An exploration of common reed (*Phragmites australis*) bioenergy potential in North America

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SUMMARY

In North America, reed (*Phragmites australis*) is typically considered to be a weed although it provides important ecosystem services. Small, sparse, patchy or mixed reedbeds are more suitable as habitat for many species than extensive dense reedbeds, whose habitat functions can be enhanced by the selective removal of biomass. We propose that above-ground reed biomass could be harvested for bioenergy, at the same time improving habitat for biodiversity by thinning or fragmenting the more extensive reedbeds. Biofuel pellets manufactured from reeds harvested at Montréal (Canada) had moisture content 6.4 %, energy content 16.9 kJ g^{-1} (dry mass), ash content 3.44 %, and chloride content 1962 ppm. Thus, reed as a material for fuel pellet manufacture is similar to switchgrass (*Panicum virgatum*), which is commonly cultivated for that purpose and requires higher inputs than harvested wild reed. We discuss these findings in the context of environmental considerations and conclude that the bioenergy potential of reed could most expediently be realised in North America by combining material harvested from the widespread spontaneously occurring reedbeds with organic waste from other sources to create mixed biofuels. However, reeds with high levels of chlorine, sulphur or metals should not be burned to avoid air pollution or equipment damage unless these problems are mitigated by means of appropriate season of harvest, equipment, combustion regime, or use of a mixed feedstock.

KEY WORDS: biofuel; fuel pellets; habitat management; paludiculture; *Panicum virgatum*; wetland

INTRODUCTION

Biomass includes all living and dead plant matter as well as organic wastes derived from plants, humans, marine life and other animals. Trees, grasses, hay, animal dung, sewage, garbage, wood residues and other organic components of municipal solid waste are all examples of biomass (Tester *et al.* 2005). Plant biomass used as an energy feedstock can be produced renewably, and carbon emitted from burning biomass fuels is compensated by carbon removed from the atmosphere by the plants before harvesting (as well as some carbon fixed in underground organs that remains in the soil after harvesting). Although biomass accounted for only 5 % of the energy used in the United States of America (U.S.A.) in 2012 (U.S. EIA 2013), there is potential to increase this figure substantially, and the combustion of fuel pellets manufactured from finely ground plant materials is increasing in both the U.S.A. and Europe. Although the amount of net primary productivity available for bioenergy is small compared to the energy demand of the world's human population (Dukes 2003), biofuels derived from unwanted biomass, including weeds and wastes, could be an economical and ecologically acceptable energy source.

An ideal bioenergy species would have a high content of lignocellulose, relatively low levels of nitrogen and ash, efficient use of light for photosynthesis, and high productivity on non-farmland (Madakadze *et al.* 1999). Sustainable biofuels should be produced with low inputs of fossil fuels and chemicals, and from land with little or no alternative value (Delucchi 2010). Several crops are being developed for use as bioenergy feedstocks, prominently maize (*Zea mays*) and switchgrass (*Panicum virgatum*). Ethanol produced from maize is not economically viable and does not provide a positive net energy balance; its manufacture and use contribute to air, water, and soil pollution as well as global warming and food shortages overseas; and the crop requires large amounts of pesticides (Giampietro *et al.* 1997, Pimentel 2003). High-cellulose crops such as switchgrass are currently the most promising sources of biomass for fuel production (Lynd *et al.* 2008). Switchgrass has high yields, high nutrient use efficiency and a wide natural geographical distribution. However, Young *et al*. (2011) opined that switchgrass and maize might not be the most sustainable bioenergy crops.

Phragmites australis (Cav.) Trin. ex Steud. (common reed, Poaceae; hereinafter "reed") is physically and chemically similar to switchgrass. Its properties, combined with its ability to thrive without cultivation and produce large quantities of annually harvestable biomass, often in essentially single-species stands in a variety of habitats, make the plant an ideal candidate for bioenergy (Zhao *et al.* 2011). The Old World haplotype M of reed has been spreading rapidly in North America (Saltonstall 2001), where it tends to reduce plant diversity in wetlands (Weis & Weis 2003). Many public and private agencies are attempting to reduce reed in order to reinstate native marsh plant communities (Virginia Invasive Species Council 2005, U.S. Fish and Wildlife Service 2007, Wisconsin Department of Natural Resources 2007,). After reed has been cut or treated with herbicide, it may be disposed of as landfill (Wisconsin Department of Natural Resources 2007). In North America there have been few attempts at commercial utilisation of reed beyond collecting culms with tassels for dried plant arrangements in floristry. The use of unwanted reed material to replace industrially farmed bioenergy crops such as switchgrass would be highly preferable to landfill disposal (Young *et al.* 2011).

Experimental use of reed for bioenergy, in various forms (pulverised, chopped, shredded, bales, pellets, briquettes, biogas, pyrolysis oil or char, ethanol), has been reported from China, South Korea, Turkey, several European countries and the U.S.A. (Björk & Granéli 1978, Hansson & Fredriksson 2004, Komulainen *et al.* 2008, Sutcu 2008, Sathitsuksanoh *et al.* 2009, Szijártó *et al.* 2009, Gravalos *et al.* 2010, Jagadabhi *et al.* 2011, Zhao *et al.* 2011, Kitzler *et al.* 2012, Park *et al.* 2012, Patuzzi *et al.* 2012, Kask *et al.* 2014). Because pellets of compressed, finely ground woody material and switchgrass are already in commercial use for domestic space heating in North America, pellets of reed can be produced with relatively low capitalisation and this form was chosen for our own trials.

In this article we report some of the chemical and physical properties of fuel pellets manufactured from reed harvested in North America, more generally examine the properties of reed that make it a suitable bioenergy feedstock, and assess the overall feasibility and environment-friendliness of producing biofuels from reeds.

METHODS

Old World reeds were harvested near Montréal (Canada) and converted into fuel pellets at Technophrag, Montréal. We performed laboratory analyses of the moisture and energy contents of the pellets at Bard College. Moisture content was determined using a laboratory dryer. The pellets were weighed and placed in the dryer at 60 °C, where they were dried to constant mass. To measure calorific (energy) content, pre-weighed pellet samples were combusted in a Parr® 6725 Semimicro Oxygen Bomb Calorimeter with a 6772 Calorimetric Thermometer. Pellets were also analysed at the Cornell Nutrient Analysis Laboratory for a standard set of metals and metalloids, plus silicon (as silicate, which is a major constituent of reed ash), sulphur and chloride (on account of the significance of these elements for furnace corrosion). Chloride was analysed on a Spectro Arcos axial viewed plasma. The other elements were determined by wet digestion of a sample with nitric and perchloric acid and measurement by inductively coupled argon plasma atomic emission spectroscopy (ICP-AES).

RESULTS

Data from our laboratory analyses and literature review (Table 1) show that the variables of interest for bioenergy are similar for reed and switchgrass, except that standing crop biomass is higher in reed and reed sometimes contains more chloride. The analysis of reed pellets for element content revealed no causes for concern about pollution from combustion gases or ash disposal (Table 2).

Table 1. Characteristics of above-ground portions of common reed (*Phragmites australis*) and switchgrass (*Panicum virgatum*), and pellets made from common reed, that are relevant to bioenergy use. Values marked with asterisks (*) are for reed pellets manufactured by Technophrag from Old World reeds harvested near Montréal, Canada (this study).

Characteristic	***Switch-grass***	***Reed pellets***	***Reed***	
Above-ground biomass (g m^{-2} dry mass)	388–755 [1]	-	980–2642 [9]	(U.S.A.)
Photosynthetic efficiency (%)	< 1 [2]	-	2.14 [10]	(U.K.)
Productive lifespan (yr)	> 15 [3]	-	20−100 [11]	(U.K.)
Moisture content (%)	13−15 [4] (fresh mass)	6.40 *	5 [12]	(dry; U.S.A.)
			4.06 [8]	(ground; Greece)
Cellulose content (%)	54−67 [4] (fresh mass)	-	27.8 [13]	(dry; Slovakia)
			33−36 [14]	(Hungary)
Ash content (% dry mass)	4.5−5.8 [4]	3.44 *	6.1 [15]	(dead; U.S.A.)
			3.13− 8.08 [16]	(U.S.A.)
	2.3−5.9 [5]	7.46 [8]	8.21 [8]	(ground; Greece)
Energy content (kJ g^{-1} dry mass)	17.4 [4]	16.9 *	16.9 [17]	(U.S.A.)
		16.5 [8]	17.5 [8]	(Greece)
Chloride (g kg^{-1} dry mass)	0.15–0.99 [6]	1.96 *	0.015 [18]	(Austria)
	0.02–0.26 [7]			

References: [1]Makaju *et al.* (2013); [2]Heaton *et al.* (2008); [3]Elbersen (2004); [4]McLaughlin *et al.* (1996); [5]Bakker & Elbersen (2005); [6]Christian *et al.* (2002); [7]Renz *et al.* (2012); [8]Gravalos *et al.* (2010); [9]Meyerson *et al.* (2000); [10]Lawson & Callaghan (1983); [11]Hawke & José (1996); [12]Sathitsuksanoh *et al.* (2009); [13]Baran *et al.* (2002); [14]Szijártó *et al.* (2009); [15]Roman & Daiber (1984); [16]Lanning & Eleuterius (1985); [17]de la Cruz (1983); [18]Kitzler *et al.* (2012).

Table 2. Concentrations of various elements in reed fuel pellets (dry mass basis).

Element	Concentration (mg kg^{-1})
Al	280.2
As	0.0780
B	2.489
Ba	17.3
Ca	1711.4
Cd	0.0288
Cl	1962
Cr	2.548
Cu	1.362
Fe	702.0
K	2196.6
Mg	566.0
Mn	91.1
Mo	0.159
Na	860.1
Ni	0.398
P	212.0
Pb	0.825
S	898.2
Si	240.9
Sr	19.1
Ti	11.7
V	0.643
Zn	14.8

DISCUSSION

Suitability of reed for fuel pellet manufacture

Harvested reed is potentially a high quality biofuel feedstock that could be used to produce various fuels including fuel pellets (Table 1). However, the indicators of quality that we determined (moisture content by drying at 60 °C, ash content by combustion at 450 °C) are not strictly comparable with those determined to European (EU) standards, which stipulate temperatures of 105 °C and 550°C for these two determinations, respectively.

The properties of fuel pellets depend on feedstock, season of harvest and a variety of other factors. The U.S.A. Pellet Fuels Institute (PFI) recognises three grades of pellets, each with specifications for length, diameter, bulk density, chloride, ash content and fusion temperature, moisture content, energy content and durability (PFI 2011). For the lowest grade pellets, ash content should be ≤ 6 %, moisture content ≤ 10 %, and chloride ≤ 300 ppm (PFI 2011). However, the Grass Pellet Quality Index (Cherney & Verma 2013) allows maximum levels of 0.4 % (4000 ppm) sulphur and 0.2 % (2000 ppm) chloride; neither level is exceeded by the Technophrag pellets (Table 2). As far as we know, no standards have yet been established specifically for reed fuel pellets anywhere in the world. However, the Technophrag reed pellets (Table 2) had ash content well under 6 % and, if it were necessary to reduce the moisture, ash, or chloride content of the pellets in order to achieve compliance with relevant standards, reed material could be mixed with other organic matter such as switchgrass, food crop residues or yard waste.

Burning reed pellets with high levels of chlorine, sulphur, metals and some other elements could result in damage to combustion equipment (Kask *et al.* 2014), as well as undesirable air pollution and contamination of soil and water from use of ash as fertiliser (Becidan *et al.* 2012). The levels of heavy metals and major elements in reed depend on the geochemical environment, pollution of the water and soil in which the reeds grew, and the season. Reeds are known to accumulate contaminants including selenium, mercury, copper, zinc, cadmium, chromium, iron, and lead (Gries & Garbe 1989, García-Hernández *et al.* 2000, Windham *et al.* 2003). Therefore, both the soil where the reeds grow as well as the reeds to be harvested for biofuel should be sampled for pollutants. Chlorine, sulphur, potassium and nitrogen are reduced in reed harvested after overwintering (Szijártó *et al.* 2009). Thus, where contaminant problems arise, pooling reeds from polluted and unpolluted wetlands and harvesting in late winter may dilute the content of undesirable elements to acceptable levels. Finally, appropriate combustion equipment can help reduce stack emissions (Roy *et al*. 2013).

Environmental considerations

Fuel pellets made from reed and switchgrass have similar energy content and physical properties, and reed produces more biomass than switchgrass (Table 1). Reed thrives without energy or fertiliser inputs for cultivation and, unlike switchgrass, grows spontaneously in a variety of habitats that are too wet or have soils that are too poor for most agricultural crops. After combustion of the pellets, the reed ash remaining can be spread on fields as fertiliser (Komulainen *et al.* 2008) if it is not contaminated with heavy metals. Therefore, exploiting reed for bioenergy would be more environmentally friendly and more economical than using maize, switchgrass or wood cellulose (Pimentel 2003, Hansson & Fredriksson 2004).

The traits that make certain plants good bioenergy crops also potentially increase invasiveness (DiTomaso *et al.* 2010), although assessments of potential negative biodiversity impacts arising from the utilisation of weeds as biofuels are so far lacking from studies on various species. Field pennycress (*Thlaspi arvense*), a common introduced forb that has been studied as a potential biodiesel crop in Illinois, U.S.A. (Moser *et al.* 2009) is apparently non-invasive. On the other hand, amongst the species (including reed, unknown haplotype) tested as potential biofuel crops in Minnesota peatlands by Andrews (1989), cattails (*Typha* spp.) are variously regarded as benign or invasive (e.g., Shih & Finkelstein 2008); and kudzu (*Pueraria montana*), suggested as a possible feedstock for ethanol production (Sage *et al.* 2008), is a highly invasive introduced leguminous vine.

Old World reed is considered an environmental weed or invasive pest in North America (Weis & Weis 2003), and this has been the case for at least the past century. Wetland managers have expended considerable efforts to kill reed colonies and replace them with native freshwater- or salt-marsh plants such as cattail or cordgrass (*Spartina* spp.). This management is justified as restoration of habitat for native plant communities, water and marsh birds, and fish, and is becoming increasingly important. Thus, utilising Old World reed in North America might create economic pressure to expand populations of a species that could have negative impacts on biodiversity at certain sites (Raghu *et al*. 2006, Barney & DiTomaso 2008, Mack 2008, Meyerson 2008). The risk can be reduced by harvesting reed where it already occurs, rather than planting it for bioenergy at new locations (Sathitsuksanoh *et al.* 2009). This would, in any case, be unnecessary; although exceptions might be made on derelict land such as brownfields, salinised areas or strip mines where many plant species are difficult to establish and maintain, and reed could serve either as a long-term cover for habitat or a short-term crop to improve soils for other species. On-site processing of harvested reeds could reduce the possibility of seeds or vegetative propagules (culm bases, rhizome segments) being dispersed by transport of harvested material.

Notwithstanding the widespread negative attitude towards reed, there is considerable evidence that reedbeds provide important ecosystem services and, in certain situations, good habitat for many native animals and plants. Although they tend to avoid extensive and dense reedbeds, many species of birds and other native biota can be found in small reedbeds, patchy reedbeds interspersed with large shallow pools, and reedbeds with admixed woody plants (Kiviat 2013). Reed litter prevents the development of other plants (Holdredge & Bertness 2011) and, although Granéli (1989) believed that litter accumulation in European reedbeds inhibited new shoots of reed to the advantage of other species, it seems more probable that reducing the standing stock of litter by regular harvesting would promote vegetational diversification. Thus, depending on the character of a reedbed and the surrounding landscape, partial harvest of reed biomass can be expected to improve habitat for many native organisms while maintaining certain non-habitat ecosystem services. Harvesting reed for bioenergy could reduce reed biomass where it is a troublesome weed and provide a use for the reed material that is removed. Removal of patches of reed would temporarily open space in the reedbed habitat for use by biota that cannot utilise dense reedbeds, and harvesting repeatedly from the same reedbeds would gradually weaken reed genets and reduce biomass production. This would be desirable for biodiversity management in many situations, although adverse for long-term bioenergy production.

These observations may be referenced to experience from Europe, where reed is generally regarded as beneficial but nonetheless becomes an environmental weed in some cases (Maheu-Giroux & de Blois 2005, Szijártó *et al.* 2009, Björk 2010). Among these are fish production ponds in the southern Czech Republic where reedbeds are managed to prevent extensive spread within the pond (Hejný *et al.* 2002); fen meadows in Switzerland where reed has been mown to reduce competition with rare plants (Güsewell *et al.* 1998); Lake Hornborga in Sweden, where areas of reed were removed to improve habitat for water and marsh birds (Hertzman & Larsson 1999); and various wetlands in England where reed is managed for biodiversity by partially removing reed biomass (Burgess *et al.* 1995, Hawke & José 1996).

Harvesting of reed has some further implications for ecosystem services. Especially if it is conducted in late summer, there are benefits for eutrophic waters because nutrients are removed from the habitat (Komulainen *et al.* 2008). Over longer time scales, reedbeds act as net sinks for greenhouse gases (Brix *et al.* 2001) and, because underground biomass predominates over above-ground biomass, reeds sequester carbon in the soil even when the culms are harvested.

Prospects for reed as a biofuel in North America

Reed is especially well-suited for wetland treatment of wastewater (Vymazal 2010), and it is likely that reedbeds in North America could be managed for water treatment and fuel harvest in combination. Above-ground reed biomass may be harvested from reedbeds in small amounts by hand cutting with a sickle or scythe, or at larger scale by mechanised mowing with a variety of light or heavy machinery. It may also be possible to use locally available farm equipment and labour that are typically idle during the non-growing season for winter harvesting and even partial processing of reeds. In northern climates, physical damage to soils and roots can be minimised by harvesting reedbeds during winter months when the ground is frozen or ice-covered and above-ground material is relatively dry (Hawke & José 1996). Although mechanical harvesting presents some risk to biodiversity, chemical control and classical biological control are even riskier options as they may threaten native plants and wildlife, the non-habitat ecosystem services provided by reedbeds and, ultimately, human health (Kiviat 2013).

Because reeds are bulky, processing them to produce fuel bricks or pellets, biogas *etc*. on or near the site where they are harvested would be most efficient, whilst also helping to contain any risk to biodiversity as described above. This could be accomplished by using equipment that is either stationary and capable of accepting a variety of organic material types in addition to reed, or portable so that it could be moved from one reedbed to another.

It is possible that a few places in North America, such as Great Salt Lake, Utah, which has 14,000 ha of marshes dominated by Old World reed (Karin Kettenring, personal communication), could sustain a reed bioenergy industry. In most other regions, which do not have enough reed-dominated vegetation to solely support a bioenergy industry, there is still substantial potential for combining reed that is unwanted for biodiversity reasons with waste biomass including agricultural and food processing byproducts, urban yard wastes, livestock manure and bedding, and the organic components of garbage, to produce biofuels. On the basis of the discussion above we recommend that, in realising this potential, it will be advantageous to carefully select reed harvesting sites, techniques and management regimes taking into account site characteristics, management goals and the socioeconomic landscape.

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