An Analysis of the Densified Wood Fuel Industry in the Lake States

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INTRODUCTION

The densified wood fuel industry in the Lake States consists largely of small firms that procure forest or mill residues, densify them into pellets or briquettes, and deliver the resulting product for use as fuel. Pellet producers make up the largest segment of the industry. Major markets for pellets are public schools, institutional users, and light commerce/industry. Briquettes, on the other hand, are sold mostly to homeowners, with some used in schools.

In the Lake States region, densification of wood for fuel began around 1979. With the help of government involvement and incentives, and with an inexpensive resource base, the Lake States has developed the largest concentration of densified wood fuel plants in the country. There are now 10 densification operations in the Lake States. Production of fuel has ranged from 35,000 to 70,000 tons per year the past three years.

An important factor in the growth of the densified wood fuel industry was the rapidly increasing price of liquid fuels from 1973 to 1981 and the belief that this trend would continue indefinitely. With the current (1987) low oil and gas prices, densified fiber fuels are not as attractive to users as in the recent past. The result is that the densified wood fuel industry is highly competitive, with excess capacity and narrow profit margins. Demand for densified wood fuels is flat and is likely to continue so until there is a significant increase in oil and gas prices. Because demand was expected to grow, potential markets were overestimated by many firms entering the business, resulting in overcapacity, price cutting, and inadequate profits. A recent shake-up in the industry can be largely attributed to inadequate profits due to price cutting.

This report documents the history of the wood pellet and briquette industry in the Lake States region[1] and identifies problems and opportunities associated with this industry. It emphasizes the economic and policy environment that resulted in significant growth of the densified wood fuel industry in the region, and explores characteristics of other regions of the country in which there has been little development of densified wood fuels.

This report is intended as a planning and reference document for future producers and users of densified wood fuels. It also provides a description of the industry for those not familiar with it.

Included are: (1) a brief international and national history of the densified wood fuel industry, with emphasis on the Lake States region; (2) a description of the marketing structure of the industry, and of government and public agency involvement; (3) an analysis of the economics of production and use; and (4) a discussion of new developments and problems facing the industry.

Information for this study was gathered through personal interviews, plant visits, telephone calls, and published and unpublished reports.

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[1]Minnesota, Wisconsin, Michigan

THE PRODUCT AND PROCESS

The term biomass fuel refers to a wide variety of materials (Table 1). However, in most cases the term is used as a synonym for wood and bark residue fuels. The term densified biomass fuels usually refers to wood and bark fuels that have been dried and compressed to increase their density. Two important features distinguish densified biomass fuels from other biomass fuels: (1) low moisture content, and (2) high bulk density (10).

Table 1. Common biomass fuels (10).

Forest	Agricultural	Other
whole tree chips	grass	animal manure
cordwood	straw	sewage sludge
mill residues	corn stover	refused-derived
1) sawdust	sunflowers	fuels
2) bark	artichokes	
	bagasse	

Biomass fuels currently used in Minnesota are:

1) whole tree chips
2) sawdust
3) bark
4) cordwood
5) peat
6) wood pellets/briquettes
7) sunflower hulls
8) sugarbeet seeds
9) corn stalks
10) marigold petals
11) artichokes
12) hay
13) legumes
14) oat hulls

Green biofuels have certain disadvantages, the major ones being high moisture content, non-uniform size, low bulk density, and low conversion efficiency. Densification removes many of these disadvantages, thus reducing transportation and storage cost. Densification also results in consistent product dimensions, easier handling and storage, and more efficient burning.

Currently, densified wood fuels in the Lake States are made primarily from forest industry residues generated at sawmills, secondary manufacturers, and pulpwood chipping plants. Sawdust, bark, and other trim waste make up most of the residues used (1). One producer of pellets in Minnesota uses whole tree chips in the pelletizing process (16).

Both pellets and briquettes are produced in Minnesota. A fuel pellet resembles an animal feed pellet with the diameter from 3/8" to 7/8" and the length from 1/2" to 1-1/2". The briquette product is about 3 inches in diameter and ranges in length from 12-inch "logs" to 3-inch or thinner briquettes.

The densification process for wood residues involves five major steps:

Collection. In the early years of the densified wood fuel industry much of the residue was from wood piles which were several years old. Because this reserve has been consumed, fresh residues are now more typically used. Today, most plants utilize residues (bark, sawdust, shavings, chips, and other waste scraps) generated by a nearby sawmill operation.

Particle size reduction. Hammermills, hogs, or chippers are used to reduce residues to particles approximately the size of sawdust.

Drying. Rotary drum dryers, often fired by wood wastes, dry residues to a moisture content of approximately 10 to 18 percent. The energy for drying is typically obtained by burning dry fines in a suspension burner (1).

Densification. Wood fuels are shaped by loading residues into a pellet or log extruder. The material is compressed and forced through a die the diameter of the intended product. There are several theories relating to the self bonding of wood between adjacent particles of biomass. The most appropriate ones are bonds formed due to thermal softening of lignin and other phenolics, hydrogen bonds, and polar bonds (11).

Pellets are usually manufactured by continuously feeding and forcing compressed feedstock against the face of a hard steel die perforated with a dense array of holes. The pressure results in extrusion of densified pellets. The maximum production rate of one pellet machine is approximately five tons per hour.

Briquettes are typically produced by the Hausmann method, developed in Switzerland and known in Europe as the Glomera press method. In this process the residue is partially compacted while being fed vertically by a screw auger into a chamber. A horizontal reciprocating ram forces the material through a die where a log or briquette is formed, depending on the type of die used (11). The maximum production rate of one briquetting machine is approximately 1.5 tons per hour.

Screening and cooling. The final product is screened to remove undesirable fines and is also cooled prior to storage.

HISTORY

Early Developments

Densified wood fuel development dates back to 1864, when a U.S. patent was obtained to mix sawdust, wood chips, and other similar materials, and to then subject the feedstock to heat and pressure in a mold, resulting in a fuel pellet (31).

Wood briquettes have been used in the United States for at least 75 years. They were originally made of wood residues compacted between the faces of roller bearings. One of the best known fuel logs in the United States, the "Pres-to-Log," was first produced around 1933 with a machine developed by

Wood-Briquettes Inc., in Lewiston, Idaho. This machine was popular with wood products firms looking for a way to utilize wood residues profitably. the logs were sold primarily as a recreational fuel for camping and fireplaces (11).

In 1961, Sprout-Waldron & Co., a manufacturer of agricultural feed pellet machines, began producing bark pellets in Knoxville, Tenn. This product was designed to be burned with coal (13).

Recent Activity in the United States

Many attempts to develop wood densification plants were made across the country in the 1960s and 1970s, with little success due to low economic feasibility. Then in 1977 a pilot plant was built in Brownsville, Ore. utilizing the patented "Woodex" pelletizing process.

Following the Woodex plant was the Western Power Co. pellet mill in Burney, Calif. It went into operation in 1978 and markets were established in northern California and southern Oregon. Raw material shortages in 1982, due to curtailment of mill operations in the Burney area, brought about a decision to close the plant. Other companies that constructed pellet plants were Biomass Energy Corp. in the eastern United States, Guaranty Fuels in the southern United States and Minnesota, and various plants in the western United States (3). Interest in biomass densification grew in the early 1980s. during the past decade over 30 plants have operated in the United States and Canada. Many of these have since closed (Table 2).

Table 2. Recent producers of densified wood fuels not operating in November 1986.

Woodex, Brownsville, Ore.
Forest Fuels Inc., Medford, Ore.
Western Power Co., Burney, Calif.
Day Resources, Sand Point, Idaho.
Biomass Energy Corp., Fort Fairfield, Maine.
Biomass Energy Corp., Lincoln, Maine.
Guaranty Fuels, Goldston, N.C.
Guaranty Fuels, Cleveland, N.C.
Guaranty Fuels, Bristol, Fl.
Guaranty Fuels, Stillwater, Minn.
Blackduck Pressed Wood Products, Blackduck, Minn.
American Bio-energy, Gilbert, Minn.[1]
Northern Bio-fuels, Crosby, Minn.
Cole Forest Products, Grand Rapids, Minn.
Snowy Range Wood Products, Laramie, Wyo.
Danridge Pellet Fuels Inc., Danridge, Tenn.
Sprout-Waldron & Co., Knoxville, Tenn.
Phoenix Corp., Shawano, Wis.
Bemidji Fiber Fuels Inc., Bemidji, Minn.

[1] Former Aspenol plant.

It is interesting to note that states such as Oregon, Georgia, and North Carolina, which have had strong state-encouraged wood energy programs, all lack a significant densified wood fuel industry. The emphasis in these states has been on green wood residue fuels. This appears to be because the wood-fuel using industry is made up of large energy users, and because state programs did not emphasize densified fuels.

Montana and Oregon each currently has two pellet plants in operation, and the northeastern region has one or two plants. The number of operating plants in any area has fluctuated frequently with closings and reopenings. This points to the fact that the densified wood fuel industry is both very competitive and immature. Figure 1 shows densified wood pellet and briquette plants operating in the United States as of November 1986.

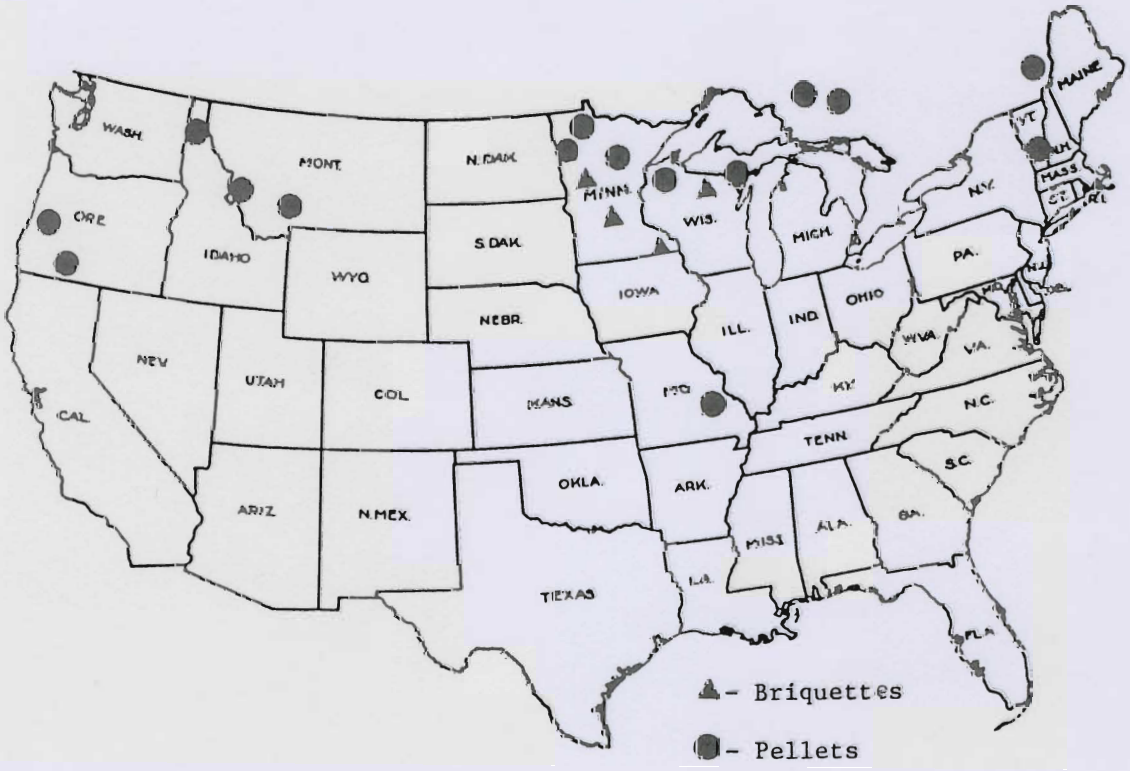

Figure 1. Densified wood pellet and briquette plants operating in North America (November 1986).

Recent Activity in Other Countries

Canada currently has three pellet plants in operation. They are owned by the Shell Oil Company and were built at a cost of about $5 million (Canadian) per plant. Construction was subsidized by the Canadian government through its Forest Industry Renewable Energy Program ($288 million Canadian) (21).

Raw material for Canadian pellet mills is sawmill waste purchased from neighboring mills. The pellets are shipped primarily to paper mills, and also the heating markets of southern Ontario and northeastern United States (3). It is interesting that the primary market, the paper mill industry, uses large quantities of energy--a market not generally believed in the United States to be well suited to wood pellets. In addition to serving a different market, Canadian pellet plants are larger than U.S. plants.

Currently there does not appear to be much development of densified wood fuels in countries other than the United States and Canada. One major reason is that most developed countries do not have an inexpensive supply of wood waste. Biomass densification plants in Europe largely use agricultural and paper waste.

Recent Activity in the Lake States

During the middle 1970s, fossil fuel prices rose dramatically due to the Arab oil embargo. This situation led to increased use of wood for energy, and set the stage for densified wood fuels.

The densified wood fuel industry in the Lake States is relatively new, starting production in 1979 (Table 3). Today, the area contains the largest concentration of high-capacity wood densification plants in the world (Figure 2).

Just why is the Lake States region a leader in the production of densified fuels? This probably can be attributed to a number of factors, including:

1) Minnesota imports almost all its fuel. A desire by state policymakers to lower this dependence has led to interest in alternative fuels and a push for legislation that provided incentives for fuel conversions and production.

2) The region has an available abundance of inexpensive wood residues.

3) The private sector is willing to invest capital in densified fuel production.

4) High winter space-heating costs encourages users to seek alternative fuel.

5) Oil shortages in some parts of the region during the early years of the energy crisis made users uncertain of the supply of conventional fuels.

6) Several key individuals from the industry have aggressively promoted wood fuels and developed markets.

7) It was cheaper to convert existing boiler systems to use densified fuels than to install new systems using green fuels.

Although there is a significant densified fuel industry in the region, it has suffered setbacks and reverses. In the early years, errors typical of a new industry were made: (1) insufficient analysis of the markets; (2) poor selection of equipment; and (3) faulty plant engineering. In recent years the marketplace has become highly competitive due to excess capacity. Price cutting has become commonplace and poor profit margins have resulted in the closing of several plants. Price cutting has also led to a reduction in product quality as firms have attempted to reduce costs in order to compete.

Very recently, excess capacity problems have been reduced due to the closing of several large pellet plants. Prices have stabilized and an effort has begun to produce a higher quality product.

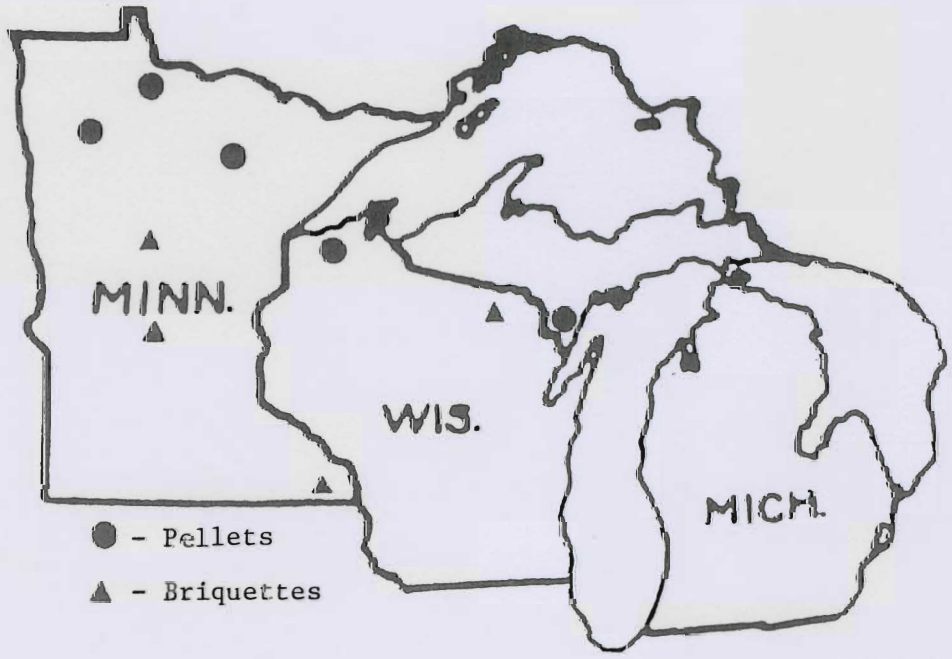

Figure 2. Densified wood pellet and briquette plants in the Lake States (November 1986).

The Aspen Fibre Corporation plant in Marcell, Minn. was the first pelletizing plant to go into operation in the Lake States. The corporation was established on April 3, 1977. A financing package was completed in late 1978, and construction began in April 1979. The processing plant came on line in December 1979, and began regular production in April 1980. That plant was constructed at a cost of approximately $2 million. Most of the equipment was obtained from an alfalfa pelletizing plant in Graston, Minn.

Table 3. Chronology of the development of densified wood fuels in the Lake States.

1977
*Aspen Fibre Corp. established.
1979
*Minnesota Coal Conference pushes for the use of wood for energy.
*Stillwater pellet plant ready for production.
*Aspen Fibre begins production of wood pellets.
*Mountain Iron, Minn. heating facility is Aspen Fibre's first customer.
*Laporte, Minn. school is the first school to use pellets.
1980
*Stillwater, Minn. pellet plant closes.
*St. Joseph and McGregor, Minn. schools begin using pellets.
1981
*Aspenol, Inc. purchases Stillwater plant and moves it to Gilbert, Minn. It also retrofits an agricultural pelletizing plant in Thief River Falls to use wood. Financial problems idle the company's plants.
1982
*Forest Fuels Corp. opens a pellet plant in Ino, Wis.
*Cole Forest Products begins production of wood briquettes.
*Durkee Manufacturing produces wood briquettes.
*Minnesota's Iron Range Resources and Rehabilitation Board (IRRRB) makes money available for heating conversions.
*Fiber Fuels Institute is established to promote use of all biomass fuels in Minnesota.
1983
*Legislation is passed in Minnesota to permit third-party financing of state facility heating systems for fiber fuel conversions.
*Blackduck Pressed Wood Products begins making briquettes.
*American Bio-energy, Inc. purchases Aspenol plant at Gilbert and goes into production.
*Northern Bio-fuels builds pelletizing plant in Crosby, Minn.
1984
*U.P. Bio-energy reopens a pellet plant in Menominee, Mich.
*Blackduck Pressed Wood Products closes.
*Cole Forest Products closes briquette operation.
*Rapid River Grain & Seed Co. in Baudette, Minn. begins producing wood pellets.
1986
*Gas and oil prices begin a dramatic slide. The price advantage pellets and briquettes once had no longer exists.
*Northern Bio-fuels closes due to fire.
*American Bio-energy closes due to residue quality and supply problem.
*Alternative Fuel Corp. opens pellet operation in Plymouth, Minn. using waste paper.
*Dynamic Resources opens wood pellet plant in Bagley, Minn.
*Maust Fiber Fuel begins production of fireplace logs in Preston, Minn.

About 1975 the operators of the sawmill adjacent to the future site of Aspen Fibre shut down their tepee burners because of air pollution problems; consequently, an outlet for disposal of mill residues was needed. At that same time there was a hay shortage due to a drought. This led to the idea of using the wood residues for cattle-feed pellets. Aspen Fibre worked in conjunction with the Minnesota Department of Natural Resources (DNR), the University of South Dakota, the University of Minnesota, and Cargill Corp. in developing pelletized animal feed. In 1977 the bottom fell out of that market due to lower costs of conventional feed. The company then decided to place the marketing emphasis on pellets as fuel for heating (28). The first wood fuel customer of Aspen Fibre Corporation was the heating plant for the town of Mountain Iron, Minn. It converted from coal to pellets to meet air quality standards.

In 1979, a pellet plant was built by Guaranty Fuels in Stillwater, Minn. The plant was designed to utilize chips from diseased elms and supply the Stillwater State Prison with pellets for heat. Allegedly due to residue supply difficulties, the plant failed (29). Nevertheless, the effort did serve to further the densified fuels industry. The construction of the Stillwater plant along with promotion of the idea by the Minnesota DNR created interest in densification and helped set the stage for expansion of the industry.

The major push for densified wood fuel use in Minnesota, led by Aspen Fibre, came in the fall of 1980. Coal-using schools were targeted first, because those institutions didn't required extensive conversions. The industry also targeted oil-burning institutions, which would require conversions of the boiler system. State programs providing loans to school districts for energy conversion to fiber fuels helped accelerate the conversion to fiber fuels.

The major reasons that schools converted to densified fuels are:

1. fuel costs were reduced;
2. densified fuels provided an alternative to oil, gas, and coal;
3. densified fuels represented a natural renewable resource;
4. densified fuel use provided in-state employment;
5. there was political pressure to convert; and
6. there was quick payback on wood fuel systems.

Beginning in 1980, a number of densification operations went into business. In 1982 and 1983, six new plants were built in Minnesota and Wisconsin. By 1984, however, four of these six new operations were no longer in production.

Fiber Fuels Institute

In December 1982 the Fiber Fuels Institute (FFI) was established. It soon became one of the driving forces in promoting the use of fiber fuels in the Lake States. Its main purpose is to promote the production and use of wood, agricultural residues, and peat to replace oil, gas, and coal.

FFI staff and officers have worked closely with legislators and government agency personnel. Thus, the institute has successfully assisted in forming public policy, encouraging public participation in the continuing development of the industry, and implementing public wood-energy programs.

The objectives of FFI have been to:

1. promote increased markets for fiber fuels;
2. educate business managers, institutional directors, and homeowners about fiber fuels;
3. provide a forum for the exchange of technical information within the industry; and
4. establish and publish standards for fiber fuels (5).

Past activities of the FFI include:

1. development of quality and performance standards and specifications for fiber fuels;
2. collection and dissemination of state government public policy documents related to the biomass energy industry;
3. research on activities pertaining to the intensive production of woody biomass material;
4. expansion of markets in the area of publicly owned and operated facilities, principally in Minnesota, through promotion of legislation to encourage the orderly conversion of public facilities; and
5. sponsorship of a trade show in the summer of 1984 and several technical conferences.

The current membership in FFI includes owners and operators of fuel production plants, machinery and equipment manufacturers, researchers, energy system engineers, and government officials.

Establishment of FFI was important to the industry because it educated potential users, gave credibility to the industry, and encouraged cooperation among fuel processors. Currently FFI is much less active than in the past due to the poor economic condition of the industry.

CURRENT STATUS OF THE INDUSTRY

Industry Infrastructure

Currently there are 10 densified wood fuel producers in the Lake States region and 10 producing plants elsewhere in the country (Table 4). The largest densified fuel producers are the pellet manufacturers. In Minnesota, pellets comprise over 90 percent of the densified wood fuel volume sold in 1985 (Figure 3).

Table 4. Producers of densified wood fuels, (November 1986).

Pellet manufacturers

1. Modoc Lumber Co., Klamath Falls, Ore.
2. Bio Shell of Canada, Hearst, Ont.
3. Bio Shell of Canada, Iroquois, Ont.
4. Bio Shell of Canada, Lac Megantic, Quebec.
5. Green Mountain Pellet Co., Gasset, Vt.
6. East Perry Lumber Co., Frohna, Mo.
7. Aspen Fibre Corp., Marcell, Minn.
8. Rapid River Companies, Baudette, Minn.
9. Forest Fuels Corp., Ino, Wis.
10. Northwest Pellet Mills, Brownsville, Ore.[1]
11. Lignetics Inc., Sand Point, Idaho.[2]
12. Mountain Energy, Livingston, Mont.
13. Bitterroot Timber Products, Darby, Mont.
14. U.P. Bio-energy, Menominee, Mich.
15. Dynamic Resources, Bagley, Minn.

Briquette manufacturers

16. Sonoco, Baker Div., Durkee Plant, Pine River, Minn.
17. Ferche Millwork Inc., Rice, Minn.

Fireplace Logs

18. Nagel Lumber Co., Land-O-Lakes, Wis.
19. Maust Fiber Fuel Inc., Preston, Minn.

1. Former Woodex plant.
2. Former Day Resources plant.

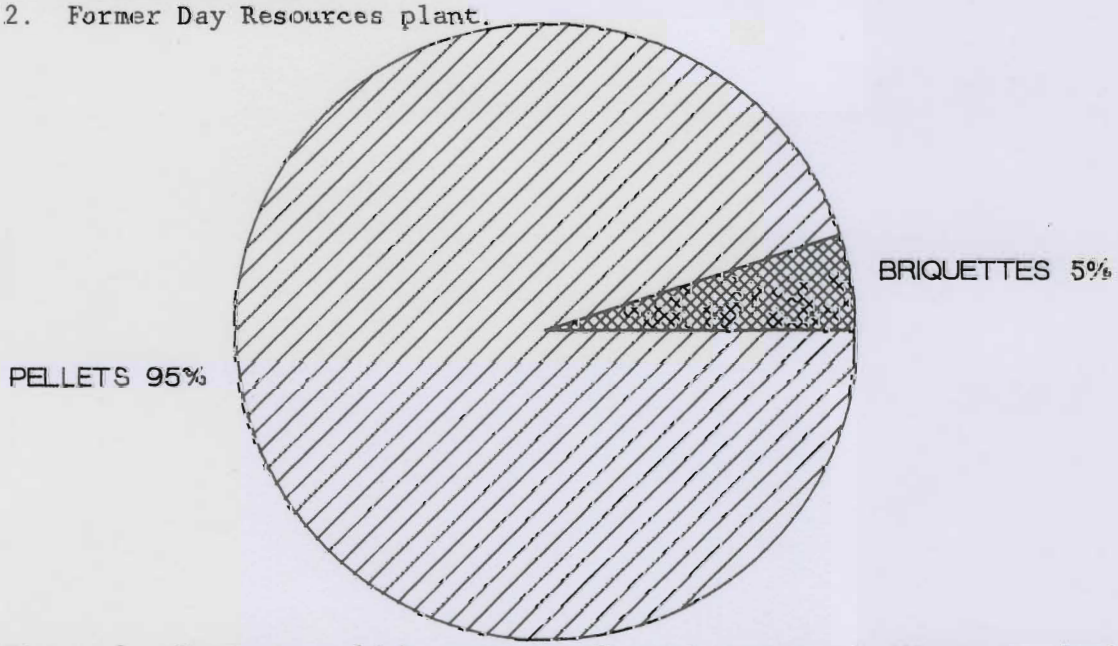

Figure 3. Products sold by percent of total tonnage in Minnesota during 1985 (4,8,14,16,30).

A major indicator of the growth of the densified wood fuel industry is the number of furnaces converted from coal, oil, or gas to wood pellets. The number of conversions in Minnesota has grown steadily since 1980, but is expected to level off and possibly decline in the near future due to lower oil and gas prices (Figure 4). Production of pellets and briquettes grew steadily until the 1985-86 heating season (Figure 5). Lower demand and the closing of several densification operations that season caused approximately a 20 percent reduction in production. The apparent increase in conversions but decrease in densified wood fuel production is probably due to lower pellet use by larger users, but an increase in the number of new smaller conversions. The figures are difficult to interpret, however, because the number of conversions is based on a calendar year while pellet production is based on a heating season (October - March).

Pellet and briquette manufacturers are quite different in their operations and business strategies. Pellet producers are characterized by large production capacities, high capital investments, and free-standing operations. In contrast, briquette production is usually a side operation to utilize wood waste, so production is much lower, and the capital expenditure for equipment is less.

Most pellet plants have capacities of 40,000 tons per year and have maximum design capacities of 5 tons per hour per machine, whereas briquette producers can only produce about 1.5 tons per hour, and most produce less than 3,000 tons per year (Table 5). Briquette plants typically operate only one machine.

Table 6 describes the products manufactured by companies listed in Table 5. Characteristics of pellets and briquettes are similar except for size and ash content. Briquettes have a lower ash content, mainly due to the utilization of clean residues from secondary manufacturing operations.

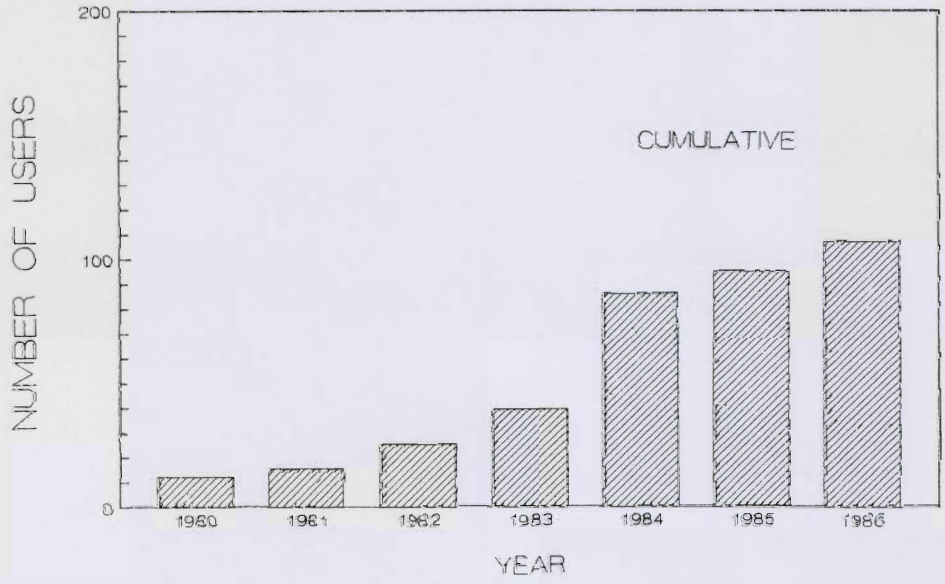

Figure 4. Cumulative number of densified wood fuel users in Minnesota (22,23,24,25).

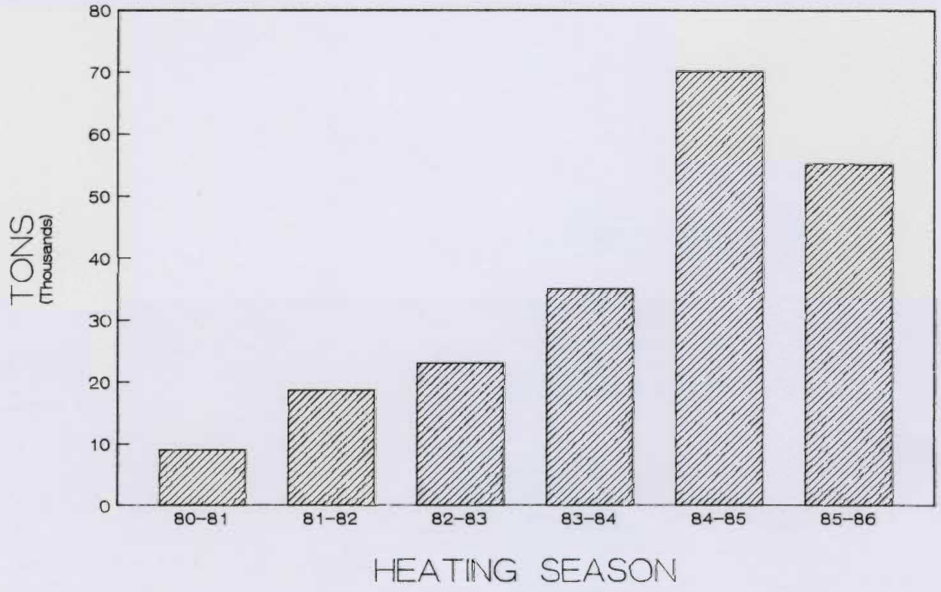

Figure 5. Tons of pellets and briquettes produced in Minnesota and Wisconsin (2,6,9).

Table 5. Summary of densified wood fuel producers in the Lake States region (1,4,17,26,27,32,33).

	Production Levels (tons/year)			
Plant	Maximum capacity	Current (Nov./86)	Excess capacity	On-site storage (tons)
Aspen Fibre	40,000	22,000	18,000	6,200
Nagel Lumber	15,000	-	-	-
Durkee	2,500	2,000	500	1,000
Rapid River	40,000	4,000	36,000	16,000
Ferche Millwork	4,000	1,000	3,000	2,000
U.P. Bio-energy	125,000	-	-	5,000
Forest Fuels	36,000	18,000	18,000	3,400
Dynamic Resources	20,000	10,000	10,000	200
Maust Fiber Fuel	11,000	11,000	0	2,000

Table 6. Product description of densified wood fuels produced in the Lake States region (1,4,17,26,27,32,33).

Plant	Type	Size dia.x l	Btu/lb	Ash %	Moisture %	Bulk Wt /CF (lb)
Aspen Fibre	Pellet	3/8" x 3/4"	8,100	3	<10	40
Durkee	Briquette	3" x 3"-5"	8,900	.55	7.5	50
Rapid River	Pellet	1/4" x 3/4"	7,800	1	<10	42
Ferche	Briquette	3.5" x 1"-5"	8,200	.32	5.8	55
U.P. Bio-energy	Pellet	3/8" x 1.5"	8,800	3	5.0	35
Forest Fuels	Pellet	3/8" x 3/4"	8,100	4	4-6	38
Nagel Lumber	Briquette	3.6" x 4"-12"	8,000	2.2	10	55
Dynamic Resources	Pellet	3/8" x 3/4"	8,500	2.8	7	40
Maust Fiber Fuel	Log	3.5" x 12"	9,100	.5	8	55

Marketing strategies differ somewhat between pellet and briquette producers. Since most pellet producers produce only pellets, they must obtain a profit from the sale of pellets to continue operating. Their main goals are to make a profit and minimize per-unit costs through market expansion. In contrast, briquette producers utilize residues from their primary manufacturing operations that otherwise would be landfilled or hauled away. The primary goal of the briquette producers has been to eliminate the cost of disposing of residues, and to make a profit if possible. Briquette manufacturing is not the main business of these firms, and its contribution to profits of the firm is not generally critical to the viability of the company.

Expected Product Demand

Current densified wood fuel demand in Minnesota is approximately 36,000 tons/year (8). As stated earlier, this demand is expected to be level or even decline slightly for the next several years because of low prices for oil and gas. Also, competition from alternative fuels such as paper pellets, refuse-derived fuels (RDF), and agricultural pellets is likely to intensify. A sharp increase in fossil fuel prices will have to occur before product demand will increase.

Pricing

Previously, pellet and briquette pricing benefited from the continuing upward spiral of fossil fuel costs. Pellet prices rose from approximately $34 per ton in 1981 to over $50 per ton in 1986. If oil and gas prices remain steady at 1986 levels it is unlikely that densified fuel producers will be able to obtain higher prices for their product. Current prices leave a very thin profit margin, and continuation of recent price cutting may lead to lower quality pellets and more plant closings. If the densified wood fuel industry is to enjoy long-term health, selling prices will have to increase in relation to production costs.

Transportation Methods and Costs

Each mill is different in its procurement and distribution methods. In some cases feedstock is obtained from adjacent manufacturing facilities. In other cases sawmills or independent truckers bring in the feedstock. Other producers pick up residues using their own trucks.

The delivery process for densified wood fuel products also varies from producer to producer. Some buyers haul their own fuel, but in most cases producing plants will provide contract trucking to deliver processed fuel. Transportation costs are about $1.60 to $1.85 per loaded mile. Thus, for a 24-ton load, the average cost is $0.07 per ton per mile. Fuel sales contracts are usually based on a heating season and are renegotiated every year.

ECONOMICS OF USE AND PRODUCTION

Economics of Use

Fuel costs. The main reason people use densified fuels is the cost savings over alternative fuels. Since solid fuels such as pellets are less convenient than oil or gas, there must be a cost savings over these other fuels to develop a market. Thus, one of the keys to a successful densified fuel business is to maintain a cost-competitive advantage over other fuels.

Fuels cannot be compared on a cost per ton basis, but rather on the basis of cost per unit of delivered heat value. The best comparison is on a cost per million Btu basis, taking into consideration heat content and overall efficiency of the combustion system (Table 7).

Since January 1986 fuel oil and gas prices have dropped sharply. This has narrowed the cost advantage of wood pellets over liquid fuels, making it difficult to expand the demand for densified fuel.

Densified wood fuel has been attractive in the past because it has been cheaper than liquid fuels, is cleaner burning than coal, provides rapid paybacks on furnace retrofits, and is a local source of energy.

Table 7. Typical costs of various heating fuels in Minnesota (March 1987).

Fuel	Cost	Heat Content	Efficiency[1]	Cost/MM Btu
Green wood chips	$15/ton	4,250 Btu/lb	65%	$2.71
Densified wood	$50/ton	8,000 Btu/lb	78%	$4.00
Coal	$45/ton	9,000 Btu/lb	75%	$3.33
Natural gas	$4/mcf	1,000 Btu/cuft	80%	$5.00
#2 Oil	$.50/gal	138,000 Btu/gal	80%	$4.53

[1] Typical efficiency for combustion systems; will vary widely.

Equipment costs. The economic feasibility of using densified wood fuels depends not only on fuel cost, but also on capital investment and operating costs. For residential heating, a densified fuel heating system is relatively simple, being similar to a stoker-fed coal system. But for installations calling for large energy output, densified wood fuel systems can be complex and costly. Equipment required for the use of densified wood fuels includes handling and storage equipment, control systems, pollution abatement equipment, and energy conversion equipment.

Densified wood fuel systems have higher capital investment requirements (except retrofits) and operating costs than natural gas or fuel oil systems. Therefore, sufficient savings must be obtained from the lower cost of pellets to allow a reasonable return on the capital investment (20).

Costs Relative to Green Fuels. The relative economics of pellets and green wood fuels must also be considered. Often the most reliable and economic wood-using systems for industrial firms using process energy are green fuel systems (8). A report by Steklenski and Haygreen (34) provides a detailed analysis of the costs of energy from pellet and green fuel systems.

The price differential between pellets and chips is the major factor determining the cost competitiveness between green chip and densified wood fuel energy systems. Green fuel systems generally require a higher capital investment for combustion systems, but the lower price per million Btus of fuel often makes it a more economical alternative. Larger wood energy systems have lower delivered energy costs than small systems because the larger process heat systems operate a greater number of hours per year, may operate near system capacity and can take advantage of economies of scale. These factors result in lower cost of capital recovery per unit of delivered energy.

Economics of Production

Densification of wood fuels requires labor, capital, and energy. the processing required increases the cost of densified wood fuel considerably over that of nondensified fiber fuels. The U.S. Office of Technology Assessment (36) approximated the manufacturing cost components of wood pellets (Figure 6). Assuming that the green feedstock price is $15 per ton ($2.00/million Btu) and that 14% of the feedstock is consumed to provide the energy to dry the feedstock, pellets cost about $46 per ton ($2.90/million Btu) to produce.

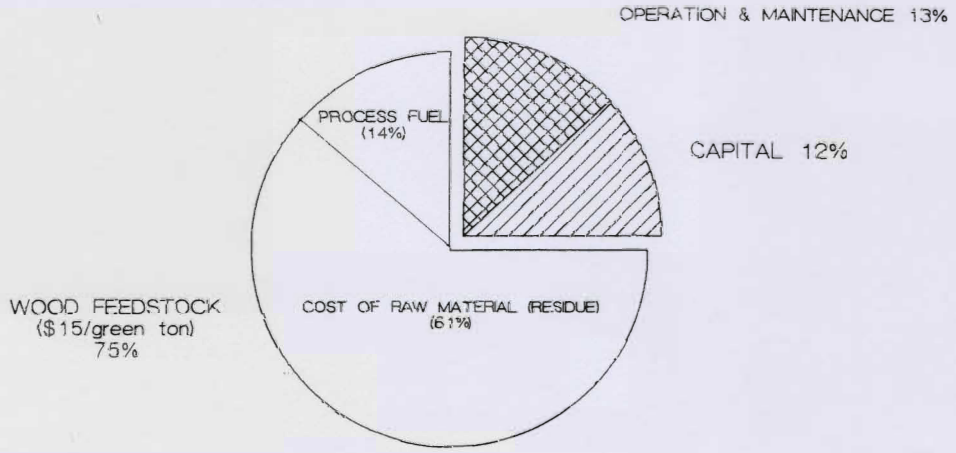

Figure 6. Cost shares of wood pellets (36).

The economics of production is very site- and time-sensitive, depending on the particular feedstock, market, and general economic conditions. Cost factors affecting the commercial feasibility include the initial capital investment, type of feedstock, operation and maintenance cost, and transportation cost (20).

Residue costs have the strongest influence on the production cost of pellets, whereas variations in capital investment only affect the selling price approximately 5% to 15% (35). The least costly feedstock is mill residue obtained from primary wood processors, currently available for approximately $0 to $10 per green ton plus transportation costs. The higher cost of logging residue and whole-tree chips ($12 to $25 per green ton) makes these feedstocks less desirable.

Transportation costs can have a significant impact on total costs due to the low energy density of the biomass feedstock and the large volume required. Shipping costs per mile for a densified fuel product are about half of that for raw feedstock.

Operation and maintenance costs include general and specialized labor, energy costs, and machinery parts and supplies. Energy costs for densification depend on moisture content, size and type of feedstock, and the specific production process and equipment used.

Production volume sharply affects overall conversion costs per ton since many of the costs are fixed rather than variable (16).

Several feasibility studies have focused upon the production of pellets in the Lake States region. A report prepared by the Arrowhead Regional Development Commission (ARDC) (1) cited a Minnesota DNR/U.S. Forest Service report that estimated the production costs of wood fuel pellets. That report used 1979 cost figures provided by three pellet plants in Tennessee, Vermont, and Minnesota. Also reported in the ARDC paper were 1983 estimated costs provided by regional pellet producers. Current costs would be higher due to inflation. Tables 8 and 9 summarize both estimates.

Table 8. Estimated production cost per finished ton of pellets (excluding raw material costs) (1).

Item	MDNR/FS (1979)	Producers (1983)
Utilities, electric	$4.60	$5.50
Utilities, furnace, fuel oil	3.00	3.00
Maintenance	4.41	8.00
Labor	2.48	6.50
General/Administration	----	3.00
Depreciation & interest	2.88	12.80
Total Production Cost	$17.37	$38.00

Table 9. Estimate of delivered selling price (feedstock, production, and delivery costs) per finished ton of pellets (1).

Item	MDNR/FS (1979)	Producers (1983)
Raw material	$18.70	$14.50
Production cost	17.37	38.00
Total break-even cost	36.09	52.50
12% margin	4.33	6.30
Pellet price F.O.B. mill	40.42	58.80
Freight[1]	5.28	5.28
Delivered selling price	$45.70	$64.08

[1] 80 miles at $1.65/mile in 25-ton van.

In 1977 an engineering and economic analysis of a wood pellet plant was done for the Koochiching-Itasca Community Action council (15). Figures cited in the report were based upon costs at Aspen Fibre Corporation and at another plant that produced alfalfa pellets. That information was used in estimating the production costs of pellets produced in other new plants assuming a level of investment of $1.1 million. Monthly operating cost estimates at three production levels can be found in Table 10.

The 1977 findings should be interpreted cautiously because the Aspen Fibre plant has some unique conditions. Used equipment was utilized in construction; furthermore, administrative costs are shared with the adjacent sawmill (15). Used equipment might reduce capital investments and thereby lower the cost per ton of finished pellets. However, maintenance costs may be higher with such equipment.

Table 10. Monthly operating cost estimates for wood pellet plant at three production levels (1977 dollars) (15).

	PRODUCTION LEVEL (tons/day) 65 (1 shift)	105 (2 shifts)	135 (3 shifts)
OPERATING COSTS			
Labor & overhead	$ 3,600	$ 5,500	$ 7,880
Administrative wages	5,200	5,800	6,200
Depreciation	13,100	13,100	13,100
Interest	6,000	6,000	6,000
Insurance	2,200	2,200	2,200
Power	1,320	1,900	2,400
Property taxes	292	292	292
Office rent & supplies	175	175	175
Telephone	450	450	450
Supplies & maintenance	1,452	2,300	3,000
Outside maint. services	198	320	400
Travel	200	200	200
Legal & accounting	460	460	460
Miscellaneous	553	890	1,130
Subtotal	$35,200	$39,587	$43,887
Cost/ton	26.67	18.63	16.02
Feedstock @ $15/ton	19,800	31,875	41,100
Total costs	55,000	71,462	84,987
Cost/ton	$41.67	$33.63	$31.02

It should be kept in mind that data in Tables 8, 9, and 10 are in 1977, 1979, and 1983 dollars and so may not reflect current costs of producing wood pellets. Furthermore, some cost assumptions in the 1977 report were based on alfalfa pellet production, which is less costly than wood pellet production. What this information does provide is a general idea of costs, the equipment used, and percentage of the cost contributed by the various cost components.

Another analysis has been done by Energy Resource Systems (7). Cost data are also based on figures from a pellet plant in Minnesota. Estimates in this study are expressed in 1986 dollars, and thus give the best idea of what a new pellet plant would cost today. The cost breakdown is as follows:

Capital costs, including a hog, drier, fine grinder, mill(s), and cooler, would be $1.8 million for a 100 ton/day plant and $3 million for a 200 ton/day plant. The plant would use about 100 kwh/ton (1200 hp) and have a maximum capacity of 5 tons/hr/machine.

Variable costs, including labor, maintenance, power, fuel and raw material at $5/ton, would be $28/ton. Two tons of green feedstock is equal to one ton dry product at 8% moisture content. Fifteen percent green feedstock would be consumed as dryer fuel.

Fixed costs (with plant capital costs at $1.8MM), including debt service, depreciation, administrative and office costs, and insurance would be $12 to $14/ton.

Total costs under this scenario would be $40 to $42/ton. Assuming transportation at $0.08/ton/mile for 50 miles and 10% profit, the sale price would be $50.00/ton. Any firm interested in densified wood fuel production should conduct a thorough economic feasibility study since variables such as method of recovering capital, cost of labor, and cost of raw materials are highly operation- and site-specific.

MARKETING

Present Situation

The densified wood fuel industry to this date has had a strong production, rather than marketing, orientation. As a result, marketing research and development has not received as much emphasis as might have been desirable for a new industry attempting to penetrate a market dominated by large, well-financed firms, although a few firms did launch marketing efforts. Market planning was not strong during the start-up of the industry and many entrepreneurs overestimated the number of potential customers.

Currently, no pellet manufacturing company in the Lake States has a full-time sales person, and some have no sales staff. There is a definite need for a well-organized marketing effort for the industry as well as for individual firms.

Production and use is heavily oriented to the winter heating season, and thus it is a very cyclical business. Producers must have large storage facilities to house inventory for peak demand periods, which causes high inventory costs.

The lack of extensive marketing has resulted in very limited public knowledge of densified fuels. Most potential users learn of densified fuel through word-of-mouth and personal selling. Forms of promotion used to date include representation at trade shows and promotion by federal and state wood energy programs and the FFI.

An intensive industry-supported advertising effort might benefit producers and increase the awareness of various marketing sectors. This could be done through mailings, personal contacts, or trade advertising. Unfortunately, the present economic problems in the industry seem to preclude such an effort. Also, the most cost-effective marketing strategy, given the specific nature of potential users, has not been determined.

The most common use for densified biomass is as fuel, although aspen pellets are also used for livestock feed. Currently there is not much active promotion in livestock feed markets.

Distribution Channels

Most densified wood fuels are distributed directly from the producer to the end user. However, there are a few wholesale distributors who sell to small users as part of another business such as selling wood stoves or hardware. A few years ago there was an effort to develop a wholesaler network, but there was not enough margin in delivered prices to make it profitable.

Present and Potential Markets

Pellets and briquettes have until recently served much the same markets. However, the use of the much larger briquettes is limited by combustion system and handling equipment design. Briquette manufacturers also have recreational markets open to them since some can produce "logs" and market them for fireplace use. Currently, briquette producers are focusing almost exclusively on the residential retail market. Potential densified fuel users in Minnesota include:

1) schools (heating)
2) government and public building (heating)
3) private industrial establishments (heating & process energy)
4) residential (heating).

In 1986 in Minnesota there were approximately 54 schools, 16 government/public buildings, and 37 private businesses/organizations using densified wood fuels (25).

Schools comprise the largest segment of present users, with government/public buildings and industrial users next. The residential sector is very small (Figure 7).

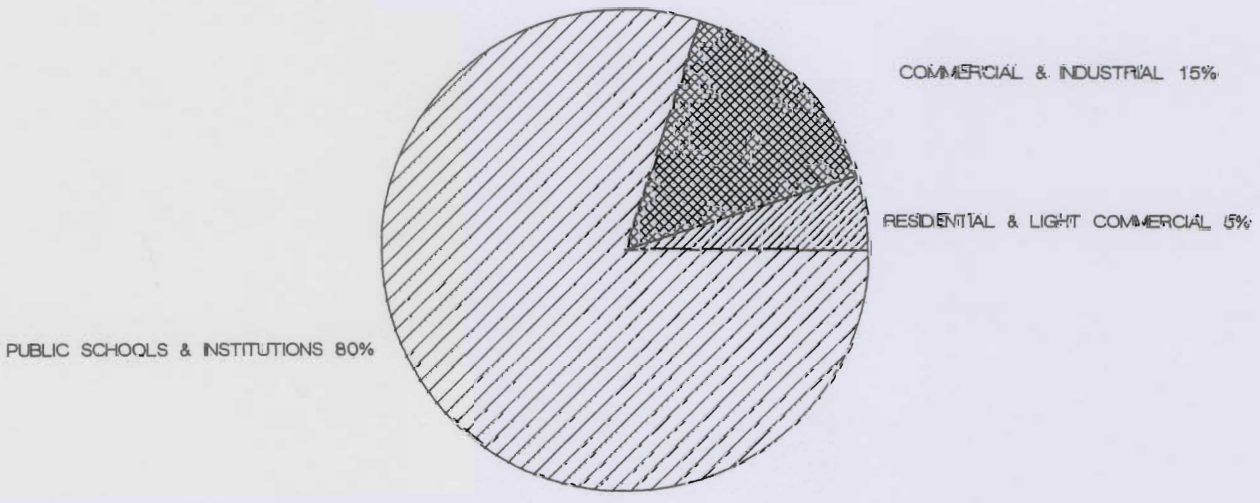

Figure 7. Densified wood fuel markets in the Lake States based on tons sold during the 1985-86 heating season (8).

The most potentially profitable market for densified wood fuels is the industrial process energy market, since it would provide a year-round demand. (Process energy is heat or steam generated to operated a manufacturing process, such as a paper mill or lumber dry kilns.) Unfortunately, this is a difficult market to penetrate for several reasons. First, as explained in the economics section, often the most reliable and economic wood-using process energy systems are green fuel systems. Second, some early conversions in public institutions were technically inadequate. Word of these problems discouraged some potential users in the industrial sector. Third, there was never a serious effort by the densified wood fuel industry to penetrate this market.

The institutional market, characterized by customers such as hospitals, was once viewed as quite promising due to prospects for financing conversions to densified wood fuels through third party financing loan programs (see governmental programs section below). But the institutional market hasn't developed, due at least in part to problems with some conversion systems resulting from high ash content of fuels.

Another market currently being sought by producers is the commercial segment, e.g., manufacturers and dairy processors, but this opportunity hasn't developed as hoped. The main problem appears to be that many of these firms are looking for convenience with their energy systems and don't want to spend money on costly conversions. It has been observed that those in charge of the energy systems are risk averters who want to avoid down time. They are not as concerned about how much they are saving in operational costs as they are about keeping the system running smoothly. The densified wood fuel industry must eventually develop a reputation for reliability and ease of operation if it is to expand into such markets.

There are several types of residential systems available to burn densified fuels. However, for the most part pellet producers are not actively pursuing the residential market because of an apparent lack of profitability. Low profits in the residential market are due to the following factors:

1) high cost of home conversion;
2) need for a wholesaler network;
3) higher handling costs; and
4) higher transportation costs due to small loads.

Although the residential market is not yet profitable, some industry leaders feel there is substantial opportunity for growth due to the ease of operation for users of fully automatic burning systems, and higher air quality when burning pellets as compared to cordwood.

Marketing Strategy

The firms in this industry that survive the current difficult times will have several characteristics in common: a good residue supply, a strategic location to markets, and an effective marketing strategy.

Marketing strategy is most critical when attempting to market a densified fuel. A firm should (7):

1) identify means to obtain industrial process markets for year-round demand;

2) be able to provide information about energy equipment conversions for new users, including information on conversion costs and equipment options;

3) know the characteristics of the fuel being sold, including heat output, proximate analysis, and ash fusion temperature;

4) know costs and characteristics of the competing fuels; and

5) aggressively analyze potential markets and develop specific strategies to meet their needs.

A better understanding of fuel-users' motivations for utilizing densified fuels is needed in order to estimate the potential market. Motivation for using wood fuels is likely to be mainly economic although non-economic factors such as reliability of supply may also be important. The economic factors can be better understood by looking at three characteristics of the fuel user:

1) the type and cost of fuel currently used
2) annual fuel consumption
3) age of the existing heating system.

Information on the fuel type and fuel cost will identify the users who are faced with high costs per unit of energy. Annual fuel consumption is an important consideration since it indicates how great the savings can be with a less expensive densified fuel. The age of the existing heating system suggests which heating systems are subject to replacement (18). If replacement is necessary then the opportunity to sell the advantages of wood fuel is much better than if the user has a relatively new oil or gas system.

The following marketing strategies may be applicable in certain situations:

1) **price discount strategy**, which offers buyers a product of quality comparable to a competitive nondensified wood fuel product at a lower price;

2) **improved-services strategy** (e.g., improved delivery schedules and routes) that would challenge the market leader by better serving buyers;

3) **manufacturing-cost-reduction strategy**, which could help increase market share by lowering manufacturing costs with subsequent savings passed on to customers; and

4) **intensive advertising campaign** to stimulate customer awareness in the various market sectors, either through personal contacts, mailings, or trade advertising (35).

Public Sector Support

One of the major reasons for the high concentration of densified fuel plants in the Lake States region is the environment created by public agencies to promote the use of densified fuel. However, it wasn't until after the first pellet plants went into operation that there was an emphasis from government agencies on the use of wood for fuel.

In the late 1970s two "Minnesota Coal" conferences in Brainerd brought together industry and government leaders to look at the use of wood for energy. It was at this time that public sector interest and support began to increase.

Federal government actions which contributed to biomass fuel development began with the Arab oil embargo. The Energy Tax Act of 1978 gave investors a 10 percent federal tax credit in addition to the normal 10 percent investment tax credit when they invested in wood conversion facilities. This program is no longer in existence. In addition, a financial program was established by Congress to encourage investment in wood energy projects. One program provided credits for the production of densified wood. In some cases this program led to capital investments in projects with a unusually high level of risk. Congress also provided financial support programs for schools and hospitals converting to wood energy (37).

Minnesota has taken the lead in providing an environment that stimulates private and public sector organizations to use fiber fuels. Programs that have contributed to the Minnesota densified fuel industry include:

1) a Department of Energy and Economic Development (DEED) program that provides 50 percent matching grants to public, nonprofit private schools and hospitals for energy conservation measures, including biomass energy retrofits;

2) state tax credits for businesses participating in new technology transfer, including biomass energy technology, although this program hasn't helped the densified fuel industry to any great extent;

3) the School Energy Investment Loan Program, which provides loans to public school districts for energy conservation measures, including biomass energy retrofits;

4) an IRRRB program--one of the most helpful to the industry--that provides loans and grants to public institutions in northeastern Minnesota for boiler conversions to use fiber fuels; and

5) a Shared Savings program that permits the state and its municipalities to lease energy conservation equipment (including fiber fuel burning systems) from private companies and provides for loan repayment through sharing of energy cost savings.

The shared fuel savings program hasn't helped the densified wood fuel industry as much as originally hoped (12) for several reasons. First, most state-operated facilities that would consider conversion under the shared fuel savings program are of the size that would best utilize a suspension

burner. However, ash fusion problems have been experienced with suspension burners due to high ash content in the pellets. Furthermore, implementation of the program required a large amount of administrative paperwork discouraging its use. Lastly, green wood fuel systems were more economical for this type of user.

Most of the early assistance for fiber fuels came from the Minnesota DNR Marketing and Utilization Program in the form of information publications, media promotions and programs, individual energy conservation analyses, demonstration projects, and other technical assistance.

An excellent source of further information for those interested in fiber fuels is a DNR annual report, "Status of Fiber Fuel Use in Minnesota." The report contains a history of fiber fuel use; a list of fiber fuel suppliers, resources, users, and consultants in Minnesota; and sources of fiber fuel information.

DEED is legislatively designated as the lead biomass energy agency in Minnesota. Besides loan and assistance programs, DEED has been working on a project, initially conceived by FFI, to develop fuel standard specifications for solid biomass fuels. Other projects of DEED include the issuing of industrial bonds to fund biomass and energy-related businesses, an Energy Loan Insurance Program, and engineering and technical assistance for biomass energy innovators encountering technical difficulties.

The Energy Loan Insurance Program insures fixed assets or capital improvement loans made by private lenders for qualifying energy projects. The program is used primarily for new or developing companies and will insure up to 90 percent of the amount of investment loans.

Another factor favoring densified fuel use in Minnesota has been the tenure of a governor who has encouraged legislation and developed an atmosphere conducive to the use of fiber fuels.

Michigan and Wisconsin also have governmental programs encouraging densified wood fuel use, although they are not as extensive as those in Minnesota. A project funded through a grant from the Wisconsin Department of Administration demonstrated small-scale commercial and residential wood pellet heating. The Wisconsin Energy Development and Demonstration Grant Program also has funded various programs concerning the use of wood pellets.

A Michigan Alternative Energy Board has been actively involved in the promotion of densified wood fuels within the state. A proposal was submitted by the Board to distribute wood pellets and furnaces to senior citizens, low-income families, and handicapped people. As a result, in 1984 a $937,000 federal grant was obtained for the program, resulting in construction of a pellet plant in Menominee, Mich.

INDUSTRY TRENDS

Despite the low current public interest in wood fuels, new industrial developments are occurring. Two pellet plants in the western United States that were closed earlier have been purchased and are resuming production. In the eastern United States a new mill is being built in Maine and an old plant in Vermont has gone back into production. In the Lake States, the U.P. Bio-energy plant in Michigan's upper peninsula has reopened.

As of May 1986 there were several plans for pelletized fuel production from municipal waste in Minnesota. There was also a pellet producer in the Twin Cities area using waste paper as the feedstock.

A project initiated by International Bio-Fuels, Inc. in collaboration with the Seaway Port Authority of Duluth is underway to market densified wood fuels to Africa and other fuel-poor Third World regions. A 250,000 ton per year wood-densifying facility is planned for Duluth to produce pellets for export (18). Construction costs are estimated at $11 million. The plan calls for procuring raw material directly from the forest, utilizing unmerchantable hardwoods. The briquettes would be shipped in 50-pound or 50-kilogram bags via the Port of Duluth (19). This plan is based upon extensive market research and testing of the acceptability of the wood fuel product in selected countries in Africa.

ISSUES AND OPPORTUNITIES

If the Lake States densified wood fuel industry is to grow a number of problems must be overcome.

One of the major problems facing the industry today is that the selling price for densified wood fuel is not likely to increase significantly, due to low gas and oil prices. The current price does not provide an attractive profit for the average producer. This situation obviously is beyond the control of the producers or region. Nonetheless, densified fuel is a satisfactory and cost-effective fuel for many users and some producers can produce at a price which allows them to remain in operation.

There are other factors, however, over which producers have some control. These factors which are of major concern today relate to fuel quality, supply reliability, and the lack of training for boiler operators. These problems affect the consumer directly. More specifically, the problems for the users of densified fuel systems are:

1) In some cases, boiler operators and maintenance staff were left out of the decision to adopt the densified wood fuel system, and thus these people are not committed to the system and to making it work.

2) Labor costs are increasing, and densified wood fuel systems are more labor intensive than the oil/gas systems they replace. Thus, the economic advantage is being eroded.

3) Mechanical costs due to the more complicated fiber fuel system have been higher than anticipated by some users.

4) Installation delays and problems have been too frequent.

5) A lack of properly trained people to operate the densified wood fuel systems has created dissatisfaction and inefficient operation of the boiler system.

6) Fuel quality (ash and fines) has been highly variable between suppliers and even between shipments, causing dissatisfaction.

7) Erratic supply, resulting from the closing of some plants, has inconvenienced some users.

Many of these problems could be reduced if there were better communication among users, fuel suppliers, and equipment suppliers.

Efforts are being made to correct these problems. The industry needs satisfied customers if it is going to survive. Efforts are underway by fuel producers to find new markets, higher quality pellets are being offered that are lower in ash content, better communication is being established between users and suppliers, and plans are underway by one equipment supplier to provide technical training seminars on furnace systems for users.

The availability and cost of residues is an important issue within the industry. Currently, the only economically feasible feedstock for most producers is mill residue. With the growing waferboard industry, the new paper mill in Duluth, Minn., and greater in-house use of residues by the forest industry, there is a growing concern as to the long-term availability of these residues. With increased competition for existing residues, it may not be possible to continue to secure feedstock until densified fuel prices rise sufficiently to make the use of woods/logging residues economically viable. Therefore, when locating any new plant it is important to consider the residue sources. Those plants that have been the most successful have a good residue supply, usually from adjacent wood-processing operations.

In such difficult times it can be said that those producers who have stayed in business for more than a few years could be considered successful. From analyzing the history of the industry, a number of factors appear to have contributed to the successful operations:

1) a dependable and inexpensive residue supply;

2) marketing research to identify existing markets;

3) adequate storage for peak seasonal demands, since reliability of supply is very important to users;

4) location of production facilities close to residue sources and markets to minimize transportation costs; and

5) proper plant layout and equipment selection for the most efficient production.

In addition, there are some areas for improvement that the current industry needs to consider, whether for a new plant or an existing operation:

1) correct manufacturing equipment and feedstocks to produce the quality of pellet desired by the user;

2) marketing and sales efforts directed toward the needs of specific user groups;

3) a cost-competitive quality product (quality is generally equated to low ash content--less than 3%);

4) a customer assistance program to insure the proper installation of conversion systems;

5) adequate training for operators of a customer's energy systems; and

6) a strong industry association, such as FFI, to promote product standards and coordinate industry-wide marketing efforts directed at consumer groups.

From the situation described in this study it seems likely that higher product quality, good communication between users and producers, and continued governmental support will ensure future growth of the densified wood fuel industry, particularly when oil and gas prices increase again. The industry can be expected to consolidate further with the most efficient plants surviving. Innovative market strategies need to be developed to attract specific groups of energy users.

In the long term, densified wood fuels have a definite niche in the Lake States energy picture, providing opportunity for utilization of a natural renewable resource, and promising reduced export of dollars to energy-rich regions. Thus, the industry will survive the currently difficult times and is likely to become a more important factor in the Lake States mix of energy resources.

LITERATURE CITED

1. Arrowhead Regional Development Commission. 1983. Minnesota Processed Wood Fuels Considerations for Export Opportunities. 35pp.

2. Aspen Fibre Corp. 1986. Information sheet.

3. Biomass densification: finally on its feet. 1983. Forest Industries 110(1): 45-49.

4. Ferche, Al. 1983. Personal communications. Ferche Millworks, Rice, MN.

5. Fiber Fuels Institute Newsletter. 1983. April.

6. Fiber Fuels Institute Newsletter. 1984. May/June.

7. Fisher, Jim. 1986. Personal communications. Energy Resource Systems, MN.

8. Fisher, John. 1986. Personal communications. Aspen Fiber Corporation, MN.

9. Fisher, John. 1986. Fiber Fuels Institute annual meeting. Plymouth, MN. May 1.

10. Flowers, L., D. Junge, M. Levi, and M. O'Grady. 1983. Technical and Economic Review of Wood Energy Systems for Military Bases. Solar Energy Research Institute. Golden, CO. 184pp.

11. Grahm, M. 1985. Process Variables in the Production of Densified Wood Fuel with the Addition of Coal Fines. M.S. Thesis, University of Minnesota, St. Paul, MN. 145pp.

12. Great Lakes Regional Biomass Energy Program. Directory: Great Lakes Region Biomass Energy Facilities. 1985. 282pp.

13. Houston, J. 1981. Pelletized fuels: the emerging industry. Wood 'n Energy, Jan. pp. 28-31.

14. Kline, Al. 1986. Personal communications. Baker Div. Durkee Plant, Pine River, MN.

15. Koochiching-Itasca Community Action Council. 1977. Engineering & Economic Analysis of a Model Plant to Pelletize Wood Residues. December. 16pp.

16. Larson, Larry, 1986. Personal communications. Rapid River Grain and Seed, Baudette, MN.

17. Maust, Bob. 1986. Personal communications. Maust Fiber Fuels, Preston, MN.

18. McCartney, W. 1986. Fiber Fuels Institute annual meeting. Plymouth, MN May 1.

19. McCartney, W., D. Helberg, and A. Barry. 1985. Applying Minnesota - Wisconsin Wood Fuel Resources in Developing Countries, Project Concepts and Opportunities for International Development Organizations. October 3. 8pp.

20. Minnesota Department of Energy, Planning and Development. 1983. Bio-energy in Minnesota: Fiber Fuel Development Boiler and Fuel Resource Survey. 57pp.

21. Minnesota Department of Energy, Planning and Development and The Seaway Port Authority of Duluth. Minnesota Processed Wood Fuel Industry, A Study of International Opportunities. Feb. 18, 1983. 329pp.

22. Minnesota Department of Natural Resources. Status of Fiber Fuel Use in Minnesota with Emphasis on Automated Systems. November, 1983. 13pp.

23. Minnesota Department of Natural Resources. Status of Fiber Fuel Use in Minnesota with Emphasis on Automated Systems. February, 1984. 38pp.

24. Minnesota Department of Natural Resources. Status of Fiber Fuel Use in Minnesota with Emphasis on Automated Systems. February, 1985. 12pp.

25. Minnesota Department of Natural Resources. Status of Fiber Fuel Use in Minnesota with Emphasis on Automated Systems. May, 1986. 18pp.

26. Nelson, Norman. 1986. Personal communications. Dynamic Resources, Bagley, MN.

27. Nordine, K. 1986. Personal communications. Nagel Lumber Co. WI.

28. Paulson, J. 1982. Bark and sawdust no waste at Aspen Fiber. Herald-Review-Grand Rapids, MN, 4 April, p.16.

29. Quads. 1979. Forest Service, U.S. Dept. of Agriculture. No. 7. August.

30. Quads. 1985. Forest Service, U.S. Dept. of Agriculture. Vol. 2, 2. Sept.

31. Resch, H. 1982. Densified wood and bark fuels. Holzforschung and Holzverwertung. 34(4): 69-74.

32. Sameloff, M. 1986. Personal communications. U.P. Bio-energy, Menominee, MI.

33. Schultz, K. 1986. Personal communications. Forest Fuels Corp., Ino, WI.

34. Steklenski, P. and J. Haygreen. 1983. Analysis of the Delivered Energy Cost and Equipment Requirements of Wood Energy Systems Utilizing Wood Chips and Pellets. Unpublished report for USDA-NCFES. 218pp.

35. U.S. Department of Energy. 1982. A feasibility study of the commercial production of densified biomass fuel at Klamath Falls, Oregon: Final report. 250pp.

36. United States Congress. Office of Technology Assessment. 1980. Energy from Biological Processes. p.71.

37. Wheatcraft, A., P. Ellefson, and D. Bradley. 1984. Forest Residues in Northeastern Minnesota: Policy Options To Encourage Management and Use. Univ. of Minn. Dept. of Forest Resources Staff Paper Series Number 44. 59pp.