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Grass pellet Quality Index: A tool to evaluate suitability of grass pellets for small scale combustion systems

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HIGHLIGHTS

- ▶ A Quality Index ranking grass pellets for combustion potential does not exist.
- ▶ Grass pellet biomass is extremely variable and therefore quality control is essential.
- ▶ Proposed system sums qualitatively different parameters into one index value.
- ▶ Model structure allows for effective evaluation and ranking.

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ABSTRACT

US renewable fuels policy strongly encourages biomass crop production, which should lead to expansion of biomass heating scenarios. Chemical composition of grass biomass can be extremely variable, depending on species, soil fertility, and harvest management. Biomass quality concerns have hindered the development of grass biomass for residential combustion, with no comprehensive evaluation system for grass pellet quality. Quality labeling will strengthen the fledgling grass biomass heating market, gain consumer confidence, and help to control combustion related emissions. The proposed system sums qualitatively different parameters into one Quality Index for relative evaluation and ranking of grass pellets for residential combustion potential. Parameters were selected and weighted for their relative importance based on available literature. Weighting was accomplished by adjusting the compositional working range for each parameter. A limit also was established for each parameter, beyond which the pellet lot was considered as unacceptable for residential combustion, regardless of the total Quality Index score. The model structure allows for effective evaluation and ranking of grass pellet lots regardless of the specific values ultimately chosen for acceptable limits and working ranges by the industry. Applying the Quality Index to a range of grass pellet types resulted in a reasonable ranking of pellets based on physical characteristics and composition.

1. Introduction

Rural North America has a tremendous capacity for energy production [1–3]. While the ongoing desire for energy security is the primary driving force for alternative energy development in the USA, environmental issues will sooner or later overshadow energy supply issues. An ideal alternative solid biomass feedstock should be nearly carbon neutral, without significant net increase in atmospheric carbon dioxide. It also needs to be seen as a valuable crop from the farmer's perspective [4,5].

The Northeastern USA has significant space heating demand, and most states in the region have state regulations controlling combustion emissions [6]. New York and the New England states represent approximately 80% of the total heating oil demand in the USA. The Northeast USA has millions of acres of abandoned and underutilized land suitable for grass biomass, without interfering with traditional agricultural crops and without the requirement for establishment [7]. Existing mixed grass stands are appropriate for grass biomass production if the energy conversion process is combustion. The use of such lands for this purpose makes this biomass option relatively immune from the indirect land use change debate [8]. Energy conversion efficiency can be very high with grass combustion [9].

Grass energy farming is a small-scale, low-technology, closed-loop energy system that will result in rural jobs and economic

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diversification, absorbing excess production capacity. In general, the desired feedstock for biomass combustion is opposite of that required for ruminant animal forage, with a range in composition among herbaceous plant species [10,11]. While grass breeding for biomass will eventually lead to compositional changes in the feedstock [12–14], major compositional changes can be achieved in the near-term through agronomic and harvest management [15].

1.1. Biomass composition and combustion

Soil type and inherent soil fertility can strongly impact mineral uptake [16]. Plant uptake of potassium (K) and chloride (Cl) are generally well correlated, due to luxury uptake of both elements in excess of plant requirements, and the common practice of fertilizing with KCl [17]. Potassium concentration has been reported as low as 0.6 g kg^{-1} to as high as 70 g kg^{-1} in cool-season grasses on a dry matter basis [18]. Concentration of most elements in grass decreases with plant age, making mature plants more desirable for combustion from a compositional standpoint. Harvest management can have a major impact on grass composition, particularly for water soluble components such as K and Cl [19,20]. Delayed baling following mowing, as well as overwintering grass in the field, also will reduce insoluble nitrogen (N) and silica (Si) in grass feedstock due to the preferential loss of inflorescence and leaf blade which are higher in N and Si content than other plant parts [21,22]. Dry matter losses in storage also are possible [23].

Biomass quality issues have hindered commercialization of grass pellets in residential combustion systems [24]. The most serious quality issues with grass feedstock are generally considered to be the alkali and chloride content [17,25–27]. Boiler corrosion and fouling are directly related to alkali and chloride content. Particulate emissions primarily consist of aerosol-forming elements like potassium and chloride, as well as sulfur (S). Chloride also acts as a catalyst, facilitating the movement of iron away from metal surfaces and the deposition of inorganic compounds [28,29]. Potassium is the primary alkali element present in grasses, with typically very low concentration of sodium [20]. Release of K can be minimized by controlling combustion temperature, but this does not prevent the release of Cl [25,26].

Nitrogen content of grass has little impact on combustion efficiency but is undesirable from an environmental standpoint. Nitrogen oxides are the second most important contributor to global acidification from human activities [25]. There are concerns that N release to the atmosphere from biofuel production negates any green house gas reduction benefits [30]. Nitrogen emissions are positively correlated with feedstock N content. Sulfur and Si, in combination with alkali, lead to reactions associated with fouling and slagging in boilers [28,31].

In general, approximately one half of the total ash content of grass is silica. Silica, in combination with K and other elements, affect the ash melting behavior in grasses [32]. The total amount of ash impacts the design of ash handling and storage systems for a given appliance, but ash content per se is not a major drawback to grass combustion within certain limits. Some residential heating appliances currently available are able to handle ash content up to 10%. Of course, total ash content is likely to be positively correlated with concentrations of undesirable elements, particularly Si and K. High total ash and Si content result in lower energy content.

Other ash forming elements such as P, Ca, Mg, Al, Fe, and Mn have less impact on combustion, or have a relatively small range in concentration in grasses. Elements such as As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V, or Zn might be a cause for concern, and German and Austrian wood pellet ENplus quality standards include analysis for heavy metals [33]. Such elements are normally present in grasses in very small quantities, significantly lower amounts than found in wood [34]. This is one of the few advantages that grass biomass has over woody biomass, as relatively slow growing woody species have the potential to accumulate significant quantities of heavy metals such as mercury. One exception might be with grass grown on fields treated with industrial sewage sludge [35], a relatively rare occurrence in the Northeast USA due to restrictions on such applications. Ash melting behavior [32] is an important parameter, but determination of melting temperatures is not feasible for routine sample analysis.

A contributor to elemental contents of grass that is difficult to assess is that of surface soil contamination. Over 100 lots of mature hay bales were sampled in New York in the fall of 2011, and ash content ranged from 38 to 212 g kg^{-1} (Cherney, JH, unpublished). Hay lots with high ash values also had corresponding very high Al, Fe, and Ti concentrations, indicative of soil contamination. Elemental components of a grass sample analysis originating from surface soil contamination will vary depending on soil type, plant digestion technique, and level of contamination [36]. Plant digestion analysis techniques only partially release elements bound in soil. Level of soil contamination is a function of how rough the soil surface is, soil moisture content, the particular type of mowing, raking and baling equipment used, and whether the grass is baled in the fall, or left standing or windrowed over winter. Soil contamination is also typically highly variable from bale to bale. The plant chemical components most impacted by surface soil contamination are silica and total ash. Soil contamination negatively affects gross energy value of the feedstock on a dry matter basis through dilution effects.

1.2. Quality evaluation

Quality standards for grass pellets would encourage their sustainable production and consumption for space heating. A survey of bioenergy experts in the EU showed that a majority of respondents agreed that there was a lack of European standards for bioenergy production, trade, and development [37]. The majority of respondents also agreed that a European-level standard would help to develop a sustainable bioenergy trade and encourage public acceptance of biomass energy, and that certification of bioenergy was necessary. Certification of biomass provides added value through product differentiation, enhancing market competitiveness.

A multi-criteria assessment model was used recently to rank biomass pellets for suitability for use in large heat and power generation plants [38]. Technical, environmental and economic factors were assigned weights and evaluated for the quantitative and qualitative criteria. While this model is useful for energy planning, it would have limited value for evaluating specific lots of pellets for compositional parameters.

Physical characteristics are the primary basis for evaluating wood pellet quality in North America [39]. Properties included in the fuel quality grade specifications include fines, bulk density,

Table 1
Pellet Fuels Institute fuel grade requirements for wood pellets [39].

Parameter	Premium	Standard	Utility
Bulk density, kg m^3	641–737	609–737	609–737
Fines, g kg^{-1}	⩽5	⩽10	⩽10
PDI[a], g kg^{-1}	⩾965	⩾950	⩾950
Moisture, g kg^{-1}	⩽80	⩽100	⩽100
Total ash[b], g kg^{-1}	⩽10	⩽20	⩽60
Chloride, g kg^{-1}	⩽0.3	⩽0.3	⩽0.3
Diameter, mm	5.84–7.25	5.84–7.25	5.84–7.25
Length, % greater than 38.1 mm	⩽1	⩽1	⩽1

[a] Pellet durability index.
[b] Total ash and chloride concentrations are expressed on a dry matter basis.