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(54) **FUEL PELLET**

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(57) **ABSTRACT**

Fuel pellets which include substantial amounts of agricultural biomass having a relatively low lignin content are provided. The fuel pellets have a low ash content, good pellet durability (e.g., as determined by their pellet durability index) and heating values comparable to conventional hardwood fuel pellets. The fuel pellet may be formed by pelleting a mixture comprising agricultural biomass which includes whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp and/or sunflower hulls. Other suitable agricultural biomass materials which may be used to form the fuel pellets include co-products from corn milling processes (e.g. corn gluten feed, white fiber), oat hulls, rice hulls, rapeseed meal, rapeseed fractions, bagasse, ground barley, cottonseed hulls, whole cottonseed, ground milo, oatmeal, oat flour, rye, broken rice and empty palm fruit bundles.

FUEL PELLET

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This application claims priority from Provisional Application U.S. Application Ser. No. 60/845,339, filed Sep. 18, 2006, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Oil and coal are commonly used for heating. However, increasing costs and environmental concerns related to fossil fuels have led to an increased demand for alternative heating fuels.

[0003] One such alternative is pelleted hardwood fuel. Hardwood pellets can provide sufficient heat to be an efficient fuel. However, pelleted hardwood fuels face some of the same limitations as fossil fuels. For instance, hardwood trees that are harvested take years to replace with new growth. Also, the increased efficiencies achieved in the lumber and paper industries place constraints on the amount of hardwood scrap that is available for pelleting. Hardwood also has a high lignin contents (e.g., typically at least about 25 wt. %). High lignin contents can result in the production of tar-like residues when the fuel is burned. This may necessitate processing of hardwood materials to remove a portion of the lignin content prior to being used to form a fuel pellet. Accordingly, there is a continuing need for alternative fuels that are renewable and in adequate supply.

SUMMARY

[0004] The present application is directed to fuel pellets formed from a mixture which includes an agricultural biomass. Typically, the fuel pellets include substantial amounts of agricultural biomass having a relatively low lignin content, e.g., about 60 wt. % (dry basis) or more of the agricultural biomass. The fuel pellets may have a low ash content, good pellet durability (e.g., as determined by their pellet durability index) and heating values comparable to conventional hardwood fuel pellets. The fuel pellet may be formed by pelleting a mixture comprising agricultural biomass which includes whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp and/or sunflower hulls. Other suitable agricultural biomass materials which may be used to form the present fuel pellets include co-products from corn milling processes (e.g. corn gluten feed, white fiber), oat hulls, rice hulls, rapeseed meal, rapeseed fractions, bagasse, empty palm fruit bundles, almond hulls, walnut meal, and the like. In some embodiments, it may be useful to formulate the fuel pellet such that it has an ash content with composition and/or characteristics comparable to that of fly ash. Additional agricultural biomass materials which may be used to form the present fuel pellets include ground barley, cottonseed hulls, whole cottonseed, ground milo, oatmeal, oat flour, rye and/or broken rice. The agricultural biomass may be used "as is" or may have undergone some physical or chemical process(es) prior to being used to produce the present fuel pellets. For instance, the agricultural biomass is to produce the fuel pellet may have has undergone a pretreatment process such as size reduction, homogenization, thermal pretreatment or the like.

[0005] The fuel pellet typically has an ash content of no more than about 5 wt. %, desirably, no more than about 4 wt. % and, more desirably, no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6000 BTU/lb (dry basis), desirably at least about 6500 BTU/lb (dry basis), more desirably at least about 6800 BTU/lb (dry basis) and, preferably, at least about 7000 BTU/lb (dry basis). In some embodiments, the fuel pellets may have a heating value of about 7,500 BTU/lb (dry basis) or higher. Typically the agricultural biomass will have a lignin content of no more than about 10 wt. % (on a dry basis). In many embodiments, the mixture desirably includes at least about 60 wt. %, suitably at least about 75 wt. % and, often, at least about 90 wt. % of such agricultural biomass. Suitably, the lignin content of the fuel pellets is no more than about 10 wt. %, and, desirably no more than about 5 wt. % (on a dry basis).

[0006] In one embodiment the fuel pellet comprises an agricultural biomass selected from the group consisting of corn (e.g. cracked corn and/or whole corn), corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6000 BTU/lb (dry basis), desirably at least about 6500 BTU/lb (dry basis), more desirably at least about 6800 BTU/lb (dry basis) and, preferably, at least about 7000 BTU/lb (dry basis).

[0007] Another embodiment relates to a fuel pellet formed by pelleting a mixture comprising about 40 to 90 wt. % corn; and about 10 to 60 wt. % of an agricultural biomass selected from the group consisting of corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6000 BTU/lb (dry basis), desirably at least about 6500 BTU/lb (dry basis), more desirably at least about 6800 BTU/lb (dry basis) and, preferably, at least about 7000 BTU/lb (dry basis).

[0008] Yet another embodiment relates to a method of producing heat comprising burning a fuel pellet wherein the fuel pellet comprises an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6000 BTU/lb (dry basis), desirably at least about 6500 BTU/lb (dry basis), more desirably at least about 6800 BTU/lb (dry basis) and, preferably, at least about 7000 BTU/lb (dry basis).

DETAILED DESCRIPTION

[0009] Biomass fuel pellets for use in stoves and boilers should conform to a variety of requirements. The pellets should have a sufficient heating value when burned to be an efficient source of energy. The pellets should also have a low ash content to prevent equipment fouling. To avoid unsafe burning conditions, the pellets should also have a sufficient integrity such that the amount of fine particles is kept low.

[0010] To be economical, a fuel pellet should desirably have a heating value of at least about 6000 BTU/lb (dry basis), desirably at least about 6500 BTU/lb (dry basis), more desirably at least about 6800 BTU/lb (dry basis) and, preferably, at least about 7000 BTU/lb (dry basis) when burned. In an exemplary embodiment the present fuel pellets may have a heating value of about 7200 BTU/lb (dry basis) or even higher. Conventional hardwood can have a heating value as high as about 7900 BTU/lb.

[0011] Another requirement for a heating fuel is a low ash content. Ash produced by burning fuel may result in fouling of equipment. In some embodiments, an adequate ash content may be no more than about 5 wt. %, suitably no more than about 4 wt. %. and, more suitably, no more than about 3 wt. %. In other applications, it may be desirable to provide a biomass fuel pellet with an ash content of no more that about 2.5 wt. %. In yet other embodiments, the ash content may be no more than about 2.0 wt. % or no more than about 1.7 wt. %. For certain applications, fuel pellets with an ash content up to about 15 wt. % may be quite suitable.

[0012] Biomass fuel pellets must also have a sufficiently high integrity to limit the presence of fine combustible particles. A pellet's integrity can be measured by its pellet durability index ("PDI") as measured via a procedure similar to that described in Feed Manufacturing Technology III (American Feed Industry Association, Arlington Va. McEllhiney, R. R. (technical Editor). 1985. Appendix G Wafers, Pellets, and Crumbles—Definitions and methods for determining specific weight, durability, and moisture content; Section 6 Durability; Paragraph 2, Pellets and crumbles) the disclosure of which is herein incorporated by reference. The procedure includes the following steps:

[0013] 1) Obtain a composite product sample by obtaining several samples at regular intervals throughout production. The samples should be mixed together for testing.

[0014] 2) Screen sample with the appropriate screen as set forth on the Screen Sizes for Pellet and Crumbles Durability Tests, by shaking it 30 times.

[0015] 3) Place a 500-gram sample (+/−10 grams) in a tumbler compartment. An exemplary tumbler may be 25×12.5×12, including four chambers and tumble at about 54 rpm.

[0016] 4) Tumble sample for 10 minutes.

[0017] 5) Screen sample with the appropriate screen as set forth on the Screen Sizes for Pellet and Crumbles Durability Tests by shaking it approximately 30 times.

[0018] 6) Document the amount of sample and the amount of screened product.

[0019] Biomass fuel pellets desirably have a PDI of at least about 90 and more desirable at least about 95. The biomass fuel pellets may be generally cylindrical in shape and have a diameter of about 2/16 of an inch to 6/16 of an inch. More desirably, the fuel pellets may have a diameter of about 3/16 of an inch to 5/16 of an inch. The fuel pellets may have an aspect ration (i.e. diameter: length) of about 1:1 to 5:1.

[0020] Other properties, such as sulfur and moisture content have effects on pellet fuel performance. High sulfur contents can lead to pollution causing combustion products. Also, high moisture content in a fuel may reduce efficiency. Table 1 shows the reported values for properties of a conventional hardwood pellet as well as those for a variety of agricultural biomass fuels. Other agricultural biomass based-fuels may be suitable as well. Table 7 lists a number of other potential ingredients. The predicted BTU/lb for these materials was derived from standard feed analyses of the nutrient components in a particular ingredient.

TABLE 1

Fuel	Property	As Is	Dry Basis
Hardwood Pellet	Moisture	7.08 wt. %	
	BTU/lb.	7955	8573
	Ash wt. %	0.34 wt. %	0.36 wt. %
	Sulfur wt. %	0.01	0.01
Alfalfa	Moisture	12.25 wt. %	
(leaf and stem)	BTU/lb.	6934	7729
	Ash wt. %	7.94 wt. %	9.06 wt. %
	Sulfur wt. %	0.195	0.22
Aspen	Moisture	6.02 wt. %	
	BTU/lb.	7786	8501
	Ash wt. %	2.48 wt. %	2.67 wt. %
	Sulfur wt. %	0.02	0.02
Corn Gluten Feed	Moisture	12.06 wt. %	
	BTU/lb.	7199	8097
	Ash wt. %	3.78 wt. %	4.30 wt. %
	Sulfur wt. %	0.33	0.375
Corn - shell	Moisture	13.43 wt. %	
54.5 lb/bu. T.W.	BTU/lb.	6924	8100
13 wt. % moist.	Ash wt. %	1.13 wt. %	1.23 wt. %
	Sulfur wt. %	0.11	0.13
Corn - high oil	Moisture	12.49 wt. %	
56.2 lb/bu T.W.	BTU/lb.	7398	8480
12.9 wt. % moist.	Ash wt. %	1.17 wt. %	1.34 wt. %
	Sulfur wt. %	0.095	0.11
Corn - waxy	Moisture	139 wt. %	
56.6 lb/bu. T.W.	BTU/lb.	7073	8113
13 wt. % moist.	Ash wt. %	1.26 wt. %	1.44 wt. %
	Sulfur wt. %	0.12	0.135
Corn Cob	Moisture	7.12 wt. %	
	BTU/lb.	7369	7911
	Ash wt. %	2.16 wt. %	2.32 wt. %
	Sulfur wt. %	0.04	0.04
Corn Stover/Stalks	Moisture	9.14 wt. %	
	BTU/lb.	7057	7768
	Ash wt. %	6.81 wt. %	7.64 wt. %
	Sulfur wt. %	0.035	0.04
Dried Distillers	Moisture	9.27 wt. %	
Grain with solubles	BTU/lb.	8459	9422
(DDGS)	Ash wt. %	4.16 wt. %	4.13 wt. %
	Sulfur wt. %	0.4	0.45
Dried Distillers Grain	Moisture	13.35 wt. %	
with out solubles	BTU/lb.	8473	9848
(DDG)	Ash wt. %	1.96 wt. %	2.24 wt. %
	Sulfur wt. %	0.34	0.4
Oats	Moisture	12.49 wt. %	
	BTU/lb.	7143	8242
	Ash wt. %	3.17 wt. %	3.58 wt. %
	Sulfur wt. %	0.135	0.16
Soybeans	Moisture	10.25 wt. %	
	BTU/lb.	8783	10230
	Ash wt. %	5.19 wt. %	6.22 wt. %
	Sulfur wt. %	0.29	0.33
Soybean Hulls	Moisture	11.38 wt. %	
	BTU/lb.	6660	7570
	Ash wt. %	4.17 wt. %	4.22 wt. %
	Sulfur wt. %	0.07	0.08
Straw - wheat	Moisture	8.26 wt. %	
	BTU/lb.	6839	7375
	Ash wt. %	10.40 wt. %	11.33 wt. %
	Sulfur wt. %	0.07	0.075
Straw - oat	Moisture	6.91 wt. %	
	BTU/lb.	7153	7626
	Ash wt. %	7.90 wt. %	8.49 wt. %
	Sulfur wt. %	0.05	0.055
Sugar Beet Pulp	Moisture	9.70 wt. %	
	BTU/lb.	6597	7345
	Ash wt. %	3.80 wt. %	4.31 wt. %
	Sulfur wt. %	0.14	0.16
Sunflower Hulls	Moisture	8.65 wt. %	
	BTU/lb.	8474	9654

TABLE 1-continued

Fuel	Property	As Is	Dry Basis
	Ash wt. %	2.86 wt. %	3.13 wt. %
	Sulfur wt. %	0.14	0.15
Wheat Middlings	Moisture	12.58 wt. %	
	BTU/lb.	7228	8415
	Ash wt. %	5.18 wt. %	6.00 wt. %
	Sulfur wt. %	0.15	0.17
Wheat	Moisture	10.38 wt. %	
(Hard Red Spring)	BTU/lb.	7159	8063
	Ash wt. %	2.08 wt. %	2.28 wt. %
	Sulfur wt. %	0.20	0.22

[0021] During combustion of the fuel pellets, if materials containing potassium, sulfur and/or chlorine are present, K, S, and Cl can vaporize and deposit on metal surfaces. The resulting deposited layer may eventually melt and become sticky, which can result in the trapping of nonvolatile materials, containing elements such as Si, Ca, and Mg. Such elements may react with alkali metals, sulfur and/or chlorine The products of such reactions (e.g., alkali silicates) and/or chloride salts can lead to breakdown of the protective oxide layer on metal surfaces and ultimately contribute to accelerating corrosion. It can be advantageous to have low levels of inorganic compounds incorporating the elements listed above in the present fuel pellets. Example, for residential appliances, the Pellet Fuel Institute has a maximum limit on water soluble Na in fuel pellets of 300 ppm.

[0022] The following examples are presented to illustrate the present invention and to assist one of ordinary skill in making and using the same. The examples are not intended in any way to otherwise limit the scope of the invention.

EXAMPLES

Example 1

[0023] Six batches of biomass fuel pellets were made. Table 2 shows the weight percents for each component of the fuel pellet. The fuel pellet formula was weighed out and mixed in a ribbon mixer for 3 minutes. Once the mixing is complete, the loose mix was conditioned with steam. The conditioned mixture was then pelleted at a temperature of 140-180° F. utilizing a ¼ inch die then cooled using a counter flow cooler. The cooled pellets were then screened to remove any remaining fine material.

TABLE 2

	Sample					
	1	2	3	4	5	6
Cracked Corn	75	50		50	55	75
Whole Corn			50			
Wheat Middlings	25	25	25	25	35	25
Soy Hulls		25	25	25		
DDGS					10	

[0024] Samples from each batch were tested for Moisture content, heating value, and ash content. All but one sample was tested for sulfur content as well. Table 3 includes the results of the testing wherein sample numbers correspond to the samples in Table 2.

TABLE 3

Sample	Property	
1	Moisture	12.37 wt. %
	BTU/lb.	7028
	Ash wt. %	2.63 wt. %
	Sulfur wt. %	0.15
2	Moisture	11.68 wt. %
	BTU/lb.	6987
	Ash wt. %	33 wt. %
	Sulfur wt. %	0.14
3	Moisture	11.09 wt. %
	BTU/lb.	7015
	Ash wt. %	3.37 wt. %
	Sulfur wt. %	0.15
4	Moisture	11.14 wt. %
	BTU/lb.	7059
	Ash wt. %	3.50 wt. %
	Sulfur wt. %	Not Tested
5	Moisture	13.7 wt. %
	BTU/lb.	7175
	Ash wt. %	2.67 wt. %
	Sulfur wt. %	0.17
6	Moisture	14.49 wt. %
	BTU/lb.	7435
	Ash wt. %	1.7 wt. %
	Sulfur wt. %	0.11

Example 2

[0025] Table 4 shows the weight percents for each component of six exemplary fuel pellet formulations. The fuel pellet formula may be weighed out and mixed in a ribbon mixer for 3 minutes. Once the mixing is complete, the loose mix may be conditioned with steam. The conditioned mixture will then be pelleted at a temperature of 140-180° F. utilizing a ¼ inch die then cooled using a counter flow cooler. The cooled pellets were then screened to remove any remaining fine material.

[0026] A variety of materials may be used in place of and/or together with the agricultural biomass materials listed above. For example, corn, corn byproducts, oats, oat byproducts, wheat, wheat byproducts, rice, and rice byproducts. Also, oilseeds and oilseed materials may be used. Such material include soy beans, soy bean byproducts, sunflower seeds, sunflower byproducts, rapeseeds and rapeseed byproducts.

Illustrative Embodiments

[0027] A number of illustrative embodiments of the present methods and compositions are described below. The embodiments described are intended to provide illustrative examples of the present methods and compositions and are not intended to limit the scope of the invention.

[0028] The present fuel pellets may be formed from a mixture which includes substantial amounts of agricultural biomass having a relatively low lignin content, e.g., about 60 wt. % (dry basis) or more of the agricultural biomass. The fuel pellets desirably have a low ash content, good pellet durability (e.g., as determined by their pellet durability index) and heating values comparable to conventional hardwood fuel pellets. In some instances, the fuel pellets may have an ash content as high as about 15 wt. %, although lower ash contents, e.g., no more than about 5 wt. % and, more desirably, no more than about 3 wt. %, are commonly suitable for many applications. The fuel pellets may be formed by pelleting a mixture comprising agricultural biomass which includes whole corn, corn cobs, corn stover, wheat, wheat middlings,

wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp and/or sunflower hulls. Other suitable agricultural biomass materials which may be used to form the present fuel pellets include co-products from corn milling processes (e.g. corn gluten feed, white fiber), oat hulls, rice hulls, rapeseed meal, rapeseed fractions, bagasse and/or empty palm fruit.

[0029] The fuel pellets may comprise an agricultural biomass having a lignin content of no more than about 10 wt. %. Typically, the fuel pellet itself has a lignin content of no more than about 10 wt. % and, often, no more than about 5 wt. %. The pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90 and a heating value of at least about 7000 BTU/lb (dry basis). In some embodiments, the fuel pellet will have a heating value of at least about 7200 BTU/lb (dry basis) and more desirably 7500 BTU/lb (dry basis).

[0030] In some of these embodiments, the agricultural biomass may be selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, rapeseed hulls, sunflower hulls and mixtures thereof. The fuel pellet may have a PDI of at least about 90 and more preferably at least about 95.

[0031] In some of embodiments, the agricultural biomass may comprise at least about 40 wt. % cracked corn, whole corn, or a mixture thereof and preferably at least about 40 wt. % cracked corn.

[0032] In some instances, the present fuel pellets may include up to about 30 wt. % triacylglyceride material (i.e., have a "triacylglyceride content" of no more than about 30 wt. %). Typically, the fuel pellet has a triacylglyceride content of no more than about 5 wt. % and, more desirably, the fuel pellet has a triacylglyceride content of no more than about 3 wt. %.

[0033] In some embodiments, the fuel pellet further comprises a sugar alcohol component, which may comprise glycerol. Typically, the fuel pellet contains no more than about 5 wt. % of the sugar alcohol but in certain embodiments, may contain up to about 30 wt. % of the sugar alcohol. Optionally, the fuel pellet further comprises a processing aid. The processing aid may comprise paraffin wax, hydrogenated triacylglyceride, tallow, and/or a thermoplastic polymer (which may optionally be densified).

[0034] In some embodiments, a fuel pellet may be formed by pelleting a mixture comprising about 40 to 85 wt. % cracked corn, about 20 to 60 wt. % wheat middlings, and optionally up to about 5 wt. % glycerol. In many embodiments, the inclusion of 3 wt. % glycerol or less as a pelleting aid may be quite suitable.

[0035] Other suitable pelleting aids may encompass both lubricants and binders. For example, glycerol may have functionality as both. Examples of suitable binders would include, but are not limited to, lignin sulfonates, starches of various grains, gelatins, or alginates with inclusion levels as low as 0.1%. or as high as 40-50% in case of starches. Super Lube (Uniscope), Lube Aid (Ag Research), Pelltech (Borregaard Ligno Tech) are non-limiting examples of lubricants.

[0036] In some embodiments, a fuel pellet may comprise an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb (dry basis).

[0037] A fuel pellet may be formed by pelleting a mixture comprising about 40 to 90 wt. % corn, and about 10 to 60 wt. % of an agricultural biomass selected from the group consisting of corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb (dry basis).

[0038] A method of producing heat may comprise burning a fuel pellet comprising an agricultural biomass. In some instances, the agricultural biomass may include material selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. In some of these embodiments, the fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb (dry basis). In other embodiments, the fuel pellet may have an ash content of no more than about 2.5 wt. % ash, desirably no more than about 2.0 wt. % ash, and more desirably no more than about 1.7 wt. % ash. The fuel pellet commonly has a density of at least about 35 lbs/ft^3 and desirably no more than about 45 lbs/ft^3. Suitably, the pellets have a density of about 40-43 lbs/ft^3.

[0039] A fuel pellet may comprise an agricultural biomass wherein the pellet has an ash content of no more than about 3 wt. %, a PDI of at least about 90, a sulfur content of no more than about 0.2 wt. %, a moisture content of no more than about 15 wt. % (more desirably no more than about 13 wt. %), a triacylglyceride content ("TAG content") of no more than about 5 wt. % and a heating value of at least about 7000 BTU/lb (dry basis). In some embodiments the agricultural biomass may have a lignin content of no more than about 10 wt. % and desirably no more than about 5 wt. %.

[0040] In some embodiments, the fuel pellet may comprise from 0.1 to 5 wt. % glycerol. In other embodiments, the fuel pellet may comprise at least about 0.5 wt. % glycerol. In yet other embodiments, the fuel pellet comprises about 1 to 3 wt. % glycerol.

[0041] In some embodiments, the fuel pellet may have a generally cylindrical shape. The fuel pellet may have a diameter of about 2/16 of an inch to 6/16 of an inch. More desirably, the fuel pellet may have a diameter of about 3/16 of an inch to 5/16 of an inch. The fuel pellet may have an aspect ratio of about 1:1 to 5:1.

[0042] In some embodiments the fuel pellet may comprises a processing aid. Pellets containing such a processing aid may suitably include about 0.1 to 3 wt. % glycerol.

[0043] In some embodiments, a fuel pellet may be formed by pelleting a mixture comprising about 40 to 90 wt. % corn, and more desirably about 40 to 80 wt. % corn. The mixture may further comprise wheat, wheat middlings, soy hulls, sunflower hulls, rapeseed hulls, oats, dried distillers grains, beet pulp, corn cob, or mixtures thereof.

[0044] In yet another embodiment, the fuel pellet comprises an agricultural biomass having a lignin content of no more than about 10 wt. % (dry basis), wherein the pellet has

an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb (dry basis).

[0045] In yet another embodiment, the fuel pellet comprises at least about 60 wt. % (dry basis) of an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, soy beans, soy bean hulls, soy cotyledon fiber, dried distillers grain, oats, sugar beet pulp, sunflower hulls, co-products from corn milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, ground barley, cottonseed hulls, whole cottonseed, ground milo, oatmeal, oat flour, rye, broken rice, empty palm fruit bundles and mixtures thereof. The fuel pellet typically has an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6800 BTU/lb (dry basis), more suitably at least about 7000 BTU/lb (dry basis) and, more desirably, at least about 7200 BTU/lb (dry basis).

[0046] In yet another embodiment, the fuel pellets are formed from a mixture which includes corn, corn byproducts, oats, oat byproducts, wheat, wheat byproducts, rice, and/or rice byproducts. Also, oilseeds and oilseed materials may be used. Such materials include soy beans, soy bean byproducts, sunflower seeds, sunflower byproducts, rapeseeds and rapeseed byproducts. Commonly, the fuel pellet comprises at least about 60 wt. % (dry basis) of agricultural biomass, such as the materials described in this paragraph.

[0047] In yet another embodiment, the fuel pellets comprise at least about 60 wt. % (dry basis) of an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, soy beans, soy bean hulls, soy cotyledon fiber, dried distillers grain, oats, sugar beet pulp, sunflower hulls, co-products from corn milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles and mixtures thereof. Such fuel pellets typically have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 6800 BTU/lb (dry basis), more suitably at least about 7000 BTU/lb (dry basis) and, more desirably, at least about 7200 BTU/lb (dry basis).

[0048] In yet another embodiment, the fuel pellets are formed by pelleting a mixture comprising about 40 to 90 wt. % corn; and about 10 to 60 wt. % of an agricultural biomass which includes corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls, co-products from corn milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, ground barley, cottonseed hulls, whole cottonseed, ground milo, oatmeal, oat flour, rye, broken rice, empty palm fruit bundles or a mixture thereof. Such fuel pellets typically have a PDI of at least about 90. Such fuel pellets typically have a heating value of at least about 6800 BTU/lb (dry basis), more suitably at least about 7000 BTU/lb (dry basis) and, more desirably, at least about 7200 BTU/lb (dry basis). Such fuel pellets suitably have an ash content of no more than about 3 wt. %.

[0049] In some embodiments, a fuel pellet may comprise an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3.0%, a PDI of at least about 90%, and a heating value of at least about 7000 BTU/lb.

[0050] In some embodiments, a fuel pellet may comprise an agricultural biomass selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb.

[0051] A fuel pellet may be formed by pelleting a mixture comprising about 40 to 90 wt. % corn, and about 10 to 60 wt. % of an agricultural biomass selected from the group consisting of corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. The fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb.

[0052] A method of producing heat may comprise burning a fuel pellet comprising an agricultural biomass. In some instances, the agricultural biomass may include material selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof. In some of these embodiments, the fuel pellet may have an ash content of no more than about 3 wt. %, a PDI of at least about 90, and a heating value of at least about 7000 BTU/lb. In other embodiments, the fuel pellet may have an ash content of no more than about 2.5 wt. % ash, desirably no more than about 2.0 wt. % ash, and more desirably no more than about 1.7 wt. % ash. The fuel pellet commonly has a density of at least about 35 lbs/ft^3 and desirably no more than about 45 lbs/ft^3. Suitably, the pellets have a density of about 40-43 lbs/ft^3.

[0053] Yet another embodiment is directed to a method of producing heat comprising burning fuel pellets formed by pelleting a mixture comprising an agricultural biomass which includes whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls, co-products from corn milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles and mixtures thereof. The fuel pellets commonly have a PDI of at least about 90 and a heating value of at least about 7000 BTU/lb (dry basis).

[0054] Yet another embodiment is directed to a method of producing heat comprising burning fuel pellets formed from a mixture which includes substantial amounts of agricultural biomass having a relatively low lignin content, e.g., about 60 wt. % (dry basis) or more of the agricultural biomass. The fuel pellets desirably have a low ash content, good pellet durability (e.g., as determined by their pellet durability index) and heating values comparable to conventional hardwood fuel pellets. In some instances, the fuel pellets may have an ash content as high as about 15 wt. %, although lower ash contents, e.g., no more than about 5 wt. % and, more desirably, no more than about 3 wt. %, are commonly suitable for many applications.

[0055] Unless expressly stated otherwise, all percentages referred to herein are on a weight to weight basis (i.e., "wt. %"). In some instances, the percentages are expressed on a dry weight to total dry weight basis (i.e., "wt. % (dry basis)").

[0056] References to specific examples, use of "e.g.," use of the word "invention," etc., are not meant to restrict the scope of the recited claim terms. Accordingly, the claims are not tied and should not be interpreted to be tied to any particular embodiment, feature, or combination of features other than those explicitly recited in the claims, even if only a single embodiment of the particular feature or combination of features is illustrated and described herein. Thus, the appended claims should be read to be given their broadest interpretation in view of the prior art and the ordinary meaning of the claim terms.

[0057] As used herein (i.e., in the claims and the specification), articles such as "the," "a," and "an" can connote the singular or plural. Also, as used herein, the word "or" when used without a preceding "either" (or other similar language indicating that "or" is unequivocally meant to be exclusive—e.g., only one of x or y, etc.) shall be interpreted to be inclusive (e.g., "x or y" means one or both x or y). Likewise, as used herein, the term "and/or" shall also be interpreted to be inclusive (e.g., "x and/or y" means one or both x or y). In situations where "and/or" or "or" are used as a conjunction for a group of three or more items, the group should be interpreted to include one item alone, all of the items together, or any combination or number of the items. Moreover, terms used in the specification and claims such as have, having, include, and including should be construed to be synonymous with the terms comprise and comprising.

[0058] Unless otherwise indicated, all numbers or expressions, such as those expressing dimensions, physical characteristics, etc. used in the specification are understood as modified in all instances by the term "about." At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the claims, each numerical parameter recited in the specification or claims which is modified by the term "about" should at least be construed in light of the number of recited significant digits and by applying ordinary rounding techniques. Moreover, all ranges disclosed herein are to be understood to encompass any and all subranges subsumed therein.

TABLE 4

Fuel Pellet Formulations

	Sample No.							
	1 wt. %	2 wt. %	3 wt. %	4 wt. %	5 wt. %	6 wt. %	7 wt. %	8 wt. %
Corn	50	50	50	50	50	50	95	95
Wheat Midds	50	20	20	20	20	20		
Oat Hulls		30						
DDGS			30					
Beet Pulp				30				
Rice Hulls					30			
Soy Bean Hulls						30		
Crude Glycerol (Low Methanol)							5	
Crude Glycerol (High Methanol) 10 wt. %								5

TABLE 5

Fuel Pellet Content Profiles and Proximate Analysis

		Sample No.							
		1	2	3	4	5	6	7	8
Sample Content Profile	Protein	14.22	8.53	14.51	11.17	8.48		8.37	
	Moisture	12.41	11.99	13.14	12.39	13.55	13.20	13.43	13.50
	Fat	3.18	2.39	3.56	2.17	1.65	2.27	3.25	3.24
	Ash	3.58	3.16	3.20	3.62	6.33	31	1.20	1.21
	NDF	20.8	33.55	17.79	21.51	29.68	28.01	7.54	9.26
	ADF								
Pellet Fuel Proximate Analysis	Moisture	11.92	12.23	12.06	11.90	11.50	11.89	12.16	131
	Ash	32	2.78	3.57	3.90	6.14	2.67	1.27	1.36
	Volatiles	71.25	74.61	70.29	79.32	72.06	76.70	73.61	74.22
	Fixed Carbon	13.80	10.38	14.08	10.89	10.31	8.70	12.96	11.41
	Sulfur	0.16	0.12	0.32	0.12	0.10	0.13	0.08	0.08
	BTU/lb	7051	6978	7104	6863	6781	6954	6974	6935
	Calc. Moisture	12.33	11.97	138	12.17	11.73	12.08		
	Calc. Ash	38	2.91	3.38	2.92	6.10	2.74		
	Calc. BTU/lb	7017	6987	7076	6776	6661	6906	6980	6983

TABLE 6

Characteristics on an As Is Basis for a Number of Common Agricultural Biomass Materials

	Corn	Wheat Mids	Oat Hulls	DDGS	Beet Pulp	Rice Hulls	Soy Hulls
Protein	7.96	18.10	0.15	19.53	8.52	2.81	10.49
Moisture	13.4	11.62	10.41	14.13	11.09	9.62	10.79
Fat	2.97	3.73	0.04	4.00	0.81	0.19	1.18
Ash	0.94	5.21	4.66	6.23	4.70	15.29	4.08
NDF	7.11	33.79	87.74	26.35	37.13	61.68	58.81
ADF	1.85	9.63	40.65	7.93	25.33	44.59	42.05
BTU/lb (Analyzed)	7000	7033	6934	7232	6231	5847	6663
BTU/lb (Calculated)	6981	7150	6750	6912	6765	5983	6990

TABLE 7

Predicted Heating Value (BTU/lb) for Various Agricultural Materials

	MOISTURE	ASH	Sulfur	Predicted BTU/lb (As-Is Basis)	Predicted BTU/lb (Dry matter Basis)
Alfalfa - Dehydrated	8.9	10.3	0.25	6774	7435
Bakery By-Product <10% Fat	9.7	4.24	0.16	7573	8387
Barley Ground	12.40	2.35	0.15	6888	7863
Barley Hulls	6.37	5.98	0.13	7197	7687
BARLEY MIDDS	12	5	0.17		
Barley Screening/Malt Sprout Pellets	8.66	5.24	0.16	7209	7893
Barley Straw	10.00	8.82	0.15	6677	7419
Beet Pulp	8.2	6.44	0.22	6853	7466
Citrus Pulp	11.9	5.97	0.06	6586	7475
Cocoa Hulls <5% Fat	10.50	8.19		6959	7775
Cocoa Hulls >5% Fat	8.27	5.96		7829	8534
Coconut - Copra Meal	6.60	6.08	0.30	8039	8607
Corn DDGS	9.07	4.35	0.42	8250	9073
Corn Germ Meal - Solvent	10.90	1.93	0.37	7400	8306
Corn Gluten Feed	8.70	6.10	0.38	7266	7958
Corn Gluten Feed - MCP	57.50	2.55	0.11	3336	7849
Corn Gluten Feed - Sweet Bran	39.85	3.24	0.26	4829	8028
Corn Gluten Feed - Wet	57.50	2.60	0.10	3366	7921
Corn Gluten Meal 60% Protein	10.60	1.66	0.50	8189	9160
Cottonseed - Whole	8.36	3.50	0.23	8652	9441
Cottonseed Hulls	10.20	2.74	0.20	7209	8028
Cottonseed Meal - Dehulled Expeller	10.70	6.22	0.40	7505	8404
Malt Sprouts	5.57	5.78	0.61	7520	7963
Milo - Fine Ground	14.10	1.34	0.09	6863	7989
Oat Flour	7.85	1.83	0.17	7704	8361
Oat Hulls	9.70	5.38	0.06	6900	7641
Oat Straw	8.00	6.62	0.21	6959	7564
Oatmeal - Feed Grade	8.90	2.18	0.19	7570	8310
Oats - Whole	10.5	2.81	0.12	7314	8172
Oil - Corn	0.02	0	0	16624	16628
Oil - Cottonseed	0.99	0.00	0.00	16591	16756
Oil - Rice Bran	0.66	0.00	0.00	16248	16356
Oil - Soybean	0.02	0	0	16634	16637
Palm Kernel Meal - Expeller	8.54	4.12	0.25	7895	8632
Palm Kernel Meal - Expeller/Extruded	5.25	20.86	0.00	7034	7424
Palm Kernel Meal - Solvent	11.70	5.41	0.00	6964	7886
Peanut Meal - Beef	10	5.47	0.31	7634	8482
Peanut Meal 45% Protein	8.38	6.86	0.31	7561	8253
Peanut Meal 50% Protein	7.79	4.92	0.25	8021	8698
Rapeseed Meal 0	8.20	8.39	0.64	7312	7965
Rice - Broken	13.77	0.68	0.06	6709	7780
Rice Bran - Defatted 20% NDF	10.80	12.75	0.19	6482	7267
Rice Bran - Hi Fat	8.50	9.03	0.18	8174	8933
Rice Hulls	8.70	16.69	0.09	6030	6605
Rice Straw	4.15	14.28	0.27	6607	6893

TABLE 7-continued

Predicted Heating Value (BTU/lb) for Various Agricultural Materials

	MOISTURE	ASH	Sulfur	Predicted BTU/lb (As-Is Basis)	Predicted BTU/lb (Dry matter Basis)
Rice Straw - NH3 Treated	7.11	10.44	0.27	6817	7338
Rye	12.58	1.60	0.12	6844	7829
Rye Distillers 25% NDF	11.43	4.27	0.43	7436	8396
Rye Distillers 50% NDF	7.91	2.41	0.44	8042	8733
Rye Straw	10.00	4.50	0.10	6897	7663
Safflower Meal	7.3	4.71	0.18	7568	8164
Sesame Meal - Solvent	6.57	5.54	0.7	7909	8465
Sorghum Stover	12	9.68	0.0968	6382	7252
Soybean Germ	10.4	4.5	0.22	8371	9343
Soybean Hulls	13.30	4.65	0.18	6855	7906
Soybean Meal - 48% Protein	12	6.1	0.4	7358	8361
Soybean Meal - Expeller/Extruded	10.27	5.46	0.39	8125	9055
Soybean Screenings	10.58	13.02	0	7115	7957
Sunflower Hulls	10.8	4.72	0.11	7669	8597
Sunflower Meal - Expeller	6.67	6.47	0	8973	9614
Walnut Meal	9	3.59	0.13	7977	8766
Wheat - Ground 8-14% NDF	11.8	1.6	0.18	6970	7903
Wheat Germ	12.64	3.45	0.31	7331	8392
Wheat Germ Meal	12.92	3.84	0.31	7732	8879
Wheat Gluten Feed	11.27	6.4	0.25	7022	7914
Wheat Gluten Meal	8.17	4.06	0.25	8384	9130
Wheat Midds By-Product 27-34% NDF	12.3	4.94	0.19	7064	8055
Wheat Straw	11.00	6.94	0.17	6651	7473
Wheat Straw - NaOH Treated	8.28	8.03	0.27	6751	7360

What is claimed is:

1. A fuel pellet comprising an agricultural biomass; wherein the pellet has a lignin content of no more than about 10 wt. % (dry basis), an ash content of no more than about 4 wt. %, a PDI of at least about 90, and a heating value of at least about 7,000 BTU/lb (dry basis).

2. The fuel pellet of claim **1**, wherein the fuel pellet has a moisture content of no more than about 15 wt. %.

3. The fuel pellet of claim **1**, wherein the fuel pellet has a triacylglyceride content of no more than about 5 wt. %.

4. The fuel pellet of claim **1**, wherein the mixture comprises about 40 to 80 wt. % cracked corn.

5. The fuel pellet of claim **1**, further comprising a pelleting aid.

6. The fuel pellet of claim **5**, wherein the pelleting aid comprises a sugar alcohol component.

7. The fuel pellet of claim **6**, wherein the sugar alcohol component comprises glycerol.

8. The fuel pellet of claim **1**, wherein the pellet comprises at least about 60 wt. % (dry basis) of the agricultural biomass.

9. The fuel pellet of claim **1**, further comprising a processing aid which includes paraffin wax, thermoplastic polymer, hydrogenated triacylglyceride, tallow, or a mixture thereof.

10. The fuel pellet of claim **1**, wherein the pellet further comprises about 0.1 to 30 wt. % glycerol.

11. The fuel pellet of claim **1**, wherein the agricultural biomass has a lignin content of no more than about 10 wt. % (dry basis).

12. The fuel pellet of claim **1**, wherein the pellet has a sulfur content of no more than about 0.4 wt. %.

13. The fuel pellet of claim **1**, wherein the pellet has a density of about 40-45 lbs/ft^3.

14. The fuel pellet of claim **1**, wherein the pellet comprises at least about 60 wt. % (dry basis) of an agricultural biomass which includes whole corn, corn cobs, corn stover, wheat, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls, co-products from corn milling processes, co-products from wheat milling processes oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles and mixtures thereof.

15. The fuel pellet of claim **1**, wherein the agricultural biomass is selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, soy beans, soy bean hulls, soy cotyledon fiber, dried distillers grain, oats, sugar beet pulp, sunflower hulls and mixtures thereof.

16. The fuel pellet of claim **1** comprising about 40 to 90 wt. % corn.

17. The fuel pellet of claim **1**, wherein the fuel pellet has an ash content of no more than about 5 wt. %, and a heating value of at least about 7,500 BTU/lb (dry basis).

18. A fuel pellet formed by pelleting a mixture comprising:

about 40 to 90 wt. % corn; and

about 10 to 60 wt. % of an agricultural biomass which includes corn cobs, corn stover, wheat, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls, co-products from corn milling processes, co-products from wheat milling processes, almond hulls, walnut meal, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles or a mixture thereof;

wherein the fuel pellet has an ash content of no more than about 4 wt. %, a PDI of at least about 90, and a heating value of at least about 7,000 BTU/lb (dry basis).

19. The fuel pellet of claim **18**, wherein the mixture further comprises about 0.1 to 5 wt. % glycerol.

20. The fuel pellet of claim **18**, wherein the mixture includes about 10 to 60 wt. % whole corn, cracked corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls or a mixture thereof.

21. A fuel pellet comprising at least about 60 wt. % (dry basis) of an agricultural biomass selected from the group consisting of whole corn, cracked corn, corn cobs, corn stover, wheat, soy beans, soy bean hulls, soy cotyledon fiber, dried distillers grain, oats, sugar beet pulp, sunflower hulls, co-products from corn milling processes, co-products from wheat milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles, almond hulls, walnut meal and mixtures thereof;

wherein the fuel pellet has an ash content of no more than about 4 wt. %, a PDI of at least about 90, and a heating value of at least about 7,000 BTU/lb (dry basis).

22. A method of producing heat comprising burning a fuel pellet formed by pelleting a mixture comprising an agricultural biomass which includes whole corn, cracked corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls, co-products from corn milling processes, oat hulls, rapeseed meal, rapeseed fractions, bagasse, rice hulls, empty palm fruit bundles, almond hulls, walnut meal and mixtures thereof;

wherein the fuel pellet has a PDI of at least about 90, and a heating value of at least about 6,000 BTU/lb (dry basis).

23. The method of claim **22**, wherein the agricultural biomass is selected from the group consisting of cracked corn, whole corn, corn cobs, corn stover, wheat, wheat middlings, wheat straw, soy beans, soy bean hulls, soy cotyledon fiber, alfalfa, dried distillers grain, oats, oat straw, sugar beet pulp, sunflower hulls and mixtures thereof.

24. The method of claim **22**, wherein the mixture further comprises a pelleting aid.

25. The method of claim **22**, wherein the fuel pellet includes at least about 60 wt. % (dry basis) of the agricultural biomass; and the fuel pellet has a heating value of at least about 7,000 BTU/lb (dry basis) and an ash content of no more than about 15 wt. %.

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