Assessing the Technology Options for Creating a BIOHEAT Industry in Alberta

Final Report

Presented to

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Executive Summary

In industrialized countries heat-related energy applications represent the largest energy demand of most nations. The rising cost of natural gas and heating oil along with the need to reduce greenhouse gas (GHG) emissions have created growing interest in bioenergy for commercial heating applications. Relative to other biofuel options, bioheat from fuel pellets represent one of the most economically efficient means to displace fossil fuels in industrialized countries and can be developed from non-food crops on marginal lands.

The efficient densification of herbaceous biomass is an essential factor in the development of fibre sources such warm season grasses and crop residues from the agricultural sector. The province of Alberta has a longstanding experience with biomass densification and should have little difficulty in developing the leading technical experience necessary to produce high quality densified fuels for solid biofuel applications. The most important factors found necessary to make high quality pellets from fibrous grass feedstocks were fine grinding with the use of hammermill screens of 3-32"- 7/64", use of high quality saturated steam of at least 90°C, and use of pellet die with an L/D of 8.5-9:1. Research studies and practical experience also are demonstrating the viability of producing high quality fuel briquettes from highly fibrous agricultural feedstocks. This appears to be an important strategy to create low cost regional biomass conversion facilities and to reduce delivered costs of densified fuels to commercial fuel users. The biomass energy pellet industry is now in rapid development with 442 biomass pellet plants globally. This has stimulated a dynamic pellet machine manufacturer sector especially in Europe. Some recent technological innovations in pelleting have been developed and are entering the marketplace. However the energy pellet industry is largely based on an improved version of the annular roll and die system.

Historically, the biggest barriers to the developed of densified agricultural feedstocks as fuel sources have been serious problems with combustion of these feedstocks. The main outstanding challenge has been how to burn these fuels without causing problems with clinker formation and boiler corrosion as well as avoiding the creation of ambient air pollution. A very rapid technological development of small and medium scale combustion systems is occurring globally as a result of the pressing need to develop clean and green renewable fuels. With Canada's farming sector there is a growing popularity for round upright fixed bed stoker systems as well as sloping grate boilers for large greenhouses. Incremental improvements in efficiency, convenience, and lower particulate loads are being made with a series of technological innovations in the combustion chamber design and air control systems for these commercial boilers.

The use of grass pellets for use in small boilers is now entering a major thrust of commercial development as wood pellets are becoming scarce, and feed grains and crop milling residues excessively expensive to use as fuel. The understanding of design features that are necessary to be incorporated in the combustion technologies to burn grass pellets is now well grounded within the manufacturing sector. The main need now is to gain practical field experience in large numbers of small scale systems to make the use of grass pellet technology as convenient and reliable as the use of wood pellets. Particulate emissions are strongly related to fuel type, and specifically, the ash forming content of aerosol-forming compounds including potassium, chlorine, sodium and sulfur and even lead and zinc. Using fuels that are low in the "dust critical" elements K, Cl, Na and S is of particular importance for achieving high quality biomass fuels and lowering particulate emissions during biomass combustion. It is evident that developing low K containing agro-fuels is of paramount importance if low aerosol loading agro-fuel pellets are to be developed for use in urban areas. Major improvements in Canada in the development of low aerosol forming agricultural feedstocks such as overwintered warm season grasses and selective use of crop milling residues (e.g. oat hulls and flax shives) is creating the potential for a significant fuel resource. It is now well understood that feedstocks with low aerosol forming potential (e.g. especially low K, Cl , Na and S) are necessary if technical problems are to be avoided and ambient air quality targets for emissions are to be met. Alberta has a significant development potential for using agricultural feedstocks in thermal energy applications as a carbon offset strategy for the provinces carbon trading mechanism. Incentives for the agricultural industry to produce and use clean densified fuels will help accelerate their uptake.

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1.0 Advances in Densification Technologies for Agricultural Fibres

The efficient densification of herbaceous biomass is an essential factor in the development of an agro-pellet industry. This report will provide a backgrounder on the process and forms of densification, recent research findings in improving agro-pellet production, approaches at improving densification and the current leaders in the marketplace, densification technology and capital cost investments. As well as a comprehensive assessment of the major innovations and direction for future innovation will be provided.

1.1 The Densification Process

Most efforts presently are to utilize agricultural fibres in a densified form for combustion applications. To date commercial manufacturers of agricultural fuels have focused on pellets, but use of cubes and briquettes is also developing. This report will primarily focus on innovations in the field of pelleting but will also review the status of briquette production as this is promising technology for commercial fuel production. Cubing processes are similar to pelleting and many of the technology advances are applicable to both forms of densification. In general it appears that briquetting holds the most promise for producing low cost densified commercial fuels while pellets appear best suited to smaller combustion appliances. There are many advantages of densified fuels:

- the amount of dust produced is minimized;
- the fuel is free flowing, which facilitates material handling and rate of flow control;
- the energy density is increased, easing storage and transportation;
- the capital cost and building footprint required for the combustion appliance is reduced considerably compared to burning bulk biomass;
- uniformity and stability permit more efficient combustion control;
- there are less particulates produced during the combustion process;
- there are considerable reductions in labour for feedstock handling; and
- risk of fire is reduced considerably as the biomass can be stored in an enclosed bin and is more easily separated from the combustion process.

1.2 Pellet Formation

The process of pellet making was developed for the livestock feed industry and is outlined in Figure 1. The biomass is chopped to a length of fibre that ensures the pellet can be properly formed. It is then continuously fed into the pelleting cavity, where it is directed equally on either side of the edges, formed by the rollers and the inside face of the die. The rollers turn as the die rotates, forcing the material through the die holes by the extreme pressure caused by the wedging action. As the pellets are extruded, adjustable knives cut them to the desired length. The goal is to produce a pellet with a good hardness and a minimum production of fines (material broken off in the pelleting and handling process).

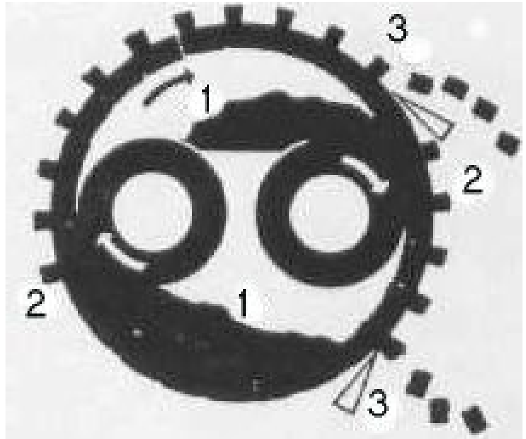


Figure 1. Diagram of pelleting process; 1) loose material is fed into pelleting cavity; 2) rotation of die and roller pressure forces material through die, compressing it into pellet; 3) adjustable knives cut pellets to desired lengths.

A number of properties are commonly known to affect the success of pelleting, including:

- moisture content of the material;
- density of the material;
- particle size of the material;
- fibre strength of the material;
- lubricating characteristics of the material; and
- natural binders.

1.3 Pelleting Productivity

Pelleting productivity is measured by manufacturers in terms of production yield, in units of pounds or kg per Hp. In the case of sawdust residues, this value varies from about 15-35 lbs per Hp, depending on the source of the wood residue; hardwoods are in the low range and softwoods are in the high range (Drisdelle, 1999). In theory, the more pliable the fibre, the easier it is to exude through the roller die. Other factors influencing productive yields include steam and residency time (cooking or conditioning) in order to create a more pliable fibre. The overall goal is to create a more fluid pelleting process, where a lower friction co-efficient is created between the die extrusion surface and the fibre.

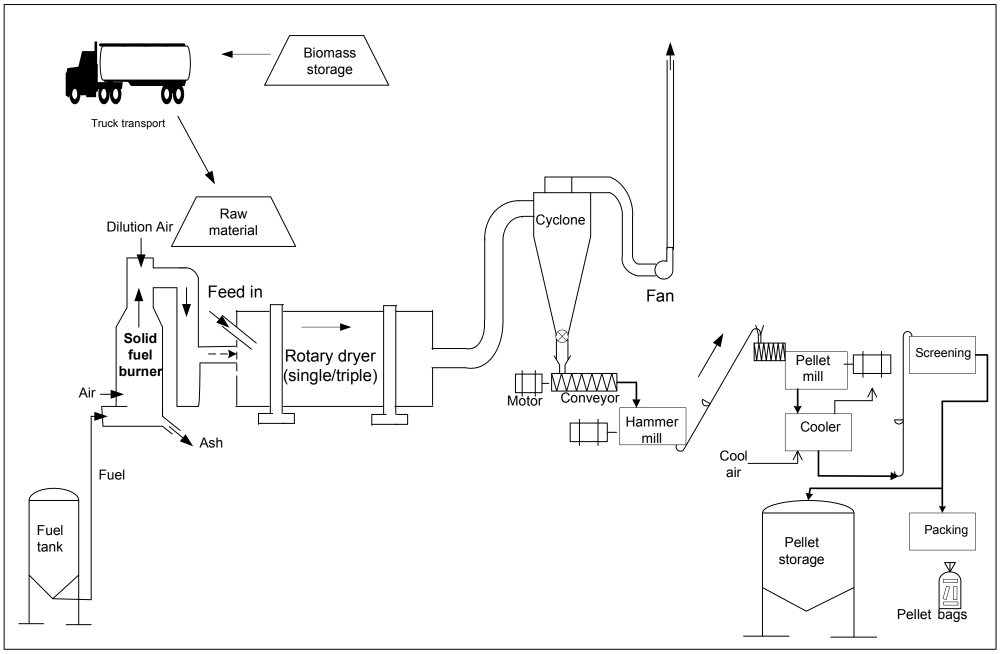


Figure 2. Schematic layout of a typical biomass pelleting plant (Mani *et al.*, 2006).

1.4 Pellet Binding

The pellet is bound together by the lignin exuded from the feedstock. This process results when fibre passes through the extrusion holes, heating up the die and creating elevating temperatures (75-85°C). Lignin within the material starts to flow from the fibre cell walls and has the effect of binding with other fibres during extrusion. During the process some moisture is driven off as steam. The resulting product is a uniform flowing material with a bulk density several times higher than that of the starting raw material. Pelleting grasses increases the bulk density of baled biomass (typically at 150 kg/m3) by about 4 fold. This begins with fine grinding process where the bulk density increases to approximately 200 kg/m3 and then it subsequently increases to 650-700 kg m3 in a pellet form.

2.0 Densification in North America

Alberta has 11 agro-fibre pellet and cubing plants (Appendix 1). The main processing factors that have been studied to improve the pelleting process are die geometry, steam conditioning temperature, pressure, moisture optimization, length of the grind, and binding agents. The various pelleting machines are reviewed later in his report.

2.1 Dies

In North America, most wood and alfalfa pellets that have been produced historically are 6.3 mm (¼ inch) long. In northern Europe, the most common sizes are, in decreasing order, 7-8mm, 9-10 mm and 6-7mm (Vinterback *et al.*, 1998). Dies need to be selected based on the fibre characteristics of the feedstock to be processed. A balance needs to be found between pellet durability and throughput when choosing dies. The longer the fibre stays in the die the more durable the pellet. However long fibre retention times in dies can result in reduced throughput and operational problems such as plugging.

Production experience in commercial plants with pelletizing highly fibrous herbaceous biomass like oat hulls and warm season grasses has found that a length over diameter (L/D)of the die should be approximately 8.5-9:1(Michel Viau, personal communication). This range is intermediate to that generally used for wood pellets (4-5:1) (Michel Viau, personal communication) and the alfalfa dehydration industry (10:1) (Hill and Pulkinen, 1988). The diameter of the die also affects production. Hill and Pulkinen (1988) found that smaller diameter size dies, when combined with fibres that are relatively difficult to pelletize, require slower RPM. In a laboratory pellet study, higher speeds (501-565 rpm) were found to plug 6.1 mm dies, but low quality alfalfa was successfully pelleted at rotation speeds of 250-316 rpm (2.8 and 2.6 m/s respectively). Rapid die rotation tends to overload the pellet motor due to the high fiber content of the forage.

There appears to date to have been no assessment of the relative merits of using larger dies with slower RPM to pelletize switchgrass. This likely could be a means to further optimize warm season grass pellet production. Modest increases in pellet size could likely be tolerated on most pellet stoves without changing grate sizing. Thus, the potential for increasing pellet size in North America may warrant investigation if suitable L/D dies can be used in conjunction with the bigger size pellet produced. This may reduce costs by reducing grinding size requirements. Michel Viau of Vifam Services in Montreal has successfully produced 5/16" (8mm) pellets made from overwintered switchgrass and burned the material in a 9 kW gasifier pellet stove.

2.2 Binder

Reviews of the binding process and characteristics of plant tissues to form pellets have been completed in recent years (Tabil *et al.*, 1997; Sokhansanj *et al.*, 1999, Samson *et al.* 2005). The mechanism of binding is made possible by natural cohesion between particles and the mechanical load that forces inter-particle contact. It is now widely experienced that binding properties of warm season grasses or oat hull pellets is often weak because of the low protein and starch content of the biomass. Some binding agents that can improve binding and durability include the use of corn stalks (Kaliyan and Morey, 2006) and wheat bran (Don Nott, personal communication). Production of switchgrass and oat hull pellets without binders is being successfully achieved but requires several basic process conditions to achieve high density and high durability pellets.

2.3 Feedstock Particle Length and Screen Size

Most agri-fibre and wood pellet mills are producing a 6.4 mm (¼ inch) pellet in North America. A number of studies have examined the impact of the length of chop on the pellet process. Overall it has been realized that fine grinding produces denser pellets and increases the throughput capacity of machines as the material passes through the machine more easily (Dobie 1959). Fine chopped material also provides a greater surface area for moisture addition during steam treatment. As well, fine chopping creates materials that have smaller fissures that can lead to breakage.

Most commercial alfalfa pellet mills are using hammermills with a 7/64 (2.8 mm) inch screen to produce a suitable length of chop. It is often recommended that the chop size be one half the diameter of the pellet being produced. While screen size is important it is only one component of the grinding apparatus and other aspects such as the number of hammers, the screen hole design, and hammer tip speed also affect the fineness and uniformity of the grind when used in commercial installations (Michel Viau, personal communication). In commercial production trials producing switchgrass pellets in Quebec, a grind of 7/64" has been used (Jannasch *et al.*, 2001). Agrecol Corporation in Wisconsin has used 3/32" (2.4 mm) screens for grinding warm season grasses to successfully make grass pellets (Mark Doudlah, personal communication).

More recent lab studies with switchgrass and other herbaceous feedstocks suggest finer grinds than 2.4 mm hammermill screens may be necessary for further increasing pellet density and durability (Mani *et al.*, 2002; Shaw and Tabil, 2007). Working with 12% moisture biomass to produce 1/4" (6.3 mm) pellets, Mani *et al.*, (2002) found that increasing both the fineness of the grind and pressure was necessary to produce dense pellets. At least 120 MPa of pressure was required to achieve high density pellets when grinds made with 1/8"-1/32" hammermill screens were used. In a more recent study working with 3 herbaceous feedstocks (flax shives, oat hulls and wheat straw), Shaw and Tabil (2006) examined the production of ¼" pellets under 139 MPa pressure. They found hammermill screens of 0.8 and 1.6 mm increased pellet density by 10% and 3% respectively compared to the 3.2 mm screen. Increasing the fineness of grind impacted pellet durability only in the case of oat hulls. Mill operators will need to assess the relative merits of increasing the fineness of grind versus pressure as a means to increase pellet density and durability. A study on the fineness of grind on the production of switchgrass briquettes (Kaliyan and Morey, 2007) found that using the smallest sized screens of 1 mm produced the highest durability briquettes.

2.4 Pre-Treatment of Fine Grinding

An important consideration is the energy consumption in fine grinding. Mani *et al.,* (2004) tested the energy requirement for hammermilling switchgrass at 8-12% moisture content. Use of a 1/8" (3.2mm) screen size was found to consume approximately 25-30 kWh/tonne while use of a 1/16 (1.6 mm) increased energy consumption to about 55-60kwh/tonne or by approximately $3/tonne assuming power rates of 10 cents/kWh. With switchgrass at 12% moisture content, the energy consumed to grind switchgrass to 0.8mm was approximately the same as at the 16 mm grind. Some experts believe the additional cost of fine grinding may be somewhat offset by increased throughput. However there has been limited scientific analysis of the impact of fine grinding on increasing throughput productivity of pellet mills. It is known that fine grinding increases bulk density which should help the process of pre-compressing the material to ensure a steady flow through the die and reduced energy consumption in the pelleting process. However, the effect may depend on the type of fibre being pelleted and the process conditions. Working with alfalfa, Tabil and Sokhansanj (1996) found no significant reduction in energy use in the pelleting operation when the hammermill screen size was reduced from 3.2 mm to 2.4 mm.

2.5 Steam and Temperature during Densification

The alfalfa dehydration industry commonly aids the pelleting process through application of a constant quality steam at a predetermined pressure that supplies additional heat and moisture. This steam can help release and activate natural binders and lubricants in biomass sources. In the case of alfalfa it is now well documented that high temperature steam additions enhances pellet durability, and reduces energy consumption in the pelleting process. Tabil and Sokhansanj (1996) found that alfalfa pellet durability increased linearly as conditioning temperature was raised from 65 to 95°C. This pretreatment also influenced the final temperature at which the pellet left the ring role press. Hill and Pulikinen (1988) found that pellet durability was improved by 30-35% when the conditioning temperature increased from 55 to 85°C. Pellet power consumption also declined by nearly 30% through increasing pellet temperature from 65 to 95°C. One of the alfalfa dehydration producers currently producing in western Canada is currently using 110 °C for steam conditioning.

In recent years, much more advanced understanding of the role of increasing the temperature of feedstocks to be pelleted has been achieved. The parameter known as "glass transition temperature" is now being assessed on herbaceous biomass feedstocks. This term is defined as the temperature at which the material softens due to the onset of long-range coordinated molecular motion (Roos, 1995). The glass transition temperature for dry switchgrass was found to be 75-100 °C (Kaliyan and Morey, 2006; Kaliyan and Morey 2007). Reaching these temperatures appears critical for densification processes. The lignin and hemi-cellulose components of plants are known to undergo plastic deformation in the range of their glass transition zones (Back and Salmen, 1982). Working to produce 19.2 mm briquettes under 150 MPa pressure and testing 25, 75, 100 and 150 °C temperatures, Kaliyan and Morey (2006, 2007) found best results for briquette durability to be achieved using at least 100 °C temperatures. They found zero durability in the briquettes produced at 25°C. Working to produce 6.3 mm pellets using 3 herbaceous feedstocks, Shaw and Tabil (2007) also found 100 degrees C temperatures were superior to 80°C temperatures in improving pellet durability.

2.6 Moisture Content of the Feedstock

Feedstock moisture also appears to have an important effect on improving pellet density and durability. As water softens lignin, moisture often can improve durability if densification temperatures are low. However, low moisture contents of 8-12% moisture provided higher density pellets than 15% moisture content materials (Colley *et al.*, 2006; Shaw and Tabil, 2007) when other factors such as grind and temperature are optimized for pelleting switchgrass. In the case of pellet durability, Colley *et al.*, (2006) found much higher durability at the lower moisture contents tested (6.3%, 8.6% and 11.0%) than higher moisture content materials (14.8% and 17.0%). Sokhansanj *et al.*, (2005) identified the optimum range for pelleting cellulosic materials to be 8-12% moisture content, while the optimum moisture content for starch and protein material to be 20% moisture content. It is known that the starch component of herbaceous biomass becomes more pliable when moisture is present. This may be contributing to the differential response of increasing moisture content on other herbaceous feedstocks. Shaw and Tabil (2007) found some herbaceous materials to have a positive response to increasing moisture content from 9 to 15% moisture on pellet durability.

Future pelleting studies with switchgrass need to more explicitly describe the biomass quality of the warm season grass material being tested and should use a sample representative of what commercial switchgrass pellet producers would utilize for pelleting studies. There is some experience that overwintered switchgrass is a more easily pelletized or cubed feedstock than highly fibrous material harvested at the end of the growing season. This may be related to deterioration of the waxy cuticle on the grass during the overwintering period but requires further investigation.

2.7 Optimizing Densification Conditions

Considerable research and production experience in making agro-pellets has now been undertaken. The general process conditions required for good production rates, pellet density and durability requires a number of features to be incorporated into the process:

- the grass material should be approximately 6-13% moisture and ideally 8-12% moisture;
- to produce ¼" pellets, the material should be fine ground using a screen of at least 7/64" (2.8 mm) and ideally 3/32 (2.4 mm) or less;
- use of a pellet die of L/D of 8.5 - 9:1;
- bringing feedstocks up to at least 90°C; and
- utilize a high quality saturated steam and an appropriate residence time on the fibre.

The scientific reports reviewed overall appeared to report more difficulty to produce high durability briquettes than pellets. Unfortunately no direct comparisons were made between pelleting and briquetting equipment in any studies. It is evident that further optimization of briquetting processes is required. The use of feedstocks with better binding properties such as corn stalks or wheat bran likely will be required to successfully briquette switchgrass until other production parameters are optimized. Unfortunately most of the pelleting studies that have been completed to date have been on laboratory devices. It is essential that further optimization of switchgrass pelleting be completed on commercial pelleting systems. Parameters such as time of switchgrass harvest, the residence time of high temperature saturated steam, impact of various L/D dies, and the impact of increasing pellet diameter on pellet bulk density and durability require further assessment to more fully optimize switchgrass pellet production and pellet quality.

3.0 Pelleting Mills

There are two main types of pelleting equipment currently in the marketplace these are vertical units and flat units. Other new technologies are also under development. The preprocessing of the agricultural fibre material being fed through these various pellet machines is essentially the same. The dry material is milled to pass through at least a 2.8 mm mesh screen by severe beating and cutting with a hammermill. The ground material is then treated with super-heated steam at temperatures above 90°C. Subsequent mixing is done in paddle mixers, where paddles rotate at about 300 rpm. The residence or agitating time of the material, while mixing with steam, ranges from 15 to 30 seconds. The moisture content of the mix increases to 12%. The heated, moist material is then fed into the pellet mill (Samson *et al.*, 2005).

3.1. Vertical Roller pellet mills

The annular ring technology also known as the vertical roller pellet mill technology has gone through incremental improvements in recent years since its original commercial introduction into the livestock feed industry more than 50 years ago. The technology consists of a series of circular die and roll assemblies. When the dried material is introduced into the housing, internal rollers press the material against the die opening, the material is densified and extruded through the die holes in a step-wise fashion. These dies are mounted in a vertical position and are the standard units available on the market (Appendix 1). Some of the main pellet technology improvements that have been made to the technology include: the use of gear drives instead of belt drives, more convenient and rapid die and parts replacement; improved seals on roller bearings; and automated control of the roller gap during operation. These innovations achieved by the leading manufacturers are largely aimed at reducing power and maintenance costs and improving convenience. For example power costs can be reduced by approximately 10% to operate the pellet machine through more efficient energy transfer by replacing belt drive pellet mills with gear box driven mills (M. Viau, Personal Communication). However there have been few design improvements made to the annular ring pelleting technology that have created significant productivity improvements.

3.2 Flat Die Pellet Technology

The main new technology to enter the market in recent years, and increasing in popularity, is the flat or plate die technology. The leading company to market the technology is Kahl (Figure 3), while at least one Chinese company is also producing flat die pellet systems. There are many cited advantages of the flat pellet mill technology over the annular ring technology with the principle advantages being:

- more effective and consistent control of the pressure gap between the feed compression rolls and the die. This is created through a straight down pressure on the rolls which is controlled by a hydraulic nut device. In contrast the annular ring die system achieves this through applying a mechanical, pneumatic or hydraulic force through a cantilevered eccentric control of the roll dies (in the

Kahl company literature they make the analogy of the comparison between providing a force on an object by standing on it versus pushing with your hands against an object);

- The design takes advantage of natural gravity flow which helps prevent blockages as the feedstock is introduced into the top of the mill, presented to the front of the rolls, and travels downward through the press rolls and die plate and is exhausted out the bottom of the press. This design is more effective than the annular ring technology which introduces the fibre sideways into a crowded space of the ring die which makes it more prone to blockages;
- The flat die design enables a larger volume of feedstock to be presented to the die face than an annular system which is beneficial for low density feedstocks which has a harder time entering into the dies; and
- A thicker product layer is present in these systems between the pan grinder rollers and the large die surface which results in a high throughput.

Figure 3: Kahl Corporation flat die pelleting process

Other advantages include a low roller speed (2.5 m/s) which ensures a good deaeration of the product and the low roller speed makes the systems less noisy than annular mills. The largest units Kahl Corporation makes are 400 HP with die diameters of 1.25m. They state that 3 of the larger 400 HP units can produce in excess of 100,000 tonnes per year.

3.3 Ecotre System

In 2002 a new Italian designed pelleting technology known as the Ecotre System was proposed that is highly innovative (EP 1306199A2). The concept is to introduce biomass into cylindrical drawplates a portion of which is drawn into the dies while the remaining part escapes the action of the drawplates and is recirculated back through the system. The device essentially represents two toothed dies (with both holes and punches in each die) that intermesh and cause a partial drawing through of the biomass into each opposing die. The pellets thus pass from the outside into the centre of the die. The system is also designed to recirculate pellet fragments, residual dust and undersized pellets back through the pelleting process under pneumatic pressure. The systems were widely discussed since their release but have had limited commercial success to date.

The main benefits that were cited in the patent were a reduction in energy use compared to conventional pelleting technology and optimized production of pellets with constant structural and morphological characteristics.

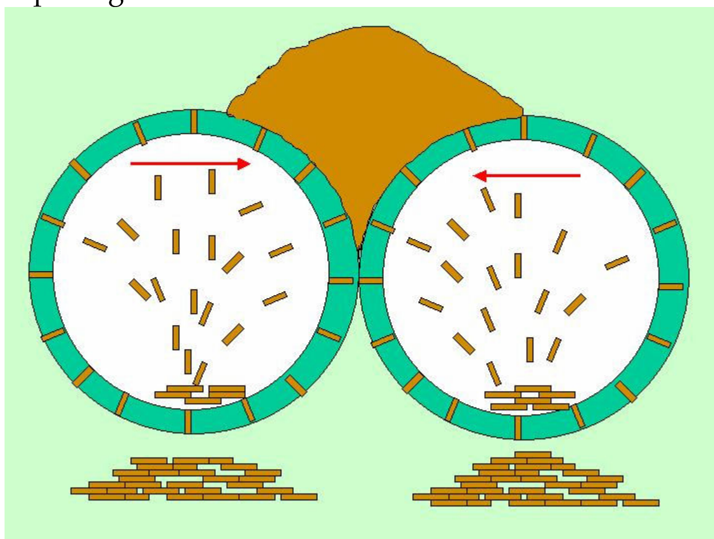


Figure 4. Ecotre pelleting system (www.ecotresystem.eu)

3.4 Predensification of Biomass Prior to Pelletization

Grasses and other fibrous herbaceous feedstocks are known to have a relatively low bulk density in a chopped form. This density can be improved somewhat through the use of fine grinding with final grind bulk densities of 200 kg/m^3 in the case of switchgrass achieved with grinding screen of 2 mm. Several groups of scientists have proposed precompacting biomass prior to pelletization (Larrson *et al*., 2008 and Sokhansanj *et al*., 2005). The main benefits that have been proposed by this approach by these scientists are to:

- reduce problems of stable pellet production which is often problematic with herbaceous feedstock such as straw;
- minimize frictional energy in pellet production which is largely responsible for the high energy consumption during the pelleting process;
- reduce cleavage production within pellets; and
- to reduce wear on dies.

Larrson *et al*., (2008) studied the effect of briquetting of grasses and subsequent reshredding to obtain raw material bulk densities of reed canarygrass in four density ranges (260, 290, 320, and 350 kg/m^3). The optimization of pellet bulk density and durability of reed canarygrass pellets was found with intermediate prec-compaction densities of 310 kg m^3 when steam and high die temperature (minimum 80°C) was used. Precompaction with briquetting could also be a way of sourcing distant fibre sources and more economically transport them to pellet mills. This approach has been proposed by Wayne Winkler of www.briquetttingsystems.com in Vancouver, Canada as an alternative means for the wood pellet industry to source new supply from forest residues without going into whole tree pelleting, which has been initiated in some areas due to lack of wood residue supply.

Sokhansanj *et al*., (2005) introduced a new concept of precompaction of biomass through the use of a series of roller compactors to create a staged compaction process with primary and secondary compaction prior to pelletization as a means to create an improved pelleting process. They conceptualized a new pelleting process to eliminate frictional forces by producing pellets externally through the use of tooth rollers (Figure 3). The conceptual design was cited as having the following features:

- pellets (or compacts) are produced externally; there is no plugging the die holes every time the feed material changes;
- frictional forces are eliminated and only compressive forces are used to form compacts;
- the system can be heated to a desired temperature to improve compact quality;
- a wide range of particle sizes can be accepted;
- compact density can be positively controlled; and
- access to the machine working parts is easier for cleaning and maintenance.

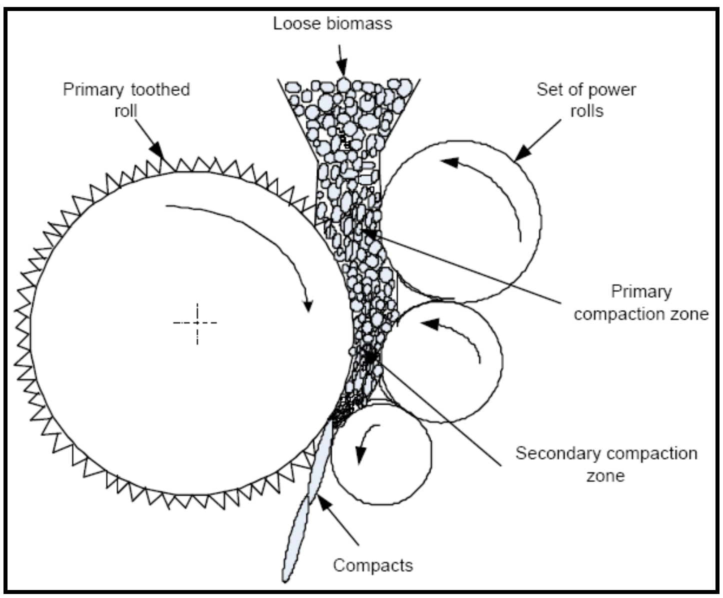


Figure 5. Conceptual design of new roller compactor for biomass densification (Sokhansanj *et al*., 2005)

3.5 Cold Temperature Pelleting

A novel approach to reduce energy consumption in pelleting through a cold temperature pelleting process also know as sheared layer embedded pelleting, was developed in China (Zhanbin, 2004). The concept is to disturb the cellulose molecules in the biomass, shift them and express them in layers in a new shape to promote improved bonding through parallel fibre orientation.

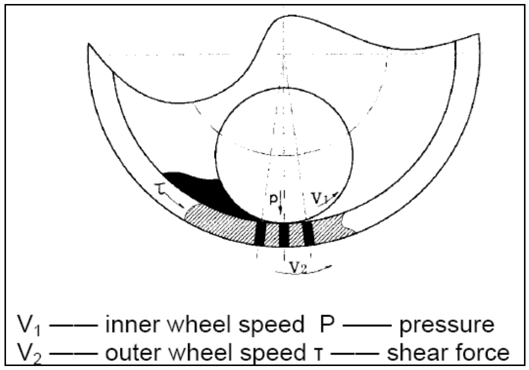


Figure 6. Schematic diagram of pelleting mechanism (Zhanbin, 2004)

Through this technique it is proposed that high temperatures required for compressing parts (typically in the range of 160-280 °C) to create lignin plasticization can be avoided. The sheared layer effect is created through a modest pressure being applied on the biomass between an inner wheel and outer wheel which operating in opposite directions at optimized speeds (Figure 5). The technology is not yet currently in the marketplace at a commercial level but appears to be an innovative new approach at improving the pelleting process (Figure 6). It also appears well suited to small scale producers as the tolerance levels on the feedstock moisture appear quite good and it can be done at ambient temperatures without steam addition (Figure 7).

Figure 7. Cold Temperature Pellet Mill (High Zones Pelletizer)

3.6 Torrefaction

A new bioconversion concept, torrefaction, is now being integrated into a commercial pellet plant in Europe as a strategy to increase the fuel value and density of pellets (Natucka, 2007). It is proposed as a means to upgrade the energy quality of pellets without causing major losses of energy in the biomass conversion process. Torrefaction is a pretreatment technology that is achieved through thermal processing of biomass in the absence of oxygen at atmospheric pressure. It is a similar concept as roasting coffee beans, except the thermal processing occurs at higher temperatures and excludes oxygen.

The main advantages of torrefaction is that it upgrades the energy density of the biomass which reduces long distance shipping costs and increases its value in metallurgical applications. Wood pellets typically have an energy value per ODT of 20.3 GJ/tonne or 18.7 GJ/tonne at 7.7% moisture. Similarly pellets produced from switchgrass pellets in eastern Canada would contain 19.1 GJ/ODT or 17.6 GJ/tonne at 7.7% moisture (Samson *et al.,* 2005). In contrast torrefied wood pellets are typically 1-5% moisture and have an energy density about 20-25% higher than wood pellets. They are pelletized with approximately half the energy of wood pellets and result in a bulk density of 750-850 kg/m^3, while wood pellets are typically about 650 kg/m^3. The energy density of torrefied pellets can reach up to 18 GJ/m^3 which approaches that of coal at 20.4 GJ/m^3 (Uslu, 2005).

The torrefied pellets are also hydrophobic, have very good pellet strength and low dust formation. The first operational demonstration unit of a torrified biomass process was achieved in France in 1987 by the Pechinay company (Uslu, 2005). Since that time a more efficient torrefaction technology plant design has been proposed known as the Energy Research Centre of the Netherlands (ECN) technology. It combusts the gas released in the torrefaction process to provided much if not all of the necessary drying energy and heat for the torrefaction. Dry feedstocks generally have a surplus of torrefaction gas created through the process. An agreement has been reached by Econcern, the Energy Research Centre of the Netherlands and Chemfo to build a commercial scale torrefaction plant using the ECN designed torrefaction technology. It is being termed the BO_2 pellet technology and promoted as a second generation pellet technology.

A recent study at Utrecht University reviewed the energy balance of the technology and projected costs versus pelleting (Uslu, 2005). The energy analysis indicated 89% of the original energy in the biomass could be recovered in a torrefied pellet form and reduces bulk density by 15%. A main advantage of the technology that is apparent is its suitability for long distance transport as both the bulk density and energy content/ODT is increased through the torrefied biomass pelleting process. It may be that in the case of Alberta the torrefication pellet technology could create commercial opportunities for pellets for use in developing export markets or as a biofuel for provision of heat for tar sands oil production in Alberta. A list of pellet mill manufacturers can be found in Appendix 2.

4.0 Cubing

The process of cubing has been described effectively in Samson *et al.,* (2005) as follows:
The sequence of operations for cubing is similar to pelleting. The system consists of a receiving/metering box. The box has a moving floor that meters the chops to the cubers. The chop is then dried in a drum dryer at 200 to 400°C, a lower temperature than that required for pellets. If the biomass is received in the form of square and round bales, they are chopped using a tub grinder. In order to maintain the chop length required for cubes, the sieves in the tub grinder are removed or large-holed sieves (hole diameter larger than 35 mm) are used. The chop is then dried in a low temperature drum dryer.

In the less humid regions of the world, the mechanical drying stage is often not required and is not practiced. The dried and cooled chop is mixed with water in a paddle mixer, which is located on top of the cuber head. The quantity of water is adequate to increase the moisture content of the chops by two percentage points. The water also acts as a lubricant. It is believed that water dissolves the pectin material on stems and leaves, forming a sort of glue. The chop must be cooled and the added water must stay on the surface of the material. Penetrated water, or warm chop, makes the stems resilient. The cubing operators often find it necessary to add a binder to increase the durability of cubes. Typical binders used are bentonite, hydrated lime, starch, ligno-sulfonates, agro colloids, and other commercial binders. The inclusion rate for bentonite or hydrated lime is generally less than 2% on a mass basis. Higher inclusion rates boost the ash content of the cubes, and cubes with high ash content are undesirable for combustion. For densifying warm season grasses for energy applications, starches would likely have the least negative impact on the combustion process and emissions.

The cuber die and press roller (wheel) can be similar to the die ring of a pelleter. Cubers have a larger diameter auger, die ring, and a single press wheel. The auger moves the chopped material uniformly to all openings in the die ring. As the material leaves the auger flight, the heavy press wheel forces the chop through the die openings in the ring. The pressures in the cuber range from 24 to 34 MPa. The natural binding properties of the herbaceous material, the high pressure of the press wheel, and heat generated by forcing hay through the dies bond the cubes. An adjustable deflector around the outside of the die ring breaks the cubes off in lengths ranging from 50 to 75 mm. Sheet metal chutes channel the cubes to a conveyor beneath the die ring. The conveyor carries the cubes to a cube cooler. Due to larger particles and possible impurities, cuber dies tend to wear more than pellet dies. Individual dies are made from sleeves that can be replaced with new ones.

Cubes are cooled in a long cube cooler. The cooler is more than 15 m long and about 1.8 m wide. The cube height on the belt in the cooler is about 300 mm. The typical residence time in the cooler is 30 minutes. Chain or belt conveyors easily handle the cubes. The minimum power requirement for cubing at the die is about 150 kW. The energy consumption is about 12-20 kW/t of cubes produced. A typical output of the cuber is 7-8 t/h (Appendix 3).

5.0 Briquetting

In industrialized countries there are two main processes being sued to produce commercial fuel briquettes, these are the piston press and the screw press. The piston press can be of both a mechanical and hydraulic drive types (Appendix 4).

In contrast to significant private sector investment in improving pelleting processes in recent years, there has been limited recent innovation in the field of briquetting. However with the rapid development of the pellet industry and increasing interest in larger densified fuels for large combustion appliances there is increasing interest especially in ram type briquetting systems such as those marketed By Nielsen, Bogma and Paelson-SPM. There also is some interest in hydraulic systems although these are less favoured presently because of higher operating cost and wear issues. The Shimano hydraulic piston press has found to be one of the more reliable units. An overview of the briquetting was recently overviewed in Samson *et al.,* (2005) and a summary of that review is excerpted and presented below:

> "The briquetting process primarily involves drying (if necessary), grinding, compacting and cooling operations. Except for the actual briquetting, the process is very similar to pelleting. The components of a typical briquetting unit are pre-processing equipment, material handling equipment and briquetting press. Pre-processing equipment includes a forage chopping unit, drying unit, and hammer mill grinder. Material handling equipment is comprised of screw conveyors, pneumatic conveyors and a holding bin. The briquetting press is used to produce compacted briquettes. Biomass can be compacted into briquettes using a range of machines."

Figure 8. Briquetting System; (A) West Fraser Westpine MDF sheet plant; (B) Federated plywood plant (Photo courtesy of Wayne Winkler).

5.1 Piston Press

High compaction process, or binderless technology, consists of the piston press and the screw press. A piston press is a reciprocating type where the biomass is pressed in a die by a reciprocating ram at a very high pressure (Eriksson and Prior, 1990). Pietsch (1997) described the compaction process of the ram/piston press. The reciprocating motion is produced by an eccentric drive or flywheel (Figure 8) symbolized by the circular representation on the left. The force exerted by a ram reaches a level that is sufficient to overcome the friction of all briquettes in the pressing channel and the backpressure caused by the column of briquettes in the cooling channel. The entire line of briquettes moves forward, with the force remaining approximately constant, and a new briquette emerges from the mouth of the press. At the beginning of the backstroke, the ram face does not separate at first from the briquette because of considerable elastic expansion of the briquette. It is important, however, to note that the surface produced by the ram face is so highly densified that, during the next stroke, it acts as the bottom of a confined volume densification chamber until friction is overcome and the product column moves forward. During the entire production sequence the surfaces of adjacent briquettes do not develop significant bonding; therefore, on discharge from the cooling channel, the product can separate easily into single briquettes similar in shape to hockey pucks.

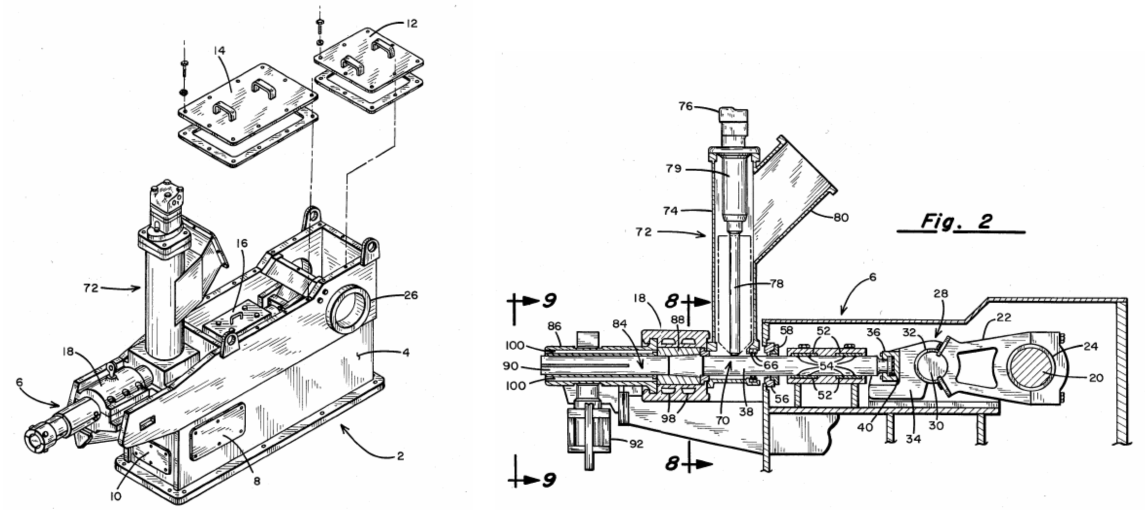


Figure 9. Briquetting Patent No. 4 599 091

The hydraulic piston press is different from the mechanical piston press in that the energy to the piston is transmitted from an electric motor via a high-pressure hydraulic oil system. This machine is compact and light. The briquettes produced have a bulk density lower than 1000 kg/m^3 because the pressure is limited to 392 to 1324 Pa. This machine tolerates higher moisture contents than the usually accepted 15% moisture for mechanical piston presses (Grover and Mishra, 1996).

6.0 Densification Capital Costs

Densification of biomass, as describe in Sections 1 and 2, increase the bulk density of the raw biomass by approximately 350% creating a fuel source that is easier to handle, store and transport. Currently there are approximately 350 biomass pellet plants in Europe, 82 in the United States, and 28 in Canada (Kassabain, 2007). The current installed capacity of wood pellet plants in Canada is estimated at 1.5 million tonnes, with the majority produced in British Columbia. Thek and Obernberger (2004) reported the pellet production cost in Sweden and Austria between $78 and $112/t, while Samson *et al.*, (2000) estimated costs for switchgrass pellets from $72 to $102 (not including drying), depending upon the raw material costs. The main difference in both studies was a larger plant capacity in the first as well as a lower cost for electricity in Sweden (Thek and Obernberger 2004). It is important to understand the costs incurred for densification are highly related to plant size, including fixed (capital) and operating costs.

6.1 Densification Plant Costs

The size of the densification plant (t/yr), operating time (h/d), personnel costs, equipment costs, and raw material costs all play a large role in the final costs of the densified product whether it be a pellet or a briquette. Several estimates of pelleting plant costs have recently been made for three wood pellet plants in North America. In December of 2007 a 90,718 t/yr wood pellet plant opened in Schuyler, New York costing $10 million dollars or approximately $5.89/GJ (assuming wood content of 18.7/GJ; Niebling, 2007). Similarly a case study of a 132,000 tonne/y wood pellet plant in William's Lake had a construction cost of $15.5 million (Bradley 2006) or $6.28/GJ of wood pellet energy output. A new wood pellet plant expected to open in West Kootenay, British Columbia in 2008, has a project cost of $5.6 million with a production capacity of 60,000 t/y or $4.99 per GJ (Kassabian, 2007). Grass or agri-fibre residue pellet plants will likely have lower costs for construction/GJ as slightly higher outputs can be expected than wood pellet mills (Samson *et al.,* 2000). It is fairly safe to estimate that grass pellet plants can be built for about $5/GJ based on current costs for wood pellet plants. In comparison, modern corn ethanol plants are more capital intensive per unit of energy produced. Even highly efficient new corn ethanol plants such as the POET ethanol plant in Ohio which produces 65 million gallons of ethanol per year and cost $105 million poet (Kassabian, 2008) or $20.41/GJ of output capacity. This creates a capital investment cost per GJ of output energy that is 400% more than a pellet mill. Well out of this range is the capital cost of commercially proposed cellulose ethanol plants. The planned Iogen wheat straw based cellulosic ethanol plant in Saskatchewan has a projected capital cost of $500 million for a 90 million litre per year plant (Globe and Mail, March 15, 2008). This would create a capital cost of $264/GJ based on an energy output of 1.89 million GJ (90 million l x 0.21 GJ/l). Overall, pellet plants represent a modest capital investment compared to both corn ethanol and wheat cellulosic ethanol plants, which cost 400% and 5000% more per GJ of annual energy output.

6.2 Pellet Plant Component Cost

A breakdown of the pellet plant costs into components was conducted by both Mani *et al.*, (2006) and Thek and Obernberger (2004). Tables 1 and 2 are adaptations from their studies and updated to $2008 CAD. Mani *et al.*, (2006) used a base case of 6 t of pellets/h with an annual production of 45,000t. The plant is assumed to operate for 24h for 310 days annually for a usage of 85%. Table 1 demonstrates the largest costs in the pellet plant were both the drying operation and the pellet mill, representing approximately 25% of the overall costs. The capital costs of the pellet plant represented $8.23/t.

Table 1. Pellet Production costs for $45,000 t/y capacity plant (2008 CAD $), adapted from Mani *et al.*, 2006.

Pellet Process Operations	Capital Cost ($/t)	Operating Cost ($/t)	Total Cost ($/t)	Percent Cost Distribution (%)
Raw material	0.47	26.64	27.11	39.0
Drying operation	3.38	10.77	14.15	20.4
Hammer mill	0.34	0.96	1.31	1.9
Pellet mill	1.96	2.58	4.55	6.6
Pellet cooler	0.18	0.29	0.47	0.7
Screening	0.15	0.07	0.22	0.3
Packing	0.77	1.88	2.65	3.8
Pellet Storage	0.10	0.01	0.11	0.2
Miscellaneous equipment	0.58	0.45	1.04	1.5
Personnel cost	0.00	17.50	17.50	25.2
Land use and building	0.29	0.07	0.36	0.5
Total cost	8.23	61.25	69.48	100

The second analysis of pellet plant costs by Thek and Obernberger (2004) represents a smaller sized European plant. The main differences in cost are that the European plant experiences much higher raw material costs/tonne than the plant in British Columbia as well as higher drying costs/tonne of production. Grinding and pelleting costs in the case of both mills are modest compared to raw material, drying and personnel costs.

Table 2. Pellet Production costs for a 24,000 t/yr capacity plant (2008 CAD $), adapted from Thek and Obernberger 2004

Pellet Plant Construction	Investment Costs ($)	Capital cost ($)	Maintenance costs ($)	Consumption Costs ($)	Operating Costs ($)	Other Costs ($)	Total Costs ($)	Specific Costs ($/t)
General investments	1007947	95655	8080	0	0	5039	108775	5
Drying	651600	71542	16290	941837	0	3258	1032927	44
Grinding	145958	20782	26273	65158	0	730	112942	5
Pelletisation	330144	47006	33014	232098	0	1651	313769	13
Cooling	22589	2480	452	7109	0	113	10153	0.3
Storage	505642	47728	7585	17812	0	2528	75655	3
Peripheral equipment	868800	123698	17376	53311	0	4344	198729	8
Personnel	0	0	0	0	529464	0	529464	22
Raw material	0	0	0	1343895	0	0	1343895	57
Total	3532680	408890	109069	2661221	529464	17663	3726308	158
Specific costs in $/t		17	5	113	22	1		158

One way to reduce costs considerably is to spread overhead costs by creating a certain scale of production. An analysis performed by both Mani *et al.*, (2006) and Wolf *et al.*, (2006) demonstrate the effect of pellet production rate on the total cost of pellet production (Figure 10). An increase in the pellet production rate (plant capacity) will substantially decrease the pellet production, due to the economies of scale for the larger plants (Figure 10). According to Mani *et al.*, (2006) the production costs start to level off at around 10 t/h or an annual production rate of 75,000 t/y. Similarly, Wolf *et al.*, (2006) saw a leveling off between 80,000t/y and 100,000 t/y.

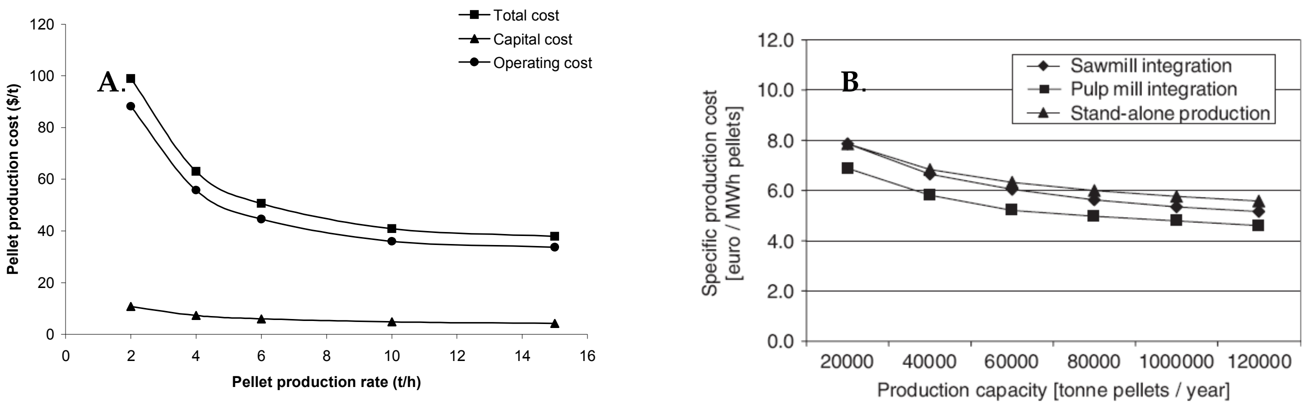


Figure 10. Pellet production cost vs. production rate; (a) Mani *et al.,* 2006; (b) Wolf *et al.,* 2006.

6.3 Briquetting Plant Costs

A major opportunity to reduce overall costs for densification may be to adopt a simpler transformation process such as briquetting for agricultural feedstocks. There is increasing interest in the development of briquettes for processing agricultural and wood residues. Several projects have been developed in the US including the installation for a briquetting unit at Ernst Seeds in Meadville, PA and Iowa. These units have successfully briquetted switchgrass with use of only a tub grinder for preprocessing. Wayne Winkler of briquetting systems in Vancouver states that 8000 tonne per year systems can be established for about 500,000 USD. The capital cost of a 2 tonne per hour briquetting unit is about $260,000. However the overall cost per tonne (capital and operating cost) is projected to be about half that of producing wood pellets. A complete cost comparison of operating and capital costs/tonne can be found in Appendix 5.

Typical systems producing 12-15,000 tonne per year can be expected to be about $9/tonne for operating cots and $9/tonne for capital costs for a total of $18/tonne. Novel biomass installation are being developed such as installing the briquetting units in a processing room located underneath a large 300 m^3 storage bin (Figure 11, Appendix 6). A new installation is scheduled to open in Washington State in 2008 that will sell fuel into the lower British Columbia Mainland greenhouse industry mainly to client using 2 large Vyncke boilers (Wayne Winkler, personal communication).

Figure 11. Briquetting and storage plant; a) C.F. Nielsen briquetter installed at base of silo; b) silo storage (Photo courtesy of Wayne Winkler).

6.4 Logistical Challenges of the Harvest and Delivery of Biomass to Pellet Plants

A major problem of ligno-cellulosic biomass processing facilities is managing the logistics of the biomass supply to conversion plants. As an example, recent plans were announced to build cellulosic ethanol plants in the U.S.A using agricultural biomass resources in the order of 600,000 tonnes annually (1650 tonne/day) (GreenBiz.com, 2007). The biomass requirements of warm season grass pellet plants are in the order of 1/10 this quantity, yet they still represent a significant operational challenge. Pellet plants considered to be economically viable are those producing a minimum of 45,000-75,000 tonnes per year (Mani *et al.,* 2006). Mani *et al.,* (2006) found that in the case of wood pellet plants, a processing volume of 75,000 tonnes per year was required to achieve a relatively low cost for wood pelleting of $41/tonne (approximately $2/GJ). Plants processing pellets in the range of 45,000 tonnes of output annually were expected to experience pelleting costs of approximately $50/tonne. It is generally accepted from research and commercial production experience that pelleting costs are somewhat lower for densifying herbaceous biomass than wood pellets because of higher throughputs and lower drying costs. Warm season grass pelleting costs are estimated to be 20% below wood pelleting costs. The installation of briquetting facilities may be a potential solution to reduce densified fuel production costs by enabling lower capital investments, reduced grinding costs and lower feedstock delivery costs than pellet plants. Mechanical briquetting systems can have total (operational and capital) costs of less than $20/tonne or approximately $1/GJ with plants of 10,000 tonnes per year (Briquetting Systems 2008). The installation of briquetting facilitates may be a good solution for Alberta farmers to develop commercial fuel sales from biomass where local biomass supply can be utilized for local energy markets. The feedstock supply necessary to feed a briquetting plant would be approximately 1/50 that of a cellulosic ethanol plant which has obvious benefits in terms of cost, risk and scale impacts on existing farm activities in Alberta.

The main advantage of pellets is that they can meet a wider diversity of energy market applications and are also a well known product in rural communities. As well, pellet producers in Alberta can also produce other pellet products for other markets including livestock feed and animal bedding for horses and pets. Producing warm season grass pellets appears to be one of the most promising biomass conversion opportunities. If target plant sizes in the order of 50,000 tonne per year are required to be commercially viable, this will require efficient logistic systems. If overwintered warm season grasses such as prairie sandreed and switchgrass in Alberta are assumed to yield 7 ODT/ha, a 50,000 tonne per year plant will require about 7,100 ha seeded to this feedstock annually. If it is assumed that 20% of the entire rural landscape is planted to switchgrass, this will require an area of 35,500 ha, this would be equivalent to an area whose radius would reach out approximately 106 km from a conversion plant. A rough assumption is that the average one way hauling distances in the order 80 km can be anticipated. Using the same assumptions as above, a briquetting plant requiring 10,000 tonnes per year would require 1,400 ha and be sourced from a surrounding land area of 7,000 ha. Assuming the plant is centrally located, this surrounding land area would have a radius of 47 km and the plant could be roughly estimated to have an average hauling distance of approximately 35-40km.

7.0 Advances in Small and Medium Scale Combustion Technologies

A very rapid technological development of small and medium scale combustion systems is occurring globally as a result of the pressing need to develop clean and green renewable fuels. In particular countries like Sweden, Denmark, Austria and Germany have very dynamic advances in research and market development. Pellet boilers have been widely introduced into these northern European countries with Austria having a total of 28,000 units and Sweden 59,000 units installed at the end of 2004 (European Pellet Center, 2006). Sweden is amongst the countries most actively pursuing pellet boilers for energy security and rural development, with 11,000 new units introduced in 2004 (Mahapatra and Gustavsson 2005). Some initial investigations from surveys performed in Europe and North America have indicated consumer satisfaction with pellet appliances and their appreciation for the technology (Mahapatra and Gustavsson 2005; Vinterback *et al.*, 1998). The major advances in combustion technology are overviewed in this section as they relate to improving performance and ambient air emissions from combustion appliances. The main approach at creating more efficient and clean combustion has been to improve combustion appliance geometries and to create appropriate air staging.

7.1 Basics of Clean Combustion

The 3 main factors to consider in developing clean combustion design technologies are the 3 T's: time, temperature and turbulence. Complete combustion of gases occurs through effective air mixing in the secondary combustion, achieving long residence times for gases to burn in the appliances along with reaching adequately high temperatures in the combustion process.

Research and experience has shown that the volume, and supply method of combustion air is of paramount importance to achieving optimization of the combustion process. All clean combustion appliances now divide the combustion chamber into primary and secondary air to enable a two stage combustion. The primary combustion zone is the area where pyrolysis occurs and the dry fuel is transformed such that combustible volatile components are rapidly released while the residual char is slower to oxidize. Effective secondary combustion is achieved through developing a well designed geometry of the combustion chamber to create turbulence and through an effective arrangement and design of the air nozzles. The air also needs to be introduced with adequate velocity. The main objectives are to create effective turbulence for gas mixing and residence time to ensure complete gas combustion. An example of a improved combustion design demonstrating these features on a biomass grate furnace is found in figure 12.

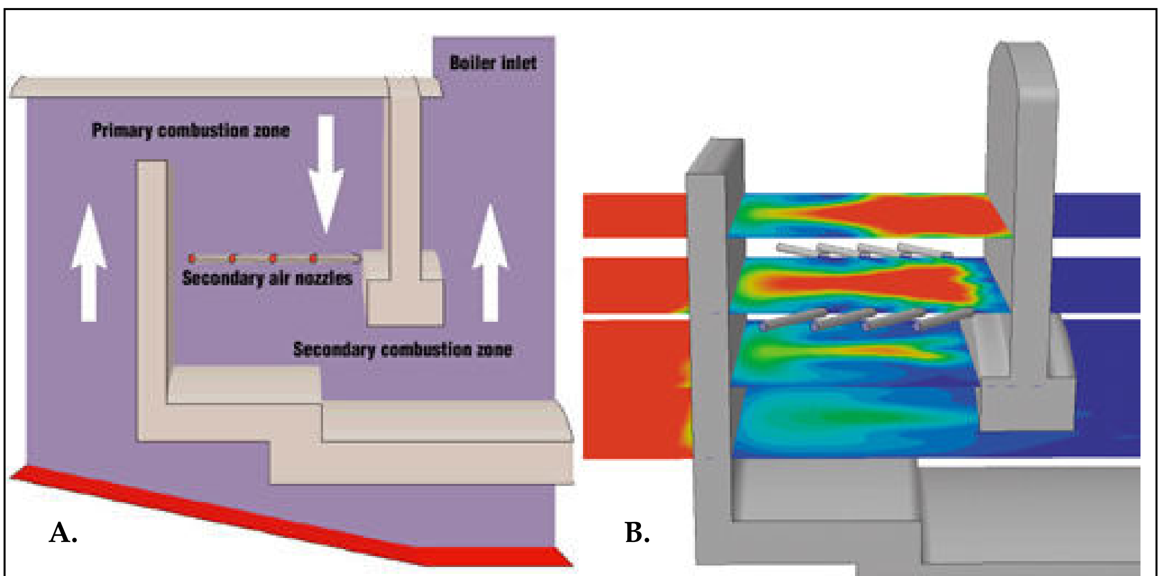


Figure 12. Biomass combustion: a) biomass fuel bed; b) optimized Austrian biomass grate furnace with contours of CO concentration in the flue gas on selected planes before and after the secondary air/fuel nozzles (Sharler *et al.*, 2000)

Many combustion systems are now being designed to be multi-fuel appliances or boilers burning wood, agricultural feedstocks and coal. However there are major differences between coal and biomass as combustion fuels. A primary difference between the fuels, which affects the combustion process, is the amount of volatiles. In coal most of the carbon is fixed and is more slowly released during the combustion processes. In contrast biomass fuels have high levels of volatiles and hence the fuel releases its energy more rapidly. Consequently biomass feedstocks require significantly more overfire air than coal to enable clean combustion by thoroughly burning the volatiles (Table 3).

Table 3. Proximate analysis of typical samples of softwood, hardwood and bituminous coal (Sims, 2002)

	Softwood	Hardwood	Bituminous coal
Volatiles	75.2	77.8	34.3
Fixed carbon	23.1	19.5	57.7
Ash	1.7%	2.7%	8%

The importance of the secondary air is not only the quantity but also how it is strategically introduced to create turbulence. One such example of an effective secondary combustion design process can be seen in the Dellpoint gasifier pellet stove; where cylindrical walls provide a confined central gasification chamber and air is injected from holes located in two spiral paths extending up the wall as mirror images of each other (Figure 13). This approach, completed at high temperatures of 1200-1370°C, creates a vertically swirling and turbulent motion which results in near complete combustion of the gases emanating from the solid fuel (Drisdelle *et al.*, 2002).

Figure 13. Dellpoint gasifier pellet stove flame (Photo Courtesy of Mark Drisdelle)

A major problem in burning high ash fuels that have significant levels of aerosol forming compounds like potassium, chlorine, sodium and sulfur are that they have a low ash melting point. This causes several problems including clinker formation and corrosion of appliances. A major problem with burning fuels at high temperatures is the occurrence of alkali species migration where potassium compounds form on the inside walls of the combustion unit (Jenkins *et al.*, 1998). One of the main strategies to address this problem is to use a lower temperature to initiate the release of gases in the primary combustion area. The problematic compounds will remain on the fuelbed where they are eventually removed through the bottom ash avoiding the secondary combustion area and boiler tubes. For example in grain combustion systems in Denmark, the feedstock is pyrolised at less than 700°C (SAOS and DTI, 2006). In larger more sophisticated combustion systems a staged combustion can occur where the temperature is gradually increased through the combustion process. Larger well designed combustion technologies are being used in large greenhouses in Canada, such as Binder and Vyncke brands, successfully utilize this approach to burn more difficult fuels with high efficiency. The more successful combustion units that are burning higher ash fuels have fuel bed systems which continuously remove ash and avoid a remixing of the burning char and burnt out ash with newly introduced fuel. This is particularly important in small boilers and stoves where the fuelbed is quite small and fuels are commonly fed from above. Ensuring there is limited to no mixing of fresh fuel and burnt out fuel, will help prevent the formation of soft surface bridging on the fuelbed, which has been widely reported when burning higher ash fuels.

It has also been well documented that the volume of excess air needs to be minimized to prevent excessive heat losses out of the combustion stack that commonly occurs when excess air required for effective combustion is employed. To gain better control of the combustion process, lamda (oxygen) monitoring controls can be used in the combustion process to maintain effectiveness. Both Lamda and CO controlled combustion appliances are now on the market which are overall providing considerably better results than temperature controlled combustion systems. It is extremely important that small scale appliances are well designed as installation of air clean up technologies are not affordable with small scale systems under 70 kW (Messerer *et al.,* 2007).

7.2 Pellet Stoves and Small Boiler Developments for Burning Agricultural Feedstocks

There now is an increasing number and diversity of pellet stoves and small boilers designs suitable for household, small commercial, and farm buildings heating. A list of technology providers is provided in Appendix 8. All these companies are incorporating features which make them better adapted to burning higher ash agricultural fuels. A list of some of the design features that stoves and boilers can include to help them achieve efficient and clean combustion of agricultural feedstocks such as feed grains or grass pellets can include:

- moving grate with limited to no mixing of fresh and already burning or burnt fuel;
- lamda or oxygen control;
- turbulence created through a well designed combustion chamber geometry and strategically introduced secondary air introduction;
- low excess air;
- use of ceramic refractory brick and high quality smooth surfaced stainless steel (to prevent adhesion by alkali compounds) in key areas where degradation from corrosion and high temperatures can occur;
- modest initial combustion zone temperatures in the primary combustion zone area followed by high temperature secondary combustion; and
- flue gas condensing system to recover additional heat and reduce particulate emissions.

The overall progress in improving the combustion process in Europe in recent years has been remarkable. The following three figures (14, 15, and 16) indicate the progress that has been made in small pellet boilers in efficiency, particulate load and CO emissions. A list of appliance suppliers is found in appendix 8. The better technologies are generally incorporating many of the aforementioned improved design features. However some design features such as use of a flue gas condensing system for heat recovery may create excessive capital costs in smaller units.

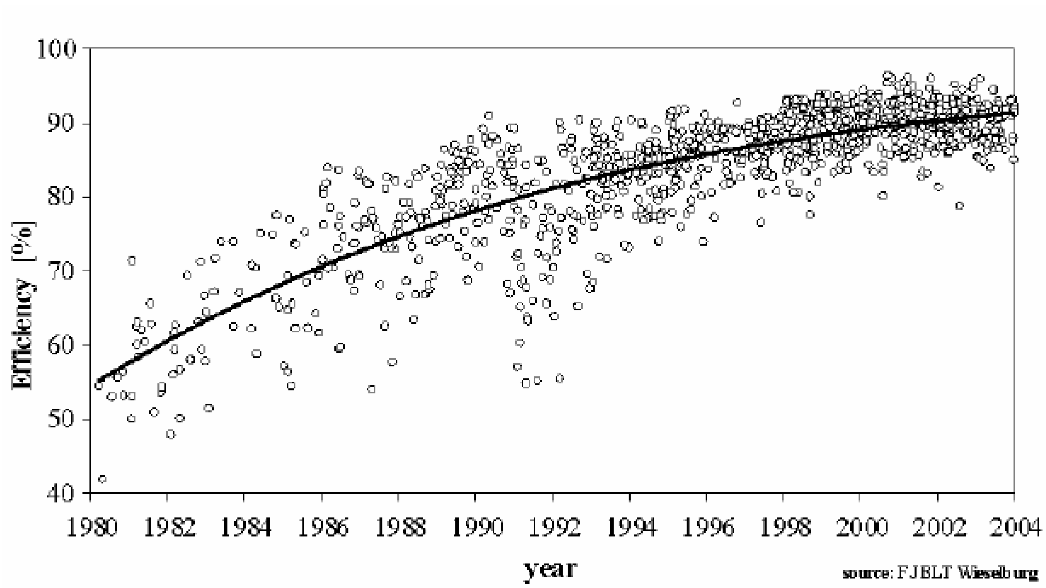


Figure 14. Efficiency of wood pellet boilers tested at FJ-BLT from 1980 to 2004 (Haslinger *et al.*, 2005)

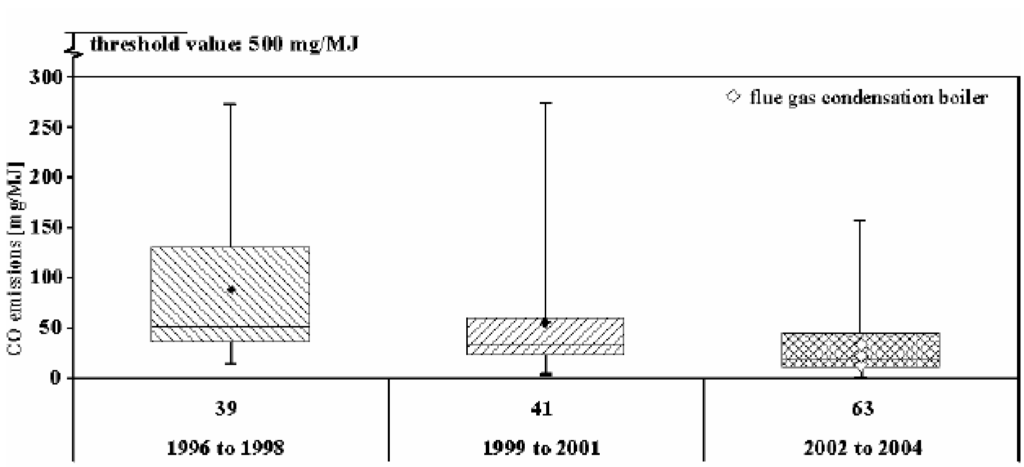


Figure 15. Carbon monoxide emissions of wood pellet boilers tested at FJ-BLT from 1996 to 2004 (nominal rating; Haslinger *et al.*, 2005)

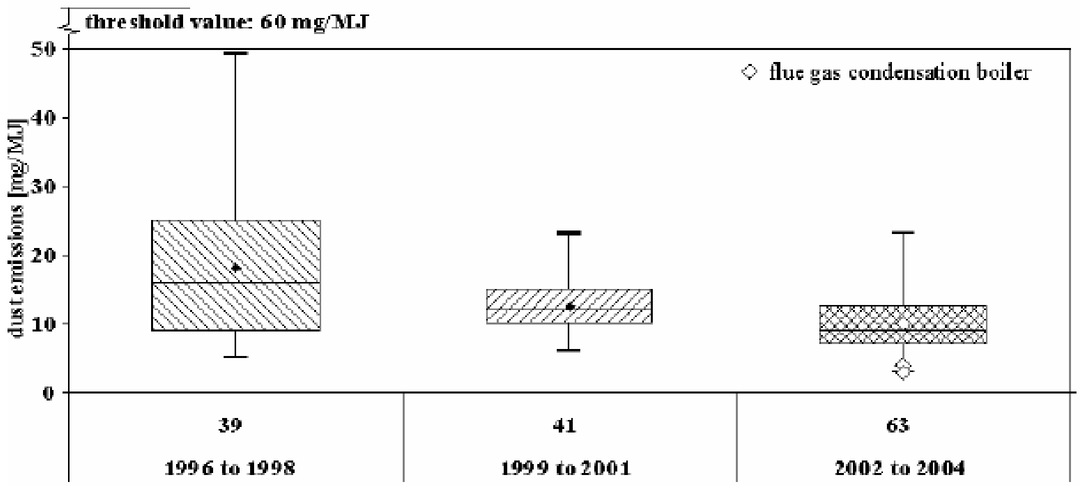


Figure 16. Particulate emissions of wood pellet boilers tested at FJ-BLT from 1996 to 2004 (nominal rating; Haslinger *et al.*, 2005)

7.3 Small to Medium Sized Commercial Boilers 150 kW- 5 MW

Within Canada there has been less technology development in the combustion field compared to Europe, as fossil fuel prices and carbon taxes are either modest or non existent in Canada. The economics of introducing sophisticated advanced combustion technology appliances is much more difficult than in Europe. As well the provinces and federal government in Canada have limited incentives for purchasing clean combustion biomass appliances. Some of the design features that are being included in advanced combustion devices (over and above the aforementioned features used in smaller units) to achieve higher combustion efficiencies and cleaner combustion from higher ash fuels are:

- recycling of flue gas to create preheated overfire air;
- use of staged combustion to gradually increase combustion temperatures;
- use of vibrating grate to prevent clinker formation;
- use of an evaporative cooler after the gasifier to remove alkali metals and chlorine from flue gas that causes problems with forming salts leading to corrosion and fouling problems (Dall Bentzen, 2008);
- use of an economizer to recover waste heat as many upright systems do not have adequate heat exchange; and
- use of a bag system to reduce particulate load.

There have been two main designs developed to service the market for small commercial boilers which will be discussed in the next two sections.

7.3.1 Round Upright Underfed Stoker Boiler

An increasingly popular commercial boiler design with rural energy users in Canada is the use of a round upright underfed stoker design. It is becoming increasingly popular especially for the small to medium sized greenhouses in the Ontario greenhouse industry. It can burn higher quality types of coal, wood pellets, off specification feed

grains and densified agricultural fuels. The popularity of these boilers is mainly due to their modest cost, small footprint for the combustion unit and fuel storage, and convenience compared to using stoker fed boilers and bulk handled fuels. Common manufacturers of the round upright underfed stoker boilers in Canada are Dekker Brand, Pelco (made by Profab Industries) and all Canadian Coal Boiler (Appendix 9).
The leading market where they are being introduced is for heating greenhouses in Ontario. The units are utilizing imported anthracite coal from Pennsylvania or oat hull pellets made from crop milling residues. They also have been successfully tested to burn overwintered switchgrass pellets. The limitations of the units for burning biomass are that they require: 1) densified biomass feedstocks; and 2) require feedstocks with low-to moderate potassium and chlorine to prevent fouling.

The units have somewhat more limited heat exchange relative to triple pass horizontal tube heat exchange boilers. This is particularly true for the units that are shortest in height and hence have the shortest heat exchange. Typically the units are designed to provide 147 kW-1026 kW of output energy and commonly multiple units are installed in larger facilities. There are various versions of the round upright underfed stoker boilers on the market. The longest standing manufacturer of these boilers in Canada is Dekker Brand boilers which originally developed the boiler for burning coal on Hutterite colonies in Manitoba in the early 1980's. The designs of the manufacturers are evolving to improve combustion performance and convenience. The main feature of the design is that fuel is fed from underneath into the centre onto a fixed fuel bed with the primary combustion air passing through the fuel. Some of the important design features that are now being incorporated into many of these systems are:

- automated cleaning of the vertical tubes;
- spiral flue gas dispersers in the vertical tubes to increase air mixing;
- increase heat absorption and slow passage of the air out of the boiler;
- preheated secondary air being recirculated from the flue gas;
- use of a waste heat recovery boiler or economizer; and
- use of a baghouse for filtering particulate emissions.

A round upright underfed stoker boiler with an additional heat recovery economizer system as well as dust collection system is displayed in Figure 17. The combination of integrating a combustion unit with a heat recovery unit to reduce exit temperatures and particulates followed by a final dust collection apparatus appears quite effective yet with moderate costs. This combination of units in a Dekker Brand system was recently tested and found to have low particulate levels of 2.0, 2.6 and 3.0 mg/m^3 for wood pellets, oat hull pellets and coal respectively (McCall Environmental, 2007). Carbon monoxide levels were also low with levels of 104, 90 and 196 for wood pellets, oat hull pellets and Alberta coal respectively. It is important that these units utilize a relatively high quality biomass feedstock or significant operational difficulties and emission problems may be experienced. These units appear well suited towards burning overwintered warm season grasses pellets and briquettes based on existing experiences with Pelco and Dekker Brand systems designed for biomass use that have overfire air.

Figure 17. Decker Brand Boiler with economizer *(www.deckerbrand.com)*

7.3.2 Chain Grate and Sloping Grate Furnaces

The second main design that is being utilized in medium sized commercial boilers is chain grate and sloping grate furnaces. These units are rectangular shaped and have the fuel passing from one end of the fuelbed to the other before being fully burnt out. A detailed overview of the technology of stoker fired boiler design and operation can be found on-line (www.cibo.org/emissions/2002/a1.pdf)

A leading Canadian supplier of the chain grate system suitable for coal or biomass is the Blue Flame Stoker listed in the appendix 9. It is widely in use in the Canadian greenhouse industry. The leading imported technology for sloping grate furnaces are Binder and Vynche technologies. The sloping grate is generally quite expensive and hence this technology is usually only used on large thermal energy applications like a very large greenhouse. A diagram of one of these systems is found in Figure 18. The grates are either air cooled or water cooled to prevent degradation from excessive temperatures. These units are better suited than the chain grate system for burning the more difficult agricultural fuels. The step grate combustion bed keeps the fuel in motion and enables excellent control over the various combustion zones on the sloping grate.

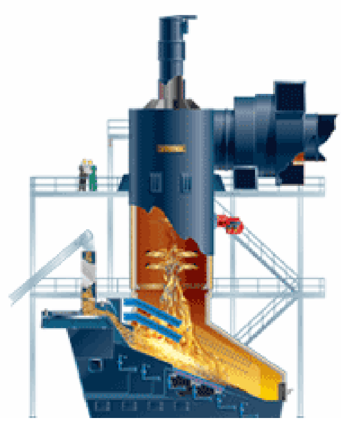


Figure 18. Vyncke sloping grate furnace *(www.vyncke.be)*

8.0 Ambient Air Emissions of Agro-pellets in Combustion Appliances

Particulate matter (PM) is a generic term used to describe a complex group of air pollutants that vary in size and composition, depending upon the location and time of its source. The PM mixture of fine airborne solid particles and liquid droplets (aerosols) include components of nitrates, sulfates, elemental carbon, organic carbon compounds, acid aerosols, trace metals, and geological material. Particulate matter emissions range from millimeter-sized cinders and soot aggregates to ultra fine nucleimode primary particles only a few nanometers in diameter (Lighty *et al*., 2000). The largest particles are removed in the combustion zone as bottom ash or wall deposits, or are collected in the post-combustion gas cleaning devices. The smaller particles or aerosol emissions travel with the combustion exhaust gas and contribute to ambient air pollution on both the urban and regional scale. Different kinds of combustion devices like internal combustion engines, heat and power plants, as well as small-scale biomass-fired boilers are examples of sources of the particulate emissions. Particulate matter absorbs and scatters atmospheric radiation contributing to radiative forcing around the globe and have significant negative impacts on human health.

Ambient particulate matter is generally described as having 2 categories coarse mode (>1 µm) and fine mode (<1 µm). It can also be described as total suspended particles (TSP) with particles sizes of PM10, PM 2.5 and PM1 (particles fractions with a diameter <10, 2.5 and 1 µm respectively). Particulates are a critical pollutant in flue gas and may be a limiting factor for industry to meet increasingly rigorous emission standards. There are potentially 5 factors which can contribute to minimizing particulate emissions:

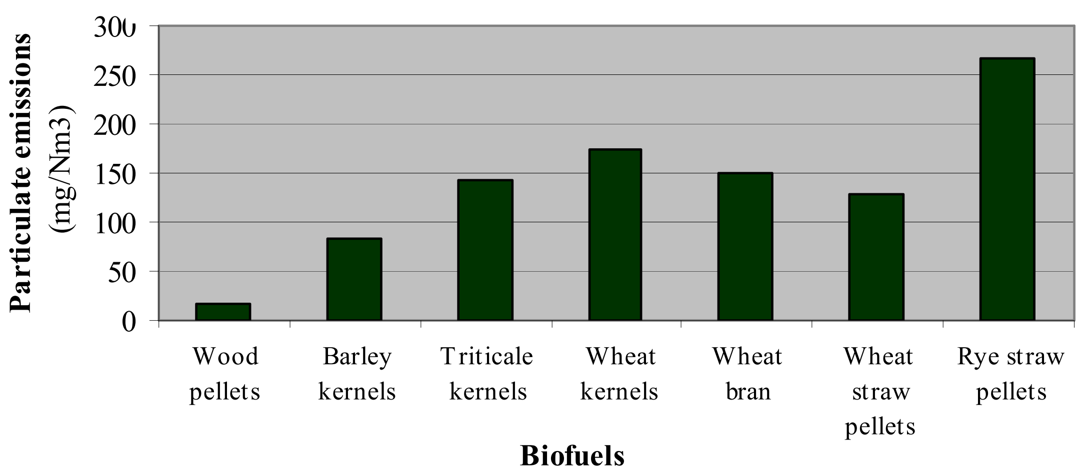
- an improved boiler design;
- use of low aerosol forming fuels;
- use of a densified form of the biomass;
- use of additives incorporated into the fuel; and
- use of a cyclone or other apparatus to trap dust.

8.1 Improved Boiler Design

Major progress has been made in improving boiler design. The main factors that have recently been identified to contribute to reducing particulate load are the use of a lamda (oxygen controlled) boiler and the use of a condensing boiler. In small scale Austrian boilers burning wood pellets emissions have been reduced from an average of 15 mg/MJ in 1996-1998 to 10 mg/MJ in 2005. Flue condensing boilers were found to reduce emissions by 50%. Haslinger *et al.* (2005) reported small scale condensing pellet boilers of 8 and 16 kW to have particulate emissions of 3 and 4 mg/MJ respectively. Johansson *et al*., (2004) tested 18 and 21 kW oil boilers and found particulate emissions of 6 and 12 mg/MJ. Thus advanced pellet boilers burning wood pellets will have no detrimental impacts in ambient air quality where heating oil is replaced. Important gains in ambient air quality can be realized where pellets replace common solid wood burning appliances. Houeck and Broderick (2005) compared PM 2.5 emission factors (adjusted for efficiency) of conventional woodstoves, catalytic certified woodstoves and certified pellet stoves emissions and found them emit 66.8, 15.1 and 2.5 lb/ton for each of the respective appliances. However recent advances in solid log boilers combustion design which include use of a heat sink have also demonstrated the potential for exceptionally low emissions at 4.4-5.7 mg/MJ (Obernberger *et al.*, 2007).

8.2 Aerosol loading and particulate matter from fuel types

The most important parameter influencing the total mass of aerosols formed during combustion is the amount of volatile aerosol forming elements from the fuel, which mainly depends on the chemical composition of the fuel. In particular Ca, Mg, Na, and K are the most important elements (Obernberger and Brunner, 2001). In terms of aerosol loading potential of fuels, wood pellets and wood logs are lower than wood chips (Obernberger *et al.*, 2007) which contain more bark material. Wood pellets are also lower than most agricultural sources of fuels. Results reported from Obernberger and Brunner (2001) indicated that the concentration of aerosols and coarse fly ashes mainly depends on the ash content of the fuel and the load of the combustion unit. For example, emissions can amount from about 100 mg/Nm^3 (related to dry flue gas and 13 vol.% O2) when burning fuels with a low ash content such as chemically untreated wood chips at low load up to about 1,000 mg/Nm^3 or when burning fuels with a high ash-content such as bark at high load.



[Figure adapted from Hartmann et al., (2007); values are from tests performed in a Guntamatic boiler made in Austria]

Figure 19. Total particulate emissions using various biofuels in a 30 kW Lamda-controlled pellet boiler (adapted from Hartmann *et al.*, 2007; values are from tests performed in a Guntamatic boiler made in Austria).

An overall ranking that appears to be emerging is that wood pellets< delayed harvest grass pellets<crop milling residues pellets and grains< straw and stalk.

Carvalho *et al.*, (2007) compared wood pellets, miscanthus pellets, corn and straw pellets as fuel. Particulate emissions varied considerably both between fuels and boilers and with the use of additives in the more difficult to burn fuels.

In the case of miscanthus pellets tested in a 15 kW lamda controlled boiler with a moving grate (to facilitate ash removal), particulate loads from burning miscanthus pellets were approximately 15 mg/MJ. This is well within the new threshold in Austria for automatically fed boilers under 400 kW which is to be set at 50 mg/MJ for wood and 60 mg/MJ for non-wood fuels (Carvalho *et al.,* 2007). Hartmann *et al.*, (2007) also found a strong difference in particulate emissions between woody biomass and herbaceous fuels. Differences may be due to both the aerosol-forming potential of the fuel and the physical form of the biomass. Compared with emissions from wood pellets (17 mg/Nm^3), particulate matter emissions from crop milling residues and feed grains ranged from 80-200 mg/Nm^3 (Hartmann *et al.,* 2007). Cereal straw pellet samples tested in the 125-275 mg PM /Nm^3 emission range. Figure 19 illustrates the particulate emissions found for the various feedstocks. Beginning with "clean" biomass, such as low ash fuels with low concentrations of aerosol forming chemical compositions (i.e. K, Ca, Mg, and Na) will produce the lowest fine particulate matter emissions.

8.2.1 Fuel Handing Improvements

In Europe there is significant interest in developing a new source of fibre to expand the market for pellets in small scale combustion appliances. Some use of whole trees for processing into pellets has began as a result of rising fibre costs associated with procuring wood residues. A promising new option may be overwintered thin stemmed warm season grasses. Previous research in Canada has found these feedstocks to lose up to 95% of theory potassium content over winter (Samson *et al.*, 2005). Promising results are presently being obtained in Germany with particulate emissions of switchgrass versus Miscanthus. Preliminary results indicate switchgrass pellets testing under 100 mg/Nm^3 which is approximately half that of Miscanthus (a thick stemmed warm season grass) (Rumpler, personal communication). In Germany a step by step plan for emission reduction regulations has been proposed for combustion appliances below 100 kW. This will call for particulate emissions in mg/Nm^3 to be reduced from 130 (present limit) to 100 by 2010 to 75 mg/nm^3 by 2015 (Stanev, 2007). The combination of low aerosol loading pellets like switchgrass with the use of advanced combustion appliances will be necessary to meet these targets using agro-pellets.

Overall processed fuels can significantly improve combustion quality and decreased particulate loading when compared with bulk fuels due to the increased uniformity of the fuel, less fines and better control over the combustion process. Biomass fines can significantly impact coarse particulate matter emissions. To reduce fuel fines, high quality pellets with improved durability can be used. It has been identified that coarse fly ash emissions also increase with increasing ash content of the fuel, increasing disturbance of the fuel bed and increasing flue gas velocities (increasing load of the combustion unit) (Obernberger *et al*., 2007).

8.2.2 Fuel Biomass Quality

Fine particulate emissions (the PM_{10} fraction) or so called aerosols are of much greater concern for human heath impacts. These particulate emissions are strongly related to fuel type, and specifically, the ash forming content of aerosol-forming compounds including potassium, chlorine, sodium and sulfur and even lead and zinc (Hartmann *et al.*, 2007). Within the ash forming elements, the easily volatile elements that have been identified are primarily K, Na, S and Cl while non-volatile elements during biomass combustion are Ca, Si, Mg, Fe and Al (Obernberger *et al.,* 2007). Using fuels that are low in the "dust critical" elements K, Cl, Na and S is of particular importance for achieving high quality biomass fuels and lowering particulate emissions during biomass combustion. Oberneberger *et al.,* (2007) examined the composition of chemical compounds and found them dominated by K, followed by S and Cl. The compounds K_2SO_4, KCl and K_2CO_3 were the most important constituents of the aerosols. Obernberger *et al.,* (2007) suggested a target of less than 0.1% for these elements to minimize concerns of aerosol formation. Please refer to Table 3 for the K, Cl and S contents of various biomass fuels. It is evident that developing low K containing agro-fuels is of paramount importance if low aerosol loading agro-fuel pellets are to be developed.

The silica, potassium and chlorine contents of grasses and other herbaceous biomass feedstocks are affected by many factors including: time of harvest, soil type, fertilizer type and rate, thickness of the stems, the relative stem to leaf ratio of cultivars, the relative water use efficiency of C_4 versus C_3 species and the rainfall to evaporation ratio where the crops are grown. In eastern Canada, the ash content of switchgrass grown on a sandy loam soils was 15% below that of a clay loam soils (Samson *et al*., 1999). However, delayed harvesting of the grass (overwintering the grass and harvesting the following spring) had an even bigger influence than soil type by reducing ash content by 39% (Samson *et al*., 2005). The potassium and chlorine contents of grass species at harvest is affected by resident levels of these elements in the soil, the rate of potassium fertilizer applied to the crop, the type of potassium fertilizer applied, the content of these elements at crop maturity, and the rate and duration of leaching of these elements that occurs in the period following maturity until harvest time (Samson *et al*., 2005). An effective way to reduce potassium content in the fall is to use early maturing varieties that have a longer period to leach out material prior to late fall harvest (Elberson *et al*., 2002). A resent study of switchgrass production by Samson *et al*., (2008) demonstrated K concentrations decreased 70% with overwintering from 0.33% in the late fall to 0.1% in early spring, meeting the suggested target of 0.1% from Obernberger *et al*., (2007).

Plant morphology can also have a significant effect on biomass quality. Lowland types of switchgrass are characterized by tall, coarse stems with rapid growth and are adapted to poor drainage and often found in floodplains. They differ notably from upland types which are characterized by short, fine stems with a high drought tolerance (Cassida *et al*., 2005). Upland types have generally been found to have higher ash concentrations than lowland types; but as they have finer stems, they also tend to have lower chlorine and potassium levels and lower water contents. This is likely a function of the thin stemmed cultivars having a larger surface area exposed to the elements (Samson *et al*., 2007).

Lowland switchgrass cultivars such as Alamo and Kanlow have been found to be moderately higher in K and Cl than upland switchgrass at the end of the season. This problem appears to be even more serious in miscanthus than switchgrass. One assessment of the average stem diameter of miscanthus found it to be 8.8-9.2 mm, with a stem wall thickness of 1.3-1.5 mm (Kaack and Schwarz, 2001). In lowland ecotypes of switchgrass, an average outer diameter of switchgrass was found to be 3.5 mm (Igathinathane *et al*., 2007) and 5 mm (Das *et al*., 2004). Stem wall thickness was reported to be 0.7 mm in lowland switchgrass varieties (Igathinathane *et al*, 2007) which is approximately 1/2 the thickness of the stem wall of miscanthus reported in other studies. Thick stemmed miscanthus ecotypes are known to have high potassium and chlorine contents, especially at late maturity (Jørgensen, 1997). For example no biomass quality reports could be found in Europe which indicated *Miscanthus sinesis giganteus* was able to achieve biomass quality targets outlined by Sander (1997) of 0.2% K and 0.1% chlorine for power generation in Denmark. Thick stemmed species are also more difficult to dry. REAP-Canada identified that even in fall harvested upland switchgrass, stems tend to retain significant moisture while other components were less than 15% moisture (Samson *et al*., 2008). Spring harvest ensures material will be harvested below 15% moisture. The low moisture content of grasses at harvest is a major advantage compared to woody energy crops. Willows for example are typically harvested at 50% moisture. If made into pellets, high moisture wood materials typically will require 21% of the raw material for energy in the drying process (Bradley 2006). Thus spring harvested grasses have a major biomass quality advantage for pellet processing because of their dry nature and can typically be harvested at 12% moisture which is highly suitable for both grinding and pelleting operations. Switchgrass in eastern Canada reached a moisture content of 7% in early May under overwintering conditions (Samson *et al*., 2008).

8.2.3 Lime Use

Biomass combustion appliance manufacturers often recommend the addition of lime (CaO) to fuels when burning agro-pellet fuels or grains to avoid problems with clinker formation and slagging. Hartmann *et al.,* (2007) found that this practice, although having no impact on the emission of carbon monoxide, volatile hydrocarbons or other gaseous pollutants, did reduce particulate loading by approximately 15%. Ronnback *et al.,* 2007 found 2% fine limestone mixed with oat grain fuel reduced total dust formation by 28%. Limestone is known to create chemical compounds such as $CaSO_4$ which have a high melting temperature, thus these species stay in the bottom ash. The authors felt this additive would be most valuable in larger combustion systems where the increased ash content of the fuel would have minimal negative impacts on combustion efficiency. The limestone also had the added benefit of reducing HCl formation. Corrosion of boilers and chimneys is a common problem when burning agro-fuels thus this is of significant importance.

Finally it is well known that emission reduction apparatus can be installed to effectively reduce particulate loads. Biedermann and Obernberger (2005) suggests using a two-stage process, first removing coarse fly ash with a cyclone fly ash unit (mainly coarse fly ash particles) and then removing fine fly ash with a highly efficient fine fly ash precipitator. Other techniques such as the use of underground flue gas pipe can also trap particulates in a cost effective manner. Ronnback *et al.,* (2007) found the use of an underground channel to reduce chlorine total dust and sulfur emissions by 40%, 42% and 67% respectively.

8.3 Pollutant Emissions

NO_X compounds play an important role in the production of particulate matter and atmospheric haze, smog, acid rain and eutrophication from nitrogen deposition in aquatic areas. Hartmann *et al.*, (2007) found that in flue gas emissions, NO_X emissions are clearly a function of the element (in this case nitrogen) content in the fuel when compared with other pollutants such as carbon dioxide (CO_2), carbon monoxide (CO) and volatile hydrocarbons (TOC). Lower N containing fuels such as wood chips, wood pellets and miscanthus fuels had NO_X emissions below 200 mg/Nm^3, while grain fuels had emissions from 400-600 mg NO_X/Nm^3.

Hartmann *et al.,* (2007) determined that NO_X emissions from biomass combustion in a small scale Guntamatic Powercorn 30 kW Lamda-controlled boiler were equivalent to 353.9 times the N content (%) to the power of 0.35 using a regression analysis. Using this relationship, NO_X emissions were estimated from the nitrogen content for common agri-fuel feedstocks, the results of which are presented in Table 4.

Low nitrogen-containing fuels having an N content less than 0.5% were identified to have the lowest overall estimates for NO_X emissions, with the overwintered switchgrass feedstock approaching the low levels achieved by the wood pellets. Some milling byproducts, specifically oat hulls and corn cobs also had low NO_X estimates and appear to be promising feedstocks for combustion based on their N content. Straw fibres also possessed moderately low nitrogen contents. However, all of the grain fuels and the processed wheat residues were estimated to produce high levels of NO_X, between 400-500 mg/Nm^3. Using mixtures of these fuels may provide some benefit in terms of making pellets, and increasing combustion efficiency and will keep NO_X emissions at acceptable levels. Overall there appears to be major environmental advantages from an NO_X standpoint of developing warm season grasses as bioheat feedstocks relative to other agricultural biomass options.

Table 4. Estimated NOx emissions associated with nitrogen content of feedstocks suitable for Alberta

Residue	**Nitrogen Content**[1] (%)	**Estimated NO_X Emissions** (mg/Nm^3)
Wood Pellets	0.3[2]	232
Energy Crop Pellets		
Fall harvested switchgrass	0.46[3]	270
Spring harvested switchgrass	0.37[3]	250
Straw Residues		
Wheat	0.48	274
Oat	0.64	303
Barley	0.64	303
Rye	0.64	303
Corn	0.8	327
Grains		
Wheat	2.24	469
Oat	2.08	457
Barley	1.92	445
Rye	1.92	445
Corn	1.44	402
Milling Residues		
Wheat bran	2.72	502
Wheat middlings	3.04	522
Oat hulls	0.64	303
Pin oats	1.28	386
Corn cobs	0.48	274

[1]Preston (2006); [2]Obernberger and Thek (2004); [3]Average of Goel *et al.*, (2000); and Adler *et al.*, (2006)

9.0 Case Study Applications of Agri-fibre Fuels

Nott Farms

Don Nott Email: dnott@tcc.on.ca
RR 4 Clinton, ON Canada, N0M 1L0; T: 519-233-7579; F: 519-482-5644

Nott Farm facilities in Clinton, ON (Photo courtesy of Better Farming Magazine)

Nott Farms operates an oat processing facility that provides them with a by-product of oat hulls. In 2006, Don Nott began using this material along with purchased wheat bran to produce crop milling residue fuel pellets for heating applications. He now has a fleet of delivery trucks and a 10,000 tonne storage bin to hold this winter heating fuel. Nott Farms supplies approximately 20 greenhouses in Ontario with their winter heating fuel. Nott Farms currently has over 200ha of warm season grasses under cultivation. For more information, please refer to the Better Farming Cover Story December 2006 http://www.betterfarming.com/2006/bf-dec06/cover.htm.

Prairie Bio-Energy Inc. www.prairiebioenergy.com

P.O. Box 560, La Broquerie, Manitoba Canada, R0A 0W0; Tel.: 204-424-5313; Fax: 204 424-5405

In 2005, Prairie Bioenergy became the first Canadian producer of densified crop residues for energy. Their biomass cubes are loaded into an overhead bin for bulk loading into trucks

Prairie Bioenergy was the first agency in Canada to sell densified agri-fibre fuels. They currently produce a blended product made of flax shives, wood residue and waste paper products using a cooper cuber (www.cooperequipmentinc.com). The product is 2.2 cm (7/8") cube, 5-6% moisture and has a bulk density of 210 kg/m^3. The primary components of the fuel cubes include a mixture of wood by-products and flax shives. The energy content is approximately 18.4 GJ/tonne. It is being sold to displace coal, mainly in commercial boilers used in large livestock barns and greenhouses.

Show Me Energy Cooperative, www.goshowmeenergy.com
102 SW Missouri Highway 58, Post Office Box 177, Centerview, Missouri U.S.A. 64019-0177; Tel: (660) 656-3780; Fax: (660) 656-3782

Show Me Energy Cooperative processing facility under construction *(www.goshowmeenrgy.com)*

Evergreen BioFuels USA (EBF), and Missouri-based Show Me Energy Cooperative (SMEC), have combined to engineer, build and manage one of the largest biomass pellet fuel production plants in North America. Evergreen BioFuels develops and manufacturing of clean renewable forms of energy for power plants, enabling them to dramatically reduce greenhouse gas emissions and contribute to a cleaner future. Show Me Energy Cooperative is a non-profit, producer owned, cooperative founded to support the development of renewable biomass energy sources in West Central Missouri through the establishment of suitable conditions in the field of energy development which incorporate the efforts, products, and goals of local agricultural biomass producers. When completed in early 2008, the $6.5 million plant will produce enough biomass to not only be used in coal utility energy production but also meet the heating needs of about 20,000 homes. The agreement between EBF and SMEC will see the annual production of 100,000 tons of biomass pellet fuels, the energy equivalent of 300,000 barrels of crude oil, which EBF will market into the local energy market to replace coal.

SMEC installed hay grind machine by Warren & Berg (left) and the Bliss Industries pellet mill *(www.goshowmeenrgy.com)*

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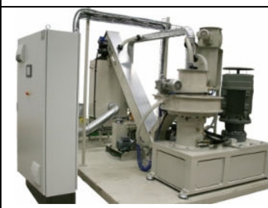
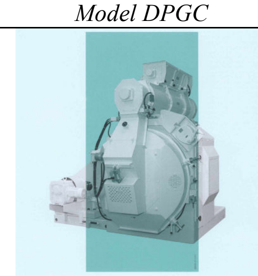
11.0 Appendices

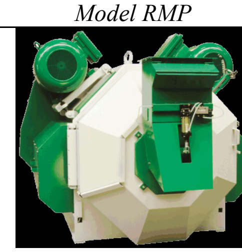
Appendix 1: Alberta Wood and Agri-Fibre Densification Processors

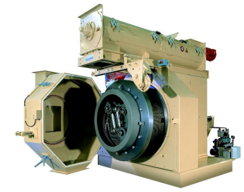
La Crete Sawmills Ltd.	La Crete, AB T: (780) 928-2292 W: www.lacretesawmills.com	Wood Pellets	AB
Kentucky Komfort	11607-178th St., Edmonton, ABT5S 1N6 T: 1-877-303-3134 W: www.kentuckykomfort.com	Wood Pellets	AB
Ecobiofuel INC	1024 Shawnee Dr, Calgary, AB T2Y 2T9 T: (403) 714-0066 W: www.ecobiofuel.com	Wood Pellets	AB
Vanderwell Contractors Ltd.	P.O. Box 415 Slave Lake, AB T0G 2A0 T: (780) 849-3824	Wood Pellets	AB
Dansons Group Inc.	26319 Township Road 531, Acheson AB T7X 5A3 Contact: jeff.thiessen@dansons.com www.dansons.com	Wood Pellets	AB
Bow Island Dehy Ltd	Bow Island, AB T: (403) 545-2293	Alfalfa Pellets	AB
Cool Spring Alfalfa	Falher, AB T: (780) 837-2244	Alfalfa Pellets	AB
Falher Alfalfa Ltd.	Box 177 Falher, AB T0H 1M0 T: (780) 837-2244	Alfalfa Pellets	AB
Green Prairie International	RR 8 S30 C11 Lethbridge, AB T1J 4P4 T: (403) 327-9941 www.greenprairie.com	Alfalfa and Tame Hay Pellets	AB
Hills Alfalfa Ltd	Rolling Hills AB T: (403) 964-3593	Alfalfa Pellets	AB
Kentucky Komfort	T: 877-303-3134 www.kentuckykomfort.com	Alfalfa Pellets	AB
Legal Alfalfa Products Ltd.	Box 480 Legal, AB T0G 1L0 T: (780) 961-3958 www.alfatec.ca	Alfalfa Pellets	AB
Lomond Alfalfa Products Ltd.	Box 268 Lomond, AB T0L 1G0 T: (403) 792-2411	Alfalfa Pellets	AB
Seven Persons Alfalfa	Medicine Hat, AB T: (403) 832-2070	Alfalfa Pellets	AB
Sun Cured Alfalfa Cubes Inc.	Box 640 Coalhurst AB T0L 0V0 T: (403) 381-4764	Alfalfa Pellets	AB
Welling Alfalfa Cubing Inc.	Box 100 Welling AB T0K 2N0 T: (403) 752-3773 www.wellingalfalfa.com	Alfalfa Pellets	AB

Appendix 2: Pellet Mill Manufacturers

AVS Plus, Ltd.	AVS Slovakia, s.r.o., Smrečianska 29, 811 05 Bratislava, Slovakia T: +4212444 53276 E: avs@avsplus.sk W : www.avsplus.sk	Produces full line of biomass pelleting with production capacity with 4 Ecotre models ranging from 1 t/h to 10 t/h, from different kinds of biomass and wood, starting from saw dust, chips or even logs and finishing with packed pellets.	
AGICO	Suite A, 4/F Jinhao Business Bld., Renmin Rd., Anyang, Henan China; T:+86 372 5965148 E: infor@agico.com.cn W: www.agitc.cn	AGICO produced a full line of biomass pelleting, specifically designed for wood and sawdust. AGICO produces 4 pellet mills (SZLH205, 350, 420, 580) with power drives ranging from 18.5kW-110kW. Pellet sizes range from 6mm to 8mm.	
Amandus Kahl USA Corporation	380 Winkler Drive, Suite 400, Alpharetta, GA USA 30004 – 0736; T: 770-521-1021; Contact Mr. Martin C. Johnson E: johnson@amanduskahlusa.com W: www.akahl.us	Kahl offers the complete pelleting process line. Flat die pelleting presses with a drive power from 3kW to 500kW. In total, 11 different sizes are available with production capacities ranging between 1.5 to 8 t/h. Pellet mills can process wood waste (shavings, chips, sawdust), straw (miscanthus, bagasse) and other biomasses. Feedstock needs to be at approximately 10% residual moisture and a granular size of approximately 4mm.	

Andrtiz Sprout Pellet Mills	**International:** Andritz AG, Stattegger Strasse 18, A-8045 Graz, Austria, T: +43 316 6902-0 **North America :** Muncy, PA, U.S.A 17756 T: 570-546-8211; Contact: Ron Rockey, E: smbiofuel@andritz.com W: www.andritz.com	<u>Andritz Sprout Gear-Drive Pellet Mills</u> • High precision single reduction helical gear transmission up to 560 kW (800 HP) • Capacities up to 100 t.p.h. • Wide range of die speeds <u>Andritz Sprout Two-stage twin drive Paladin Pellet Mill</u> • Two-stage twin drive system for ideal transmission ratios Andriz Sprout is an equipment supplier capable of supplying key machinery for final grinding, pelleting and cooling for the timber industry, sawmills and paper industry. Agricultural by-products such as straw and animal manure can also be used. The mill has operator-friendly bolt suspended die, which self-piloting effect makes changing easy. Andriz offers two pellet mills (26LM, PM30) ranging from 300kW-315kW	 *Model PM30*  *Biomass pelleting line*
Biopress	iopress Kånnavägen 3B 341 31 Ljungby, Sweden T: + 46 372 - 860 60 E :info@biopress.se W : www.biopress.se	Biopress produces three horizontal die Briquetting models ranging from 0.1 t/h to 0.9 t/h in several different combinations of plants. Raw materials include sawdust, shavings and other wastage material from the wood industry	
Bliss Industries Inc.	P.O. Box 910, Ponca City, Oklahoma U.S.A. 74602 T: 580-765-7787 E: sales@bliss-industries.com W: www.bliss-industries.com	Pioneer Pellet Mills • Wide range of die sizes, die speeds and drive power Bliss Industries provide a wide range of die sizes, die speeds and drive power. In total, 14 pellet mills are available ranging from 60kW-370kW belt driven power. These pellet mills can accommodate wood, fiber and agriculture residues	 *Model DPGC*
Bühler Inc. - Pellet Plant Systems	16 Esna Park Drive, unit 8 Markham, ON Canada, L3R 5X1 T: 905- 940 6910 ext. 227; Contact: Adrian Polman E: adrian.polman@buhlergroup.com W:www.buhlergroup.com	Bühler provides the complete biomass pelleting line capable of processing wood chips, sawdust, straw and raw vegetable materials. Bühler has four v-belt driven pelleting mills (Kubex pellet mill DPAS, DPBS, DPCA, DPGC) ranging from 90kW-280kW.	 *Kubex pellet mill*
California Pellet Mill Co. (CPM)	1114 E. Wabash Avenue, Crawfordsville, IN U.S.A. 47933 T: 1-800-428-0846 E : sales@cpmroskamp.com W: www.cpmroskamp.com	CMP provides complete biomass pelleting line. Pellet mills are ideal for producing pellets for full line feeds, wood, single ingredients, coal, poultry feed, hog feed, paper and corn wet milling.	 *Model CPM (7900)*
Drying Engineering Inc,	201 Venture Research Center, College of Agriculture and Life Science, Seoul National University 103 seodun-dong,kwonsun-gu suwon,	Produce biomass/renewable wood pellet-fuel plants with production capacity varying from 2t/h, 4t/h, 6t/h, 8t/h and 12.5t/h to 100,000t/year according to customers request.	

	Kyungki-Do Korea (South) 441744 T: +82312946740; Contact: Mr. Cho, Moon-hyun, W: http://comp.en.ecplaza.net/4.asp		
La Meccanica	Via Nicolini Padre, 1 35013 Cittadella, Italy T: +39 049 9419000 E: lameccanica@lameccanica.it W: www.lameccanica.it	La Meccanica provides complete biomass pelleting lines as well as spare parts for CPM, Paladin and Bühler. The pellet mills are specifically designed for sawdust, shavings, chips or wood waste. Six different pellet mills are available (CLM200LG, 304LG, 420HDLG, 520HDLG, 630GLG, 800PLG) with a v-belt drive power ranging form 15kW-280kW. Output production ranges from 0.08t/h in the smallest pellet mill to 3.0 t/h in the larger mills. La Meccanica estimates that a production capacity of 0.4 t/h-0.5 t/h costs 150,000 Euros, while a pellet mill with a capacity over 6 t/h is 500,000 Euros.	 *Model CLM 800P LG*
Mabrik	Marconi, 66. 08210 Barberă del Vallès, Barcelona, Spain; T: +93 729 99 10 E: admin@mabrik.com W : www.mabrik.com	Mabric provides the complete biomass pelleting line, specifically designed for alfalfa, pulp and waste	
Münch	Weststraβe 26 40721 Hilden, Germany; T: +49 2103 58996 E: infor@muench-gmbh.net W:www.muench-gmbh.com	Münch provides the complete biomass pelleting line. Pellet mills are direct-gear driven with power ranging from 5kW-335kW. The pellet mills can accommodate straw, grass, plastic waste and coal. They have a throughput of 0.2t/h to 10t/h.	 *Model RMP*
Pelleting Technology (PT) Nederland	P.O. Box 132 5480 AC Schijindel, Netherlands T: +31 73 549 84 72; E: info@ptn.nl W:www.ptn.nl	In the last 30 years PTN developed and improved their pellet mills. More than 9 different sizes of pelletmills, with capacities from 3 t/h to more than 30 t/h.	 *Progress Model*
Promill Stolz	RN 12-F-28410 Serville-France T: +33 (0)2 37 38 91 93 E : promill@stolz.fr W : www.promill-stolz.fr	Promill Stolz produces the full line of biomass pelleting systems. There are 12 models available that can densify alfalfa, beet pulp, and sawdust ranging from 160 kW to 355 kW.	
Sweden Power Chippers (SPC) AB	Skaraborgsvägen 35E 506 30 Boräs, Sweden; T: +46 33 23 97 91; E: info@pelletpress.com W: www.pelletpress.com	SPC produces the full line of biomass pelleting, designed for sawdust, cutter dust and wood. They specialize in small scale pellet presses, producing pellets ranging from 8mm-12mm. Three pellet mills are available (PP300 Kompakt, PP300 Twin and PP450 Kompakt), with drive powers of 30kW-37kW and production capacity of 0.25t/h-0.5t/h.	

			Model PP300 Kompakt
Van Aarsen	Heelderweg 11 6097 EW Pahnell, The Netherlands; T: +31-0475-579444 E: info@aarsen.com W: www.aarsen.com	Provides full biomass pelleting lines for wood. Produces 4 pellet mills (C500, 600, 750, 900) ranging in drive power of 75kW to 315kW.	 *Model C-900*

Appendix 3: Cuber Manufacturers

Cooper Equipment Inc.	227 W. 20 S. Knox, Burley, ID U.S.A 83318 T: 208-678-8015 W: www.cooperequipmentinc.com	Model 500 Cuber	
Warren and Baerg Manufacturing, Inc.	39950 Road 108, Dinuba, CA U.S.A 93618 T: 559-591-6790 E: info@warrenbaerg.com W: www.warrenbaerg.com	Produces a full line of cube densification systems. Warren & Baerg produces four cuber models (200HD, 250-HD, 250-W, and 300-W) with a production capacities ranging from 4t/h-10t/h. The 200HD is specifically designed for hay (alfalfa) material with a production capacity of 8t/h-10t/h and a drive power of 150kW. The remaining three models are used for cardboard, sludge, planer shavings, sander dust. The particle size prior to grinding required on the biomass cuber is approximately 3" with a moisture content of 10%-12%. Maintenance is expected after processing approximately 4,500 t of biomass for both the dies and press wheel.	 *Model 200 HD*

Appendix 4: Briquetting Manufacturers

Biomass Briquette Systems, LLC	P.O. Box 1835 Chico, CA U.S.A., 95927 T: 877-474-5521 W: www.biomassbriquettesystems.com	Biomass Briquette produces two (WG-50 and WG 650) automated briquette presses ranging from 0.5 t/h to 0.34 t/h. The system uses wood chips, saw dust and other agriculture residues. Design allows for incorporation of multiple units in parallel for unlimited capacity.	
Bogma	Box 71 SE-523 22 Ulricehamn, Sweden T: 46 32-262 40; Contact: Tony Paduch Mobil. +46 70 - 546 38 01 E: tony.paduch@bogma.com W: www.bogma.com	Bogmas mechanical piston presses are designed for medium to large scale briquette production, from 0.35t/h to 1.2kg/h ranging from 30kW to 55kW.	
Briquetting Systems	Suite 101-1001 West Broadway, Vancouver, BC Canada, V6H 4E4 T: 604-818-0287 Contact: Wayne Winkler E: w.winkler@briquettingsystems.com W:www.briquettingsystems.com	Offer a selection of Holzmag briquetters for various applications including wood and agri-fibre densification, mostly focussing on dust particles. Production capacity of up to 0.5t/h.	
C.F. Nielsen A/S	Solbjergvej 19 DK-9574 Baelum, Denmark T: +45 98 33 74 00 E: sales@cfnielsen.com W: www.cfnielsen.com	C.F. Nielsen provides the full line of briquetting processes. They produce 3 hydraulic cubers ranging in capacity from .08t/h to 0.3 t/h with briquette dimensions of 60 and 70 mm. Seven mechanical briquetting presses are available ranging from 0.15t/h to 1.8t/h with dimensions of 50mm to 90mm.	 BP 6000
Demeco Enterprises (Cree Industries-Canadian Distributor)	72A, Dehiwela Road, Pepiliyana Boralesgamuwa 10290, Sri Lanka T: 94 112 736 284; 204-645-4380 Contact: John O. Olsen E: demeco@sltnet.lk; cree@dowco.com W: www.demecosl.com	Demeco Enterprises uses binder-less briquetting technology with a screw type extruder. Production capacity of 0.4t/h-0.6t/h with drive power of 30kW-45kW. Briquettes are 55mm-65mm and uses agri-biomasses with a particle size of 2-6mm and m.c. of 6-8%.	
DIPIU' Macchine Impianti	Via dei Fabbri, 11 36042 Breganze (VI) Italy T: 39 0445 300709 E: info@di-piu.com W :www.di-piu.com	Dipiu produces both mechanical and hydraulic presses. The mechanical series (BRIK) produces 8 models (15kW-75kW) ranging from 0.2 t/h to 1.8 t/h with 50-90 mm cylindrical (or square) briquettes ranging from 20mm -300mm long. The hydraulic presses are designed for small-scale use (less than 8 h/day) ranging from 0.02 t/h to 0.2t/h at 5.2 kW to 11.2 kW.	

Fink Machine Inc.	PO Box 308, 124 Old Vernon Road Enderby, BC Canada, V0E 1V0 T: (250) 838-0077 E: fink@jetstream.net W: www.finkmachine.com	The Fink Briquette Press is designed for wood processing. There are three models available that offer outputs varying from 40-200 kg/hour.	
Harshad Engineering	11-A Bhaktinagar Station Plot, "Kalpana Cottage" Rajkot - 360 002. Gujarat - India T: 91 281 2462158 E: info@harshadengineering.com W : www.harshadengineering.com	Harshad Engineering produces 3 briquetting models ranging from 0.6 t/h to 1.5t/h producing cylindrical briquettes ranging from 60 mm-90mm. Raw materials range from wood waste and chips, and agro straws, stalks and husks.	
Pawert-SPM AG	Neue Bahnhofstrasse 144, CH-4132 Muttenz, Switzerland T: 0041 (0)61/465 96 60 E: info.pawert-spm@calnet.ch W: www.pawert-spm.ch/en/index2.htm	The Pawert Briquette machinery is designed for wood biproducts, straw, cotton and rice husks, and coconut and peanut shells. There are 11 models available starting at a capacity of 150 kg up to 4,600 kg/hr, ranging from 11kW to 132kW.	
Ruf GmbH & Co. KG	Hausener Straβe 101 D-86874 Zaisertshofen, Germany T:+82 68/90 90-20 E: info@brikettieren.de W: www.briquetting.com	Ruf produces 8 briquetting models (RB4,110,220,330,440, 880, 30), ranging from 0.03t/h-0.88t/h. Drive power ranges from 4kW-45kW with briquette sizes from 60x40mm-240x70mm. Feedstocks used include wood, hay, flax, millings from grinding, hemp fibre	
Sahut-Conreur	700, rue du Corbeau-B.P. 49-59590 Raismes, France T : 33 3 27 46 90 44 E : sahutconreur@wanadoo.fr W : http://www.sahutconreur.com	The capacity of a briquetting line can range from 0.5 t/h to 100 t/h	
Sree Engineering Works	7-1-1/C, Phool Bagh, Ferozguda, Bowenpally, Hyderabad - 500 011, Andhra Pradesh, India T: 0091-40-27752820 E: info@wealthfromwaste.com W : www.wealthfromwaste.com	Sree Engineering provides two models (SEW-05 and SEW-14) of RAM type briquetters producing 60 mm and 90 mm briquettes. Capacity ranges from 0.4 t/h to 1.5 t/ h with 45 to 85 h.p. Options include flash dryers and screw conveyors	

Weima America	3678 Centre Circle, Fort Mill, SC U.S.A, 29715 T: 888-440-7170 E : info@weimaamerica.com W : www.weimaamerica.com	Weima produces 4 models ranging from 0.6 t/h to 1.6 t/h producing briquettes of 50 mm to 70mm. Raw materials used include straw, wood shavings or bio-fuels such as elephant grass (miscanthus)	

Appendix 5: Briquetting Operational and Capital Costs

Nielsen Briquetters: 8 ton/hour workday, 21 days per month
(www.briquettingsystems.com/home/selections.php)

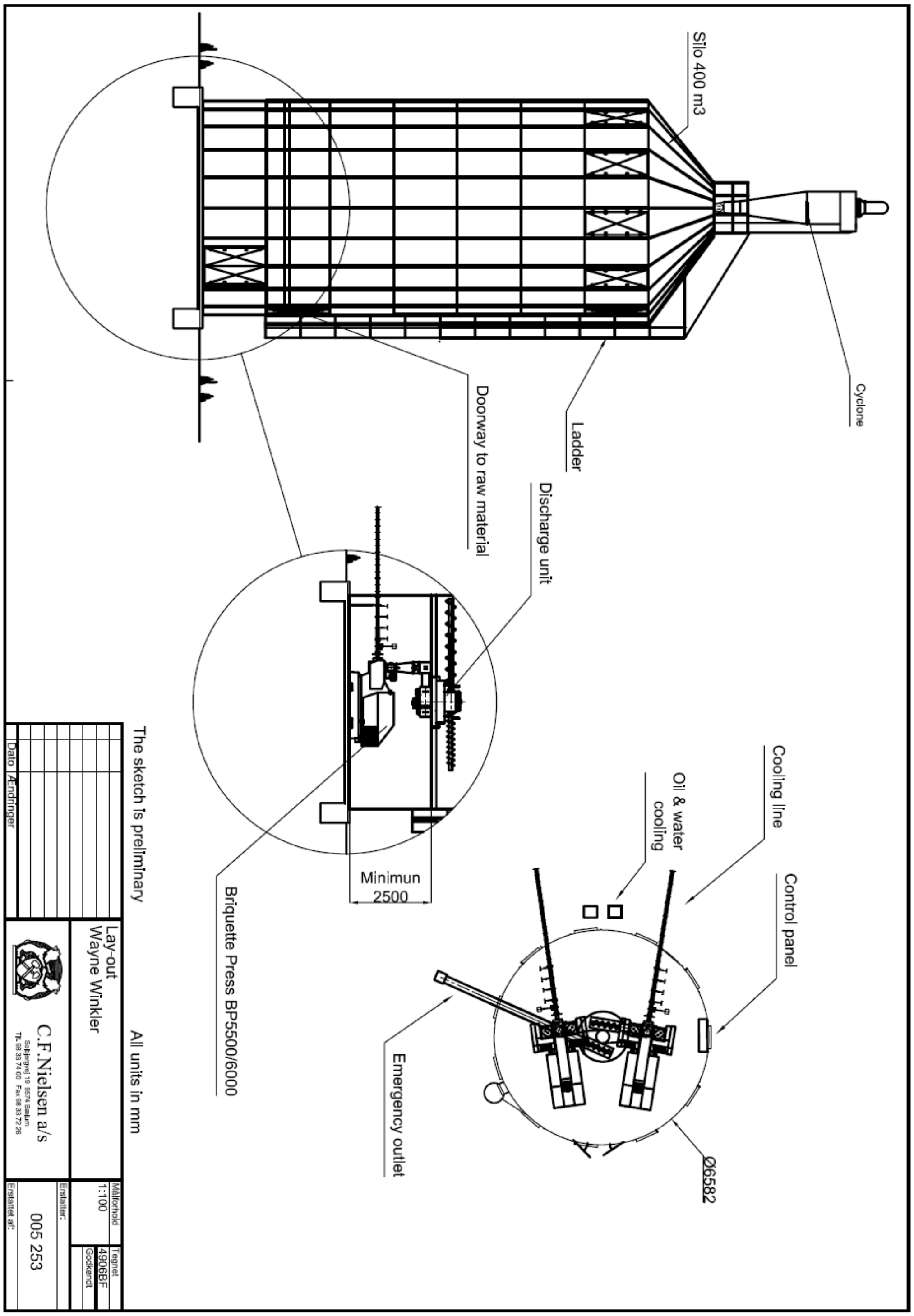
		Operational Costs per ton					Capital Costs per ton (based on length of term)			Total Costs per ton (based on length of term)		
Model	Tons/Year	Spares	Service	Electrical	Maint	Subtotal	3 years	4 years	5 years	3 years	4 years	5 years
Single Presses												
BP3200	1,109	$3.80	$1.30	$5.80	$2.50	$13.4	$67	$52	$43	$80	$65	$57
BP4000	1,663	$3.80	$1.00	$6.00	$1.70	$12.5	$49	$38	$31	$62	$51	$44
BP5000	2,661	$2.35	$0.60	$4.40	$1.00	$8.4	$38	$29	$24	$46	$38	$33
BP5500	3,105	$1.95	$0.50	$4.90	$0.90	$8.3	$34	$27	$22	$43	$35	$30
BP6000	3,992	$1.50	$0.40	$4.40	$0.70	$7.0	$30	$23	$19	$37	$30	$26
Double Presses												
BP4000	3,326	$3.80	$1.00	$6.00	$1.70	$12.5	$43	$33	$28	$56	$46	$40
BP5000	5,322	$2.35	$0.60	$4.40	$1.00	$8.4	$34	$26	$22	$43	$35	$30
BP5500	6,209	$1.95	$0.50	$4.90	$0.90	$8.3	$32	$24	$20	$40	$33	$28
BP6000	7,983	$1.50	$0.40	$4.40	$0.70	$7.0	$27	$21	$17	$34	$28	$24
Mobile Presses												
BP3200	1,109	$3.80	$1.30	$5.80	$2.50	$13.4	$59	$46	$38	$73	$59	$51
BP4000	1,663	$3.80	$1.00	$6.00	$1.70	$12.5	$46	$36	$30	$59	$48	$42
BP5000	2,661	$2.35	$0.60	$4.40	$1.00	$8.4	$34	$26	$22	$43	$35	$30

- Capital costs are based on commercial lease rates and are subject to credit approval
- Operational costs based on 15 cents/kWh, $20/hour labor and $70/hour for service
- An experienced person can see that the total capital and operations costs per ton are less than pelleting and similarly the more tonnage produced the less costs per ton. In some cases the total briquetting costs in this table per ton are equal to just the operations costs of a pelleting plant. Unless you are considering making pellets for the consumer pellet stove market we see little reason to produce pellets vs briquettes, see more on this in the fuel pucks vs pellets table. Typically the BP5500 briquetter models are used extensively to produce industrial briquettes and fuel pucks. Nevertheless we probably have a briquetter to fit your operation in an effective cost / payback scenario. They are not only effective at converting wood residuals to solid fuels they can also be the answer to your plant dust problems and at the same time produce a solid fuel.
- The Holzmag briquetters are used extensively to reduce plant dust into a more handeable and useable format. They usually can be easily connected to existing plant dust collectors. Although a few hundred pounds per hour of dust may not seem like a lot, when one who has seen what 10 or 20 pounds of dust can do inside a plant building will agree dust is a pervasive ,costly, potentially dangerous and unhealthy problem. Holzmag briquetters can be found in all the major paper and tissue mill plants as well as some of the more larger printing and binding corporations both in North America and worldwide.

Nielsen Briquetters: 23 ton/hour workday, 21 days per month
(www.briquettingsystems.com/home/selections.php)

		Operational Costs per ton					Capital Costs per ton (based on length of term)			Total Costs per ton (based on length of term)		
Model	Tons/Year	Spares	Service	Electrical	Maint	Subtotal	3 years	4 years	5 years	3 years	4 years	5 years
Single Presses												
BP3200	3,188	$3.80	$1.30	$5.80	$2.50	$13.4	$23	$18	$15	$37	$31	$28
BP4000	4,782	$3.80	$1.00	$6.00	$1.70	$12.5	$17	$13	$11	$30	$26	$23
BP5000	7,651	$2.35	$0.60	$4.40	$1.00	$8.4	$13	$10	$8	$22	$19	$17
BP5500	8,926	$1.95	$0.50	$4.90	$0.90	$8.3	$12	$9	$8	$20	$17	$16
BP6000	11,476	$1.50	$0.40	$4.40	$0.70	$7.0	$10	$8	$7	$17	$15	$14
Double Presses												
BP4000	9,563	$3.80	$1.00	$6.00	$1.70	$12.5	$15	$12	$10	$28	$24	$22
BP5000	15,301	$2.35	$0.60	$4.40	$1.00	$8.4	$12	$9	$8	$20	$18	$16
BP5500	17,852	$1.95	$0.50	$4.90	$0.90	$8.3	$11	$8	$7	$19	$17	$15
BP6000	22,952	$1.50	$0.40	$4.40	$0.70	$7.0	$10	$7	$6	$17	$14	$13
Mobile Presses												
BP3200	3,188	$3.80	$1.30	$5.80	$2.50	$13.4	$21	$16	$13	$34	$29	$27
BP4000	4,782	$3.80	$1.00	$6.00	$1.70	$12.5	$16	$12	$10	$29	$25	$23
BP5000	7,651	$2.35	$0.60	$4.40	$1.00	$8.4	$12	$9	$8	$20	$18	$16

Appendix 6: Schematic Drawing of Briquetter Inside Silo



Appendix 7: Bulk Biomass Combustion Appliances

BFI Boilers	200 rue des Pins ouest, suite 109 Alma, QC, Canada ,G8B 6P9 T: 418-662-3663; Contact: Mr. Claude Asselin E: c.asselin@falmec.qc.ca W: www.falmecboiler.com	Offer a hybrid biomass boiler that produces thermal energy (steam) or hot water from biomass (forestry) combustibles having a low or high moisture level, and can produce power from 1950 to 9300 kW http://www.falmecboiler.com/products_biomass_cogen_sys.html	
Blue Flame Stoker	Box 285, Headingley, MB Canada, R4J 1C1 T: 204-694-2398; E: info@blueflamestoker.com W: www.blueflamestoker.com	Introducing the Blue Flame Stoker, a solid fuel heating system. Designed and manufactured to assure the most efficient combustion of solid fuels, while maintaining low emissions.	
Vidir Biomass Systems Inc.	Box 700 Arborg, MB Canada, R0C 0A0 T: 1-800-210-0141 W: www.vidir.biz/index-biomass.htm	There are a few different models that range from 1200 kW to 4690 kW units	

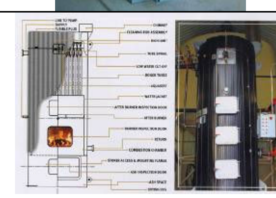
Appendix 8: Residential and Small-Commercial Stove and Boilers (10kW-150kW)

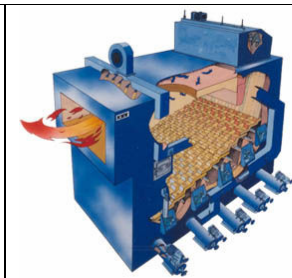
Residential Stoves (<20 kW)			
Bixby Energy Systems	9300 75th Ave. N. Minneapolis, MN U.S.A, 55428 T: 877-500-2800 W: www.bixbyenergy.com	Bixby stoves burn dry shelled corn or wood pellets. Ranging from 2.4 kW to 14.6 kW. Hopper sizes of 48 kg and 136 kg with an extension of 45 kg. An efficiency burn rate of 99% with wood pellets and 97% with corn.	
Country Flame	150 Michigan Street SE, Hutchinson, MN U.S.A, 55350 T: 1-800-495-3196 W: www.countryflame.com	Country Flame has 4 fully automated models, two pellet/corn stoves ranging from 11.9 kW to 14.6 kW and two pellet/corn inserts at 15.8 kW. Hopper sizes range from 20 kg to 34 kg and maintains a 97% burn efficiency.	
Dell-Point Technologies Inc.	4055 Lavoisier St., Boisbriand, QC, Canada, J7H 1N1 T: 514-331-6212 W :www.pelletstove.com	Produce the Europa 75 model 10 kW pellet stove and are developing a 25 kW pellet boiler. Have an efficiency of 83%, 13.2 kW and a hopper size of 25 kg.	
Elf Industries Ltd.	2840 Hwy # 26 St. Francois Xavier, MB, Canada R4L 1B4 T: 204-353-2565 W: www.elfindustries.com	Produces a 21.1 kW (EDF 800), high quality, state-of-the-art, fully automatic stove with a 33 kg hopper . Designed to burn high ash flax shives and low ash wood pellets.	
Harmon Stove Company	352 Mountain House Road, Halifax, Pennsylvania U.S.A., 17032; T: 717-362-9080 W: www.harmanstoves.com	Produces seven pellet stoves ranging from 2.4 kW to 17.9 kW with hopper capacities of 23 kg to 33 kg with extension on certain model 62 kg. Produces 1 corn stove with 13.2 kW and a hopper capacity of 80 lbs with an extension to 66 kg.	

Pelpro and Glow Boy Wood Pellet Stoves	26319 Township Rd. 531, Acheson AB, Canada, T7X 5A3 T: 877-303-3134; Contact: Jeff Theissen E: jeff.thiessen@dansons.com W: www.dansons.com	Shop Heater 120 For your workshop, the Shop Heater 120 shop heater comes with a 54 kg hopper and ranges from 4.4 to 14.6 kWh with a burn time of 22 to 60 hours. Shop Heater 300 300 lbs hopper ranges from 4.4 to 14.6 kWh with a burn time of 43 to 150 hours.	
Quadra-Fire	Hearth & Home Technologies 1445 North Highway Colville, WA U.S.A., 99114-2008 W: http://quadrafire.com	Quadra-Fire fully-automatic pellet appliances heat including pellet stoves and inserts. Four pellet stoves ranging from 2.4 kW to 17.6 kW. Four pellet inserts ranging from 2.4 kW to 17.6 kW with hoppers ranging from 20 kg to 37 kg.	
Boilers			
Biotech Energietechnik GmbH	Furtmühlstraße 32 A-5101 Bergheim BEI Salzburg Austria T: 43 (0)662 / 45 40 72-0 E: office@pelletsworld.com W: www.biotech.or.at	Biotech produces 4 pellet boiler models ranging from 2.4 kW-35 kW . Pellet storage tank range from 30 kg to 125 kg capacity	
Central Boilers	20502 160th Street Greenbush, MN 56726 T: 218-782-2575 W: www.centralboiler.com	Central Boiler produces the Bio-Advantage Power Burner 74kW outdoor wood pellet and corn furnace. Automatic power ignition, low ash and 80% efficient. Options of a free standing or side mounted hopper.	
Grove Wood Heat Inc.	935 Pleasant Grove Rd., York, PEI, C0A 1P0 T: 902-672-2090 E: grovewoodheat@pei.sympatico.ca	Grove Wood Heat has been supplying wood residue boilers into the Eastern Canadian market for the past 20 years. In 2005 they began developing specialty burners to efficiently utilize off-specification barley and other feed grains. They are currently producing cereal grain burning boilers in the 25-250 kW range. A 75 kW cereal grain burner is shown installed in a small building to minimize fire risk.	
Harman Stove Company	352 Mountain House Road, Halifax, Pennsylvania 17032; T: 717-362-9080 W: www.harmanstoves.com	The Harman PB105 Pellet Boiler has automatic ignition, automatic temperature control, and Harman's patented pellet pro feeder and burn pot. Designed for easy access to the burn pot, the entire hopper component swings open for performing maintenance and cleaning. The PB105 packs 0 to 30.8 kW and has a 93 kg hopper capacity and an extra large ash pan.	

KWB Biomass Heating Systems	235, A-8321 St., MargaretheVRaab T: 43 3155 61160 E: office@kwb.at W: www.kwb.at	The easy-to-use and convenient pellet heating system with an output range of 10-30 kW. Four model types, fuel hopper, suction conveyor system, worm conveyer and rotary-stirrer extractor systems. Thermostat controlled with automated ash removal system	
Laowan Bioenergy Technology	No.23, Chaoqian Road, Changping Science Park, Beijing China, 102200 T: 86-10-69743574 E-mail:info@laowan.com W: www.laowan.link2911.com	It is connected to the radiators for heating through water circulation, and is able to fulfill the demand of a 100-450m^2 residence. automatic control is adopted: automatic ignition, automatic feeding, and automatic ash discharge	
Verner Inc.	Sokolska 321 549 41 Cerveny Kostelec Czech Republic T: +420 491 009 823 W: http://www.verner.cz E: hofman@verner.cz	Automatic 25kW boiler burning corn, maize, grain and pellets. High efficiency ranging from 91- 92,7 %, with a burn rate of 5.6-7.5 kg/h depending on fuel type. Burn time at maximum capacity ranges from 16 h to 30 h. Options include a 240 L hopper, 1.2m^3 big bag or reservoir.	

Appendix 9: Medium Scale Commercial Boilers (>150kW-5MW)

All Canadian Coal-Fired Heaters	#85 – 52472 RR 224 Sherwood Park AB, Canada T8A 4R6 T: 780-922-2480 E: novametl@telusplanet.net W: www.allcanadianheaters.com	Five sizes of heaters from 145 to 675 kWh	
Binder	Mitterdorferstr. 5 8572 Bärnbach, Austria T:+43 3142 22544-0 E: office@binder-gmbh.at W: www.binder-gmbh.at	Binder produces 4 boilers with efficiency ratings of up to 92 percent. The TSRF model or moving grate burner for dry, high ash fuels is designed for wood pellets, peat pellets, or Agro-pellets with a moisture content of up to 25% and an ash content >1%.	
Bio-Fuel Technologies	P.O. Box 41 Beavertown, PA U.S.A 17814 T: 570-658-7491 E: info@Bio-FuelTechnologies.com W: www.bio-fueltechnologiesllc.com	Bio-Fuel chain grate boiler burns wood, corn, coal, flax shive, cotton waster, rubber and other materials. chain Grate Boiler	
Blue Flame Stoker	Box 285, Headingley, MB Canada R4J 1C1 T: 204-694-2398 E: info@blueflamestoker.com W: www.blueflamestoker.com	Blue Flame Stoker producing chain grate and walking grain combustion technologies. Biolers are used in automatically fired solid fuel systems, with horsepower ranges from 800 to 3500 kW (with other sizers available). Boilers are designed for coal, wood chips and agricultural waste.	
Decker Brand Boilers	General Delivery, Decker, MB Canada, R0M 0K0 Canada T: 204-764-2861 E: clarence@dekkerbrand.com W: www.deckerbrand.com	Full certified pressure boilers with multi-fuel capacities including wood pellets and coal. Six models range from 146kW to 1025kW.	
KMW Systems Inc.	3330 White Oak Road, London, ON, Canada, N6E 1L8 T: 519-686-1771; Contact: Eric Bertil Rosen	Specialize in designing, supplying and installing KMW Energy Systems to burn low-grade biomass fuel. Units are custom designed and engineered to suit any requirements. Energy output of existing TRF and SRF models can	

	E: kwminfo@kmwgroup.com W: www.kmwenergy.com	range between 2450 kW to 40,000 kW and they are available in configurations for hot water, low or high pressure steam, thermal oil and hot gas for drying applications. http://www.canadianboilersociety.ca/profiles/kmw.html	
New Horizon Corp.	New Horizon Corp 151 McGregor Drive Sutton, WV U.S.A., 26601 T: 1-877-202-5070 E: newhorizoncorp@gmail.com W: www.newhorizoncorp.com	Produces 4 commercial boiler line of Goliath boilers with a kW range from 53 to 1992. Burns readily available small chunks (up to 1.5 inch) of waste wood, shavings, sawdust, bark, ground corn cobs, and grains. Desired fuel moisture for optimal operation should be in the range of 30-50%. Combustion process is controlled automatically with a programmable controller. Goliath Line Boilers come with process controller with sensors, burner with automatic feeder and hopper.	
KÖB Holzfeuerungen GmbH (Distributed by Fink Machine Inc)	Flotzbachstrasse 33 A-6922 Wolfurt T: 43 (0)5574 6770-0; 250-838-0077 E :office@kob.cc; fink@jetstream.net W: www.koeb-holzfeuerungen.com	KÖB produces 11 models ranging from 80 kW to 2500 kW (Pyrot and Pyrtec lines). The PYROT is originally designed to use dry woodchips or wood pellets or wood byproduct from the wood processing industry. The combination in the PYRTEC of the moving feed grate with the tried-and-trusted burner trough and the drop-down external grate unites in optimum fashion the advantages of moving feed grate firing with the advantages of underfeed firing.	
Pro-Fab Industries Inc	P.O. Box 112, Arborg MB Canada R0C 0A0, T: 888-933-4440 E: info@profab.org W:http://profab.org/Products/Pelco.aspx	Hot water Pelco Boiler, three sizes from 220kW, 440kW and 740 kW	
Vyncke	Gentsesteenweg 224 B-8530 Harelbeke Belgium T: 32 56 730 630 E: mail@vyncke.com W: www.vyncke.be	Vyncke boilers range from 1 kW to 100,000 kW and can be supplied either as steam, hot water, thermal oil, hot gas, electricity (up to 10,000 kWe) or in any assorted combination. Capacity ranges from 1 t/h to 50 t/h. Sunflower husks, rice husks, coconut shells, coffee husks, tobacco, cotton waste and bagasse are only some of the agricultural residues we have successfully used as fuels. All boilers use dynamic Water-cooled Stepgrate allowing the use of different fuel types from coarse to fine and from wet to dry.