The different technologies available to make densified biomass fuels. Potential markets. Costs and revenues.

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1. How Densified Biomass Fuels are Made

A review of the different methods used to manufacture densified fuels from biomasses allows us to classify these methods into three basic methods:

- Extrusion
- Hydraulic compression
- Mechanical compression

Each technique uses different types of equipment. Extrusion is the forcing of the biomass through a narrow passage (a die). Hydraulic compression is the confinement by means of pressure of a large amount of biomass into a small space (also called a die). Mechanical compression is the low pressure confinement of the biomass into a shape, or the reduction of the volume of the biomass by means of forcing the biomass into a progressively narrower space (medium pressure) or by means of a dynamic impact and extremely high pressure on small amounts of biomass.

All methods rely on the same basic technology of permanently reducing the air space between the particles of the biomass and transforming loose particles into a dense and solid block. In the process, binding agents may or may not be added to the biomass in order to keep it permanently together. This paper will examine in detail each of these methods and the equipment normally used in this technology.

2. Extrusion

This method of densification produces three types of different products:

- Pellets
- Fuel logs
- Briquettes

2.1 Pellets are by far the most popular. Pellets are made by mechanical extrusion on equipment utilizing a technology derived from equipment originally designed to manufacture animal feedstock, fertilizers, plastics, and more. The same equipment, called a pellet mill, adapted to the specific requirements of wood and other biomasses, is used in the mass production of fuel pellets. A pellet mill is a sophisticated piece of equipment, and it works by feeding the prepared biomass into a die with hundreds of extrusion ports. Rollers rotating inside the die forcibly push the biomass through the ports to make the pellets. Single pellet mill presses have capacities that vary from 600 lbs. per hour up to 8 tons per hour.

To make pellets the biomass needs to be accurately prepared. It must be first cleaned from dirt, soil, stones, and metals. This step is of the utmost importance to avoid the premature wear of the vital components of the pellet mill. It must then be dried to a moisture content of 10-13%, and eventually ground to a uniform refined size by means of hammer mills. Also the finest dust of the biomass must be removed. Fines do not contribute to the binding process and actually weaken the bond between the particles of the biomass. The result would be that pellets will break apart during handling, packaging, and transportation.

The process to manufacture pellets requires operating within relatively strict parameters; it is not a forgiving process. The forming of the pellet is actually the last act of a long process of preparation of the biomass where each step is controlled by sophisticated equipment that keeps the material fed to the pellet mill within the parameters that optimizes the capacity, the final product, and the economy of the process. The equipment requires a large amount of maintenance, expensive both in terms of replacement items and in terms of downtime.

2.2 Fuel logs have been a very popular product for years. They are made by the extrusion of a refined biomass, most of the time wood particles, mixed with a small amount of smokeless natural wax. The blend of wood and wax is brought to a warm temperature, enough to make the mix flow, and then extruded at low pressures through a die to create a log. The log is cut to length, allowed to cool, and then packaged for consumer use. A very popular type of log used in fireplaces, chimeneas, and at camping sites. It is a relatively simple process, even if the mass production of these logs requires heavy investments, process control, and quality control in order to automate the process and keep the cost of manufacturing as low as possible. The great advantage is in the use of large amounts of waste wood, mostly coming from large sawmills operations.

2.3 Briquettes made by extrusion are normally made of wood sawdust or wood waste. The process is relatively simple. The wood particles are fed to a hopper and from there into a screw forcing the material through a die. The screw can be conical, therefore the reduction of volume is due to the progressive reduction in the diameter of the screw, or it can be cylindrical but with a progressive reduction of the pitch forming the helix of the screw. With both techniques the material is progressively forced into a smaller space until, at the end of the screw, it is forced through an extrusion die. When the material exits the die it is in a shape of a continuous briquette, briefly left to cool, before being cut into desired lengths and made ready for packaging. The machines are simple, with the screw driven by a motor coupled to a high reduction ratio gearbox or pulley. The housing of the screw is made of heavy steel or cast iron. The efficiency of this process is low, as large amounts of energy are used (and lost) to overcome friction (material against the casing, material against the auger) rather than in the compression of the material itself. Being small and simple systems, almost portable, these machines are very popular in developing countries. The pressure reached in the compression of the briquette is not very high, less than 10,000 psi, and the final density of the resulting briquette is low. It works well with certain species of wood and it does not work at all with others, unless lubricants, e.g. palm oil, or binders are added to the primary material. The output capacity of these briquetters is normally modest, and only in the best cases reaches 800-1000 lbs. per hour.

3. Briquettes and Pucks

Fuel briquettes are much older than any other densified fuel. Their origin goes back to the time when people needed to improve the burning efficiency of cheap fuels such as peat and coal dust. These loose materials, compressed and shaped into a briquette, would burn better and longer because air would be free to feed the flame occupying the space in between the briquettes. Briquettes can be made of many diverse raw materials and on many different types of equipment, and may have different shapes, densities, and characteristics.

When speaking of “briquettes”, most people immediately think of the charcoal briquettes used for outdoor grilling. These are made of charcoal made from the torrefaction of virgin wood coming from forestry operations, sawmills, and the like.

The charcoal is then blended with a binder (starch) in a moist condition, given shape using high speed mechanical briquetters, and eventually dried to the point the briquette retains its shape and it can be packaged for consumption. This briquetting method is mechanical and it uses a mild pressure to give shape to the briquette.

In relatively recent times have made their appearance briquettes that are made of 100% biomass, without the addition of any type of binder. These briquettes are made by compression at extremely high pressures in hydraulic or in mechanical briquetting machines. Temperature also is a factor in the formation of a solid briquette.

4. Hydraulic Briquetting Presses

Hydraulically operated briquetting machines are available in many different shapes and sizes, with output capacities that vary from a hundred pounds per hour for the small ones to more than 1 ton per hour. Compression pressures can go from 10,000 psi to 25,000 psi. Essentially there are two categories of hydraulic machines:

a. Small, light duty machines mostly used to manufacture fuel briquettes for own use in small companies that generate biomass waste;
b. Heavy duty, industrial type machines, used to manufacture fuel briquettes for the consumer market, or for the generation of space heat or power.

Both types use the same compression principle. The compression process is relatively slow, with a transient from a fast initial reduction of volume at low pressure to a longer compression phase during which the pressure reaches its peak. Each compression cycle takes from 10 to 25 seconds, depending on the amount of material loaded at each cycle, and the required density of the finished briquette. A low amount of material, combined with a long cycle time and the highest pressure will produce the highest density, and therefore the best quality briquette. However, since the cycle time does not change a lot with the amount of material loaded at each cycle, the manufacture of a high quality briquette penalizes the output capacity of the system.

5. Mechanical Briquetting Presses

Mechanical briquetting machines are designed to manufacture briquettes made of 100% biomass, with no addition of binders. These are heavy duty machines that compress the biomass by means of a ram impacting on a small amount of material at a very high speed into a die that has the shape of a mild cone. The ram strikes the material at rates between 220 and 260 strokes per minute, therefore the compression is done in less than 2/10th of a second. The die is open at the opposite end and the newly compressed material moves forward into a tight adjustable bushing that, by counteracting the forward movement of the already compressed material, positively creates enough backpressure to allow the compression by the ram. The ram is driven by a crankshaft or by an eccentric system moved by major flywheels. The compression pressure in these machines reaches the level of 36,000 psi (2500 bar), the highest pressure of any other biomass densification system. The drive system is very efficient, and 98% of the energy from the main motor is used in the compression. The energy of compaction, due to the friction between the biomass particles and fibers, turns entirely into heat, raising the temperature of the compressed biomass. Wood fibers or agricultural fibers contain lignin, a naturally occurring biopolymer that keeps the cellulosic cells together in nature. This is the binder that keeps the briquette together. Due to the high temperature the lignin “melts” exactly when the material is under the highest pressure. The combined effect of pressure and temperature, typical only of heavy duty mechanical briquetting presses, restores the broken chains of the lignin, helping the lignin to re-polymerize, and therefore binding the fibers and particles together. At this point though, the temperature of the briquette must be lowered as soon as possible, before the pressure holding the briquette together is released, to allow the lignin to harden and solidify. The best mechanical briquetters include a system to cool the compression head. When eventually the briquette is exiting the compression head its temperature is low enough to stabilize it. It takes a few more minutes for the briquette to cool down to a temperature where it becomes solid and fully stable. This is the reason why these machines have a long straight cooling channel starting at the compression head and running all the way to the point where the briquette is chopped or sawn to the desired length.

These ram type machines offer output capacities that start at 400 lbs. per hour, all the way up to 5 tons per hour. Besides being the most efficient, these machines are the least expensive to manufacture biomass densified fuel, both in terms of cost of the investment and in operational cost. These machines can manufacture high quality briquettes for the consumer market, or short pucks for the commercial, industrial, and energy markets, which are easier to transport and handle than regular briquettes. When used to generate thermal energy briquettes and pucks offer the highest ROI of any other densified fuel based on the same type of biomass.

6. Biomass used to make Briquettes and Pucks

Briquettes and pucks are made using one of the most forgiving methods to make densified fuel, therefore, accepting a long list of biomasses for densification. While briquettes that are made mostly for the consumer market are nicely shaped and ready for the fireplace or the warming stove, pucks are short disks of densified fuel that are generally handled in bulk. In this form pucks can be shipped over long distances, by truck, by rail, or by sea. Pucks are characterized by the very high density and the slow burning speed typical of briquettes, with the additional advantage that the burning speed can be adjusted by controlling the puck's length. Pucks are the ideal densified fuel for small, medium, and large boilers, regardless of whether used to generate heat for space heating, process heat for the industry, or to generate power in a power station.

A very large variety of combustible biomasses can be used in manufacturing briquettes and pucks, with the only requirements being that the biomass shall have moisture content between 8% and 12%, and the particles shall have a size not exceeding 5/8" (16 mm) for best results. The particles do not need to be uniform in size, and can vary from batch to batch. This is a partial list of proven biomasses used to manufacture briquettes:

- wood dust, saw dust, wood chips, virgin wood, recycled wood, demolition wood;
- different agrifibers like wheat straw, rice straw, hay, energy grasses (miscanthus, elephant grass, switchgrass), seed husks, corn cobs, corn stover, energy cane, sugar cane bagasse;
- cotton shrubs, grapevine clippings, fruit tree clippings, coffee shrubs;
- olive pits, peanut shells, and all other types of nut shells;
- tobacco waste, used coffee grinds, dried tomato vines;
- recycled paper, cardboard, spent bank notes;
- MSW (Municipal Solid Waste) and
- dried animal droppings, dried sludge from waste water treatment plants.

And the above materials can be used in any combination, with the list becoming longer every day.

The preparation of the biomass for briquette densification varies depending on the material and the finished product that is being made. But the aim is always the elimination of contaminants such as metals, stones, sand and dirt, the reduction of the particle size to less than ½"-¾", and the reduction of the moisture content to 10% +/-2%.

7. <u>Target Markets for Briquettes and Pucks.</u>

All potential markets for briquettes or pucks made of densified biomass have the generation of heat in common; heat that can be used for space heating, or to generate process heat, or to generate energy. These are some of the markets that can be targeted by industries that manufacture briquettes or pucks:

a. Residential (consumer) market. Space heating in stoves or fireplaces, cooking stoves, chimeneas.
b. Recreational cooking, outdoor cooking, camping.

These are seasonal markets that require an organized and specialized distribution network.

c. Space heating of commercial, institutional, and public buildings, large stores, shopping centers, industrial buildings. Existing examples are schools, libraries, public offices, privately owned office complexes, industrial manufacturing facilities.

   This is also a seasonal market, but the distribution can rely on existing fuel distribution channels.

d. Remote heating, a solution widely used in Europe (and in New York City), where heat can be sold in winter to residences, commercial and institutional buildings by delivering it directly to the point of usage. Used in relatively small communities and in some large cities, has the advantage of commuting from heat generation in the cold season to power generation for the rest of the year. The centralized heat and power station allows for an efficient use of the equipment compared to many small independently run utilization points. Requires a large investment for the distribution network.
e. Process heating, normally non-seasonal, used to satisfy the need of heat of many different industrial manufacturing processes. This market can be internal or external to the densification of the biomass. Internal process heat generation applies to sawmills, board and plywood mills, wood products manufacturers. Examples of external markets for process heat are cement factories, the drywall panel industry, quicklime factories, and an infinite number of chemical and food processing industries.
f. Generation of other fuels and electrical power. This is a non-seasonal market targeting gasifiers and medium size thermal power plants. The shipment by road, by rail, or by river or sea vessels of large quantities of pucks to these potential users is simple and cost effective, and it feeds the growing demand

for green energy. The United Kingdom, Netherlands, and European Nordic Countries already have a large number of these power plants in operation.

8. Costs and revenues associated to Briquettes and Pucks

Costs and revenues vary depending on the application, the cost of the raw material, the amount of preparation necessary, the market, the size and location of the operation, and the number of days and hours worked in a year. The interesting part is the cost of running a briquetting plant. Because of the efficiency and the relative simplicity of the equipment, the operating costs are very low. In particular the cost of maintenance is limited to the cost of replacing inexpensive wear items and the cost of lubricants. The downtime required for maintenance is in the range of a few hours per year, less than 10 hours per year per machine in the worst case scenario, i.e. with plants working 24/7.

Assuming a briquetting machine working 300 days/year, 2 shifts of 8 hrs. per day, these are the approximate costs one can expect:

	small machine	medium machine	large machine
Output, ton per hr.	0.5	1.0	2.4
Direct cost, $ per ton	7.80	6.00	5.40
Total cost, $ per ton (*1)	51.00 (*2)	38.00	21.00

(*1) The above cost includes:

- All direct operating costs: energy, wear parts, consumables (lubricants).
- Equipment depreciation based on a three (3) years payback, or equivalent leasing cost.
- Direct manpower to operate the briquetting line.

(*2) The cost refers to a single shift per day operation, more typical of a small machine. A small machine used on two shifts would actually show a higher cost per ton due to the negative impact of an overall higher cost of labor.

The above numbers do not include:

- The cost of the raw material ready for briquetting, sized and dried.
- The cost of the space required by the operation.

These costs vary substantially, based on the availability of the raw material, whether it is a waste or not, and based on the location, the cost of the space may change dramatically.

From the above numbers it is evident that small machines are more suited for local markets with a low cost of distribution of the densified fuel or to generate fuel for own use, either space heating of process heat. Medium machines are ideal to manufacture briquettes for the consumer market, or for own internal use. Large machines and plants using several machines in parallel are ideal to manufacture pucks for energy use.

9. Conclusion

While potential investors still need to prepare detailed plans to determine whether making briquettes or pucks are an alternative way to produce densified fuel, this is certainly one very attractive alternative. Limited investments, large output capacities, low cost of operation, are all factors worth further investigation.
