	6	6	6	6	6
HIGH	avg:	10.91	9.70	2391.0	0.71	114.4
	sd:	1.19	1.23	28.3	0.12	22.6
	n:	9	9	9	9	9

(average, standard deviation, and number sampled)
* exceeded detectable limit

Economic Evaluation of Energy Savings

Increased control and efficiency of lumber drying conditions will result in lower fuel requirements for Custom's wood energy system. Shorter drying cycles and more efficient conditioning treatments will result in lower steam demands as well as less lumber degrade. An added benefit of less steam production will be the savings on chemicals used to treat boiler water.

Wood waste such as sawdust and planer shavings will become available for higher value uses instead of being used as a fuel source. Local dairy farmers purchase dry sawdust and planer shavings from Custom for about $10 per ton.

Less degrade has been observed on maple kiln charges since the electronic controls were installed. Noticeably fewer defects have resulted from the increased control over relative humidity and temperatures in the dry kiln.

Total project cost for the electronic controls and computer system was about $19,000 for upgrading 1 kiln compartment. Custom plans to equip its remaining 3 kilns with similar components at an additional cost of about $30,000.

Abbreviations

BTU:	British thermal unit
CO:	carbon monoxide
CO_2:	carbon dioxide
F:	Fahrenheit
HP:	horsepower
MBF:	thousand board ft.
O_2:	oxygen

APPENDIX

Table A1

The effect of high overfire air on combustion parameters
Custom Forest Products

High Overfire Air Volume

overfire air	oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combustibles (%)	excess air (%)
HIGH	15.3	5.4	2226	*	280
HIGH	16.1	4.0	2065	2.2	417
HIGH	17.0	4.7	1844	2.3	330
HIGH	16.3	4.1	1850	2.1	400
HIGH	16.7	4.5	1721	2.1	346
Average	16.28	4.54	1941.2	2.17	354.6
Standard Deviation	0.65	0.56	201.7	0.10	55.2

*Exceeded detectable limit

Table A2

The effect of low overfire air on combustion parameters
Custom Forest Products

Low Overfire Air Volume

overfire air	oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combustibles (%)	excess air (%)
LOW	8.8	13.0	1550	1.3	50
LOW	6.9	13.8	1270	1.2	47
LOW	6.4	14.6	1720	2.3	39
LOW	5.4	15.7	2140	*	30
LOW	4.5	13.2	*	*	80
Average	6.40	14.06	1670.0	1.60	49.2
Standard Deviation	1.63	1.11	364.1	0.61	18.9

*Exceeded detectable limit

Table A3

The effect of low fuel feed rate on combustion parameters
Custom Forest Products

Low Fuel Feed Rate

fuel feed rate	oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combus-tibles (%)	excess air (%)
LOW	18.9	2.1	1011	0.87	870
LOW	19.3	1.6	870	0.73	*
LOW	19.5	1.4	866	0.72	*
LOW	19.4	1.5	791	0.62	*
LOW	19.3	1.7	798	0.60	*
LOW	19.2	3.7	840	0.69	330
Average	19.27	2.00	862.7	0.71	
Standard Deviation	0.21	0.87	79.9	0.10	

*Exceeded detectable limit

Table A4

The effect of medium fuel feed rate on combustion parameters
Custom Forest Products

Medium Fuel Feed Rate

fuel feed rate	oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combus-tibles (%)	excess air (%)
MEDIUM	15.5	4.7	1830	1.86	377
MEDIUM	16.0	4.9	1706	1.61	327
MEDIUM	16.1	5.2	1661	1.46	311
MEDIUM	16.5	4.8	1616	1.35	320
MEDIUM	16.6	4.6	1621	1.29	327
MEDIUM	15.9	4.7	1654	1.72	336
Average	16.10	4.82	1681.3	1.55	333.0
Standard Deviation	0.41	0.21	79.7	0.22	23.1

*Exceeded detectable limit

Table A5

The effect of high fuel feed rate on combustion parameters
Custom Forest Products

High Fuel Feed Rate

fuel feed rate	oxygen (O_2) (%)	carbon dioxide (CO_2) (%)	carbon monoxide (CO) (ppm)	combus-tibles (%)	excess air (%)
HIGH	9.8	10.8	*	0.55	84
HIGH	9.4	11.6	*	0.60	85
HIGH	9.5	11.3	*	0.62	91
HIGH	10.3	9.7	*	0.61	112
HIGH	10.9	9.3	*	0.84	119
HIGH	12.2	8.3	*	0.70	134
HIGH	12.0	8.7	*	0.89	138
HIGH	12.0	8.6	2411	0.82	128
HIGH	12.1	9.0	2371	0.78	139
Average	10.91	9.70	2391.0	0.71	114.4
Standard Deviation	1.19	1.23	28.3	0.12	22.6

* Exceeded detectable limit

The Wood Energy Demonstration Project

The Michigan Energy Conservation Program for Agriculture and Forestry's Wood Energy Demonstration Project was designed to help businesses and organizations throughout the state realize cost and energy savings through the use of wood as an energy source. A $300,000 direct grant program provided competitive awards to facilities to offset the cost of installing and maintaining wood energy systems. The maximum individual grant award was $75,000.

Under terms of the grant, recipients documented all installation and operating costs. Information on operating conditions and energy savings is available to any organization interested in the economics of wood as an energy source for heat or manufacturing.

Twenty-nine applicants submitted grant proposals, including primary and secondary forest products manufacturers, schools, agricultural related businesses, and a medical care facility. Nine proposals were received from businesses that use kilns to dry lumber, representing the largest single project type.

References

1. Anon. 1988. Dry Kiln Operators Manual. U.S. Department of Agriculture, Forest Service. Forest Products Laboratory. Madison, Wisconsin.

2. Armstrong, James P. and Samuel M. Brock. 1989. Predicting fuel consumption of central Appalachian kiln-drying enterprises. Forest Products Journal 39(3):57-61.

3. G & S Mill, Inc. bulletin. February, 1990.

4. Noyes Data Corporation. 1981. Biomass Gasification Principles and Technology. T.B. Read (editor). Solar Energy Research Institute. Golden, Colorado.

5. Nicholls, David L. and Karen Potter-Witter. 1990. Economic Analysis of Wood Fuel for Dry Kilns: Nine Case Studies. MECP Extension Bulletin.

6. Office of Energy Programs. 1988. Wood Fuel Users Manual. Michigan Biomass Energy Program. Public Service Commission. Michigan Department of Commerce.

7. Wellons, Inc. bulletin. Combustion Principles and the Wellons Cell Furnace.

"This bulletin was prepared with the support of the U.S. Department of Energy, Grant No. DE-FG0276CS60204. However, any opinions, findings, conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of DOE"

Issued in furtherance of Cooperative Extension work in agriculture and home economics, acts of May 8, and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Gail Imig, Director, Cooperative Extension Service, Michigan State University, East. Lansing, MI 48824.