Missouri River Watershed Coalition Conservation Innovation Grant Project

Analysis of Fuel Properties and Bioenergy Potential for Saltcedar and Russian Olive Wood

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1.0 Executive Summary

Samples of saltcedar and Russian olive wood were tested for fuel properties. Heating value, moisture content and ash properties were compared with other biomass fuels. Potential energy uses were evaluated.

Fuels from the eradication of invasive species like saltcedar and Russian olive have high costs due to the methods of treatment. They would be more expensive than coal or natural gas but it could compete with oil or propane for rural heating.

Low moisture and ash content make the wood a good fuel for bioenergy. Inorganic ash components such as chlorine, sulfur, potassium or silica are low enough so that the fuels have a high ash fusion temperature and should not present problems in burners or boilers. While the ash content is low it is too high for making a high value residential wood pellet and it is too expensive to make a low value industrial or utility fuel. It would not be worth torrefying this wood to make an industrial fuel. It has been tested and marketed as a lump charcoal. Nutrients in the wood make it a good candidate for a soil amendment like biochar.

Opportunities should be sought where the cost of eradication could be shared with another process to lower the cost as a fuel. In that case it could be a good fuel for use in small heating boilers, such as schools or institutions, or as lump charcoal. If the cost of carbonization is acceptable it could be used on site as biochar to improve the fertility of soils in the Missouri river watershed.

2.0 Introduction

2.1 Background and Objectives

T. R. Miles, Technical Consultants Inc. was asked to evaluate the fuel properties of saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) wood. We have reviewed test results from samples of each species and compared them with typical biomass fuels. We have examined the components of the ash in each species for potential problems in thermal conversion. And, we have looked at the potential viability of using these woods for bioenergy.

2.2 Current Harvest Practices

Eradication of invasive species like saltcedar and Russian olive would seem to present opportunities for biomass energy. They may be suitable for direct use as chips, for conversion to densified fuels, for torrefaction, or for carbonization to charcoal or biochar. Unlike other forest residues the shrub-like invasive species require special treatments which increase harvesting costs so they are expensive compared with natural gas, coal or forest fuels. Table 2-1. Wood from invasive species could compete with fuel oil or propane.

Table 2-1. Delivered Cost of Fuel

Fuel	Unit	Net Heating Value[1] Btu/unit	Cost/unit	$/MMBtu
Natural Gas	Therm	82,000	$ 0.20	$2.44
Bituminous coal	Ton	26,000,000	$125.00	$4.81
Wyoming coal	Ton	22,000,000	$125.00	$5.68
Forest fuels	Oven dry ton	13,800,000	$60.00	$4.35
Invasive species	Oven dry ton	13,800,000	$300.00	$21.74
Fuel Oil #2	Gallon	115,000	$4.00	$34.78
Propane	Gallon	71,000	$2.50	$35.21

Woody biomass is typically harvested and piled for later chipping into whole tree chips for fuel or fiber. The growth characteristics of saltcedar and Russian olive are

[1] USFS 2004. Fuel Value Calculator, http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf

somewhat different and have influenced the treatment methodology. Saltcedar is primarily a shrub that can grow to heights of 20’ but the stem diameters rarely exceed 3” so they would not lend themselves to any type of “log” form of decking. Figure 2-1. Russian olive, depending on age class can vary from young shrub-like forms to mature 40’ trees with up to 30” base diameters. Figure 2-2.

Management techniques used for control are driven primarily by site conditions, such as accessibility and plant densities, and treatment costs. A variety of management techniques are used in the control of these species in riparian areas. These include chemical, mechanical, or both mechanical and chemical methods. Effective saltcedar control has been achieved with hand herbicide applications (foliar and basal bark), generally with Triclopyr[2] and basal oil mixtures. Figure 2-1b. Triclopyr decomposes at 290 ºC (554 ºF). [3] It would decompose during combustion since most boilers and burners operate at 815 ºC-1100 ºC (1500 ºF-2012 ºF).

In many cases, the plants are left to naturally decompose. In some very dense patches they can be mechanically cut with the plant material piled or hauled away, and then the regrowth is treated with herbicides. Russian olive is generally mechanically cut by small-scale forestry type “feller buncher” skid steers with the material being slash-piled. Cut stumps of the trees are treated with herbicide/oil mixtures, and usually require one or two additional herbicide treatments in the following years to suppress regrowth. A review of potential harvest systems for saltcedar and Russian olive shows how various methods could be employed to prepare fuels.[4]

The riparian sites where invasive species grow are relatively easy to access and in most cases the slash piles, when left to air dry to reduce the moisture content and eliminate fuel quality reduction from leaves, could be chipped and hauled directly to a biomass plant.[5] The advantages of piling appear to be that the leaves fall off and the moisture dries. These techniques have been used for preparing Western juniper as fuel for

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[2] U.S. Forest Service. 1996.Triclopyr Herbicide Information Profile. November http://www.fs.fed.us/r6/nr/fid/pubsweb/tri.pdf

[3] Pesticide Residues in Smoke. Undated manuscript from MRWC.

[4] Dykstra, Dennis P. 2010. Extraction and utilization of salt cedar and Russian olive biomass. Chapter 6 in: Shafroth, Patrick B.; Brown, Curtis A.; Merritt, David M. (eds.), Salt cedar and Russian Olive Control Demonstration Act Science Assessment. Fort Collins, CO: US Geological Survey, Scientific Investigations Report 2009-5247. pp. 103-116.

[5] S. Bockness, 2012.

biomass plants in Nevada and California in commercial quantities greater than 60,000 tons per year.

Figure 2-1. Saltcedar

A. Saltcedar Untreated (MRWC)

B. Saltcedar Basal Bark Treatment (MRWC)

Figure 2-2. Russian Olive

A. Russian Olive Untreated (MRWC)

B. Russian Olive Brush pile (MRWC)

3.0 Wood Fuel Properties

Fuel samples from MRWC were sent to Hazen Laboratories for analysis.[6] Fuel properties for saltcedar and Russian olive are similar to other woody biomass species in moisture content, heating value, combustion properties and ash.

3.1 Heating Value

Heating values for saltcedar and Russian olive wood are compared with pine hog fuel and Douglas fir mill waste in Table 3-1. Oven dry (o.d.) heating values are similar for most species on a weight basis. Wood chips are typically delivered at 45% to 50% moisture content, wet basis (MC50) and are sold either by weight (per ton) or volume (per Unit of 200 ft3). At 50% MC saltcedar and Russian olive would have a gross heating value (GHV) of 4,138-4,166 Btu/lb. compared with Douglas Fir at 4,390 Btu/lb. In the arid conditions of the Missouri river watershed the harvested fuel is more likely to be air dried to 20% moisture content (MC20), wet basis. The heating value of the saltcedar and Russian olive wood at 20% MC is 6,620-6,665 Btu/lb.

Table 3-1. Wood Fuel Properties.

Species	**HHV** Btu/lb od	**GHV Btu/lb MC20**	**GHV Btu/lb MC50**	**Ash % od**
Saltcedar	8,275	6,620	4,138	2.88
Russian Olive	8,332	6,665	4,166	1.38
Ponderosa Pine (hog fuel)	8,821	7,056	4,410	2.37
Douglas Fir (mill waste)	8,779	7,023	4,390	0.41
Higher Heating Value (HHV) and Gross Heating Value (GHV) = HHV (1-MCwb/100)				

3.2 Moisture Content

Saltcedar samples collected by MRWC are characterized by low levels of moisture (6%-10% MC wet basis).[7] Living wood often contains 40-50% MC. If cut and

[6] Hazen Research, Inc. 4601 Indiana Street, Golden, Colorado 80403, U.S.A. www.hazenusa.com

left in a dry environment the wood can reach its equilibrium moisture content (EMC). The arid environment and harvesting practices apparently combine to dry the wood to below 20% MC.

Russian olive samples also contained very low moisture. Even mulched samples collected from the ground were dry. If the wood can be harvested and chipped at less than 20% MC then it would make a very good fuel. Low moisture means that less heat is required to evaporate the water during combustion. Fuel of this quality could be burned directly in small boilers, or it could be cofired with coal in large utility boilers.

3.3 Combustion Properties

Combustion properties of Russian olive and saltcedar samples are compared with hog fuel from ponderosa pine and Douglas fir saw mill waste in Table 3-2. Nitrogen is high in the Russian olive (1.15% o.d.) wood so that nitrogen oxide emissions could be a concern in large boilers unless it is diluted with low nitrogen fuels or treated by nitrogen reduction methods.

Sulfur is also high in saltcedar. Table 3-1. Clemons and Stark noted high concentrations of sulfur and calcium in saltcedar compared with pine.[8] Sulfur volatilizes during combustion but it can also react with calcium in the fuel. It is notable that a high concentration of sulfur was retained in the ash sample which was prepared at relatively low temperatures (<600°C, <1112 °F) in the laboratory. Table 3-3. Biochar made from saltcedar should retain the sulfur to be available for plants if it is used as a soil amendment.

[7] S. Bockness. 2012. Summary of MRWC CIG Invasive Species Biomass Testing 2011. February 20.

[8] Clemons and N. Stark, 2007, Use of salt cedar and Utah juniper as fillers in wood-plastic composites: Madison, Wis., U.S. Forest Service, Forest Products Laboratory Research Paper FPL-RP-641, 17 p.

Table 3-2. Proximate and Ultimate Analysis[9]

Fuel	Russian Olive MT		Saltcedar MT		Pine E OR		Douglas Fir OR	
Type	Chips 1/2012		Chips 1/2012		Hog Fuel		Mill Waste	
	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analysis								
Fixed Carbon	14.62	16.30	12.66	14.06	14.03	22.51	6.47	17.48
Volatile Matter	73.81	82.32	74.82	83.06	46.26	74.22	30.38	82.11
Ash	1.24	1.38	2.60	2.88	2.04	3.27	0.15	0.41
Moisture	10.33		9.92		37.67	--	63.00	--
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ultimate Analysis								
Carbon	45.96	51.26	45.50	50.51	33.38	53.56	18.95	51.23
Hydrogen	5.78	6.44	5.53	6.14	4.00	6.42	2.21	5.98
Oxygen	35.57	39.67	35.59	39.51	22.71	36.43	15.66	42.29
Nitrogen	1.03	1.15	0.45	0.50	0.18	0.29	0.02	0.06
Sulfur	0.09	0.1	0.41	0.46	0.02	0.03	0.01	0.03
Ash	1.24	1.38	2.60	2.88	2.04	3.27	0.15	0.41
Moisture	10.33		9.92		37.67	--	63.00	--
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
HHV, Btu/lb	7,471	8,332	7,454	8,275	5,498	8,821	3,248	8,779
Chlorine %	0.005	0.005	0.039	0.043			0.07	0.19

3.4 **Ash**

Ash content in the MRWC samples ranged from 1% oven dry basis (o.d.) for Russian olive to 3.3% for saltcedar.[10] Saltcedar samples contained low levels of ash (2%-3.3% dry basis) which would indicate that the wood came from a clean harvest area or had lost most of its leaves before chipping. These ash levels are low compared with Utah juniper (14% ash) or mesquite (6% ash).[11] They are more similar to pine hog fuel that contains wood and bark. Solid wood in most species contains about 0.5% ash. The bark contains 3% ash. Ash is usually higher in bark because the nutrients concentrate in the cambium layer beneath the bark. Dirt from harvest and wind-blown sand adhere to bark. High ash in saltcedar may also be due to the water soluble extractives contained in the

[9] Salt cedar and Russian olive sampled by MRWC. Pine hog fuel from an Eastern Oregon sawmill and Douglas fir from a western Oregon sawmill sampled by T.R. Miles.

[10] S. Bockness. 2012. Summary of MRWC CIG Invasive Species Biomass Testing 2011. February 20

[11] Utah juniper and mesquite samples from Arizona by T.R. Miles.

wood.[12] These water soluble nutrients volatilize during combustion and can react with each other, or with silica or chlorine, from the fuel.[13] In recent years ratios of these elements have been found to be good indicators of melting or fouling behavior in boilers.[14] Saltcedar would have a higher fouling factor than Russian olive due to the high alkali and sulfur. The ash contains low silica relative to the potassium which would suggest formation of a potassium-silica melt if there were an ash accumulation in a furnace. The potassium is likely to stay in the bottom ash rather than volatilize and deposit in the boiler. Even though Clemons found salt crystals in the wood the concentration of chlorine in the MRWC sample is low so the potential for corrosion from hydrochloric acid or alkali salts formed during combustion should be low.

The Russian olive samples had very low ash contents (1%-2.7% d.b.) and consequently they would have low concentrations of volatile alkali. The boiler fouling potential for Russian olive should be very low. It had a slightly higher concentration of phosphorous and silica than saltcedar but a lower concentration of sodium or potassium. Chlorine levels were very low. Volatile potassium should stay in the bottom ash during combustion. In general Russian olive would appear to be a very clean fuel.

Table 3-4 shows the ash fusion temperatures for both species. In this test the samples are ashed at a low temperature (<600°C, 1112 °F) in a crucible. The ash is formed into cones. The cones are observed while they are heated in reducing – air starved – and oxidizing – excess air – environments to simulate the conditions on the grate of a furnace. The Russian olive has high ash fusion temperatures (>2700°F). Saltcedar had the lowest ash fusion temperatures (2141°F -2185°F) under reducing conditions. Temperatures on the grate in biomass furnaces are often between 1500 °F and 1800°F except when the fuel is very dry or there is a high concentration of charcoal so sintering or melting is not likely to occur.

[12] C. Clemons and N. Stark, 2007, Use of salt cedar and Utah juniper as fillers in wood-plastic composites: Madison, Wis., U.S. Forest Service, Forest Products Laboratory Research Paper FPL-RP-641, 17 p. When investigating the use of salt cedar for a filler in wood-plastic composites Clemons and Stark found that salt cedar had about 9% water soluble extractives at room temperature compared with 3.4 % for pine. They demonstrated substantial reduction of soluble nutrients (S, Ca, Na, K, Mg, P) during water extraction.

[13] T.R. Miles, et. al. 1995. Alkali Deposits Found in Biomass Power Plant: A Preliminary Investigation of Their Extent and Nature. National Renewable Energy Laboratory Subcontract TZ-1-1 1226-1, Golden CO.

[14] P. Sommersacher, T. Brunner, I. Obernberger, 2012. Fuel Indexes: A Novel Method for the Evaluation of Relevant Combustion Properties of New Biomass Fuels. Energy and Fuels, 2012, 26 (1), pp 380–390 DOI: 10.1021/ef201282y

Test burns with saltcedar pellets in stoves showed nothing unusual; however it often takes long term burning for ash related problems to appear, even at the high temperatures (1000^0C, 1832^0F) associated with combustion in pellet stoves.[15]

Table 3-3. Comparison of Ash Properties

Fuel	Russian Olive MT	Saltcedar MT	Pine Hog Fuel E OR	Douglas Fir Mill Waste OR
Elemental Composition				
SiO_2	23.66	7.51	42.59	15.17
Al_2O_3	2.06	1.66	11.23	3.96
TiO_2	0.13	0.08	1.28	0.27
Fe_2O_3	0.96	0.53	9.04	6.58
CaO	19.3	27.2	14.54	11.90
MgO	7.81	6.91	3.28	4.59
Na_2O	1.3	4.46	2.10	23.50
K_2O	6.47	8.47	6.39	7.00
SO_3	2.6	36.1	1.72	2.93
P_2O_5	9.26	3.3	2.00	2.87
SrO			0.06	
BaO			0.12	
MnO			0.34	
CL	0.1	0.31		
CO2	11.7	6.1		18.92
Undetermined	14.65	-2.63	5.31	2.31
TOTAL	100.00	100.00	100.00	100.00
Alkali, Lb./MMBtu	0.13	0.45	0.31	0.14

Table 3-4. Ash Fusion Temperatures

Fuel	Russian Olive MT		Saltcedar MT	
Ash Fusion Temperatures	Reducing ºF	Oxidizing ºF	Reducing ºF	Oxidizing ºF
Initial Temperature	2700	2700	2141	2489
Softening Temperature	2700	2700	2155	2496
Hemispherical Temperature	2700	2700	2170	2499
Fluid Temperature	2700	2700	2185	2505

[15] S. Bockness www.weedcenter.org/MRWC

4.0 Bioenergy Uses

4.1 Boilers

Wood boilers are more expensive to install, own and operate than oil boilers. Fuel savings must pay for the higher costs. The amount of fuel oil replaced depends on the heating value of the fuel and the efficiency of the wood boiler. Table 4-1 shows the amount of fuel oil displaced at typical efficiencies by wood with the heating values in Table 3-1. Boiler conversion efficiency (CE) can be expected to vary from 35% to 70% of the energy in the fuel in wood boilers. Recovered heat is calculated using the equation Recovered Heating Value (RHV) = Gross Heating Value (GHV) x % Conversion Efficiency (CE).[16] A ton of dry (20% MC) saltcedar or Russian olive wood could replace 79 gallons of fuel oil at 70% conversion efficiency. At $4/gallon for fuel oil the value of the wood heat ($316/ton) would be similar to the cost of harvest. Wood must be delivered at half the cost ($156/ton) to replace fuel oil at $4 if it is burned in a low efficiency, outdoor wood boiler.

Table 4-1. Fuel Oil Replacement by Wood

Fuel, boiler	Conversion Efficiency CE	Energy in Fuel HHV Btu	Heat Delivered RHV Btu	Gal Fuel Oil	$/gal, $/ton
Fuel Oil, Btu/gal	85%	138,500	117,300	1	$4.00
[a] Wood chip boiler, 20% MC, Btu/lb, MMBtu/ton, gal/ton	70%	6,600	9,240,000	79	$316
[b] Low efficiency wood boiler, 20% MC, Btu/lb, MMBtu/ton, gal/ton	35%	6,600	4,620,000	39	$156

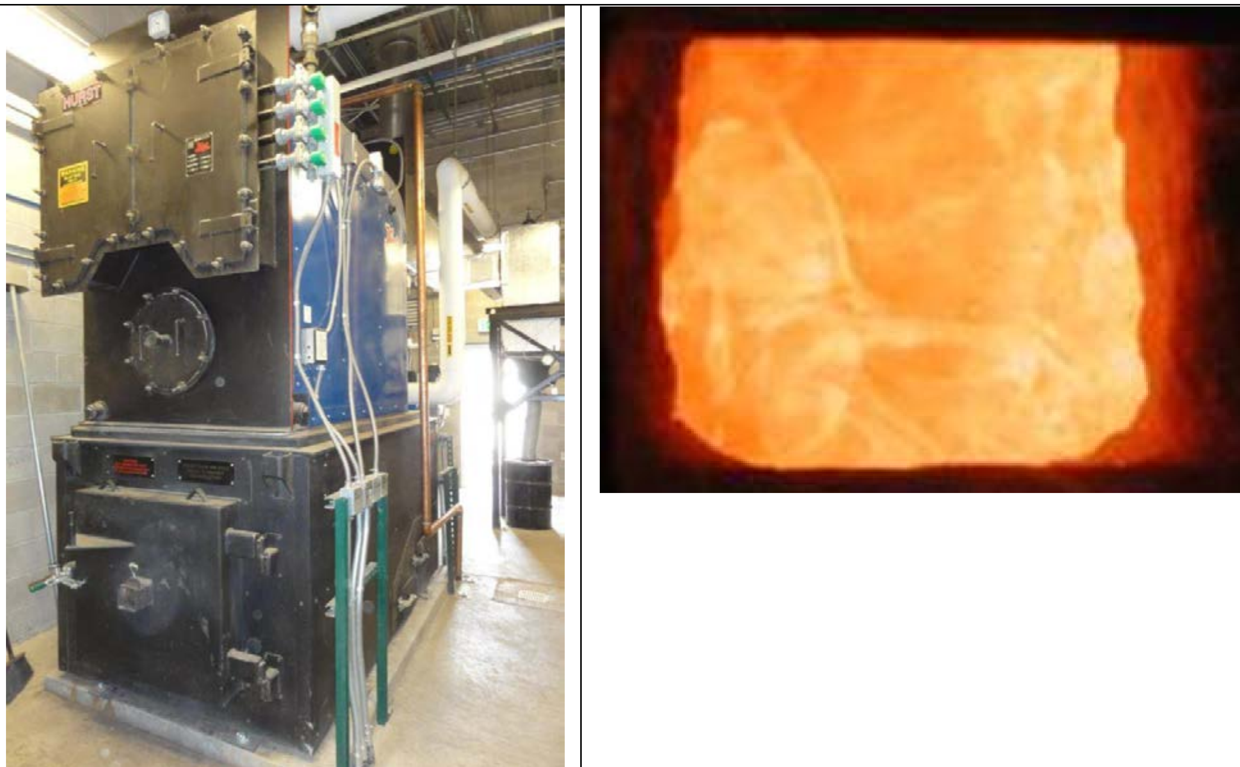
Notes:

[a] Typical conversion efficiency 70%. Recovered Heating Value (RHV) = Gross Heating Value (GHV) x % Conversion Efficiency (CE).

[b] Typical outdoor wood boiler (OWB) efficiency 35% to 40%

[16] Briggs, David, 1994. Forest Products Measurements and Conversion factors: with Special Emphasis on the U.S. Pacific Northwest, University of Washington Institute of Forest Resources, AR-10, Seattle, Washington 98195 Chapter 8.

Figure 4-1. Small Boilers



A. Small Institutional Boiler with typical efficiency of 70%. (Messersmith Mfg.)	B. Combustion in a Small Chip Boiler (Hurst Boiler)

There are many suppliers of small scale wood heating equipment.[17] Some companies that specialize in small scale boilers have developed prefabricated boilers in containers that can be used for schools and small institutions. These boilers can burn wood chips as long as they do not exceed 35% MC wb. These small boilers often supply 500,000 Btu to 3 million Btuh and consume 100-800 tons of fuel per year. At a wood

[17] David Peterson and Scott Haase. 2009. Market Assessment of Biomass Gasification and Combustion Technology for Small- and Medium-Scale Applications. Technical Report NREL/TP-7A2-46190 July 2009, National Renewable Energy Laboratory 1617 Cole Boulevard, Golden, Colorado 80401-3393 www.nrel.gov

recovery rate of 4 tons per acre a single boiler would be supplied from 100 treated acres per year.

Small boilers are often used where fuel oil or propane prices are high (e.g. $2.50/gallon propane or $35/MMBtu). If air dried wood could be delivered and converted in a boiler for $200/ton then a school or small commercial facility would realize a significant savings in fuel costs.

4.2 **Pellets**

Tests conducted by the MRWC have shown that pellets can be made from clean Russian olive and saltcedar.[18] Pellets were made in the small machine shown in Figure 4.2.

Figure 4-2. Pellets

A. MRWC Experimental Pellet Machine

B. Typical Douglas Fir Pellet

While MRWC samples were relatively dry (<8%-10% MC) [19], wood for making pellets must be uniformly less than 8% MC. A dryer would be required to make a fuel product like the pellets shown in Figure 4-2B. Commercial pellet production would require a dryer that is typically sized for 1-6 dry tons per hour.

[18] S. Bockness www.weedcenter.org/MRWC

[19] S. Bockness. 2012. Summary of MRWC CIG Invasive Species Biomass Testing 2011. February 2012.

Standards for residential and commercial densified fuels are shown in Table 4-2. While Russian olive may meet moisture and ash requirements of the Pellet Fuels Institute "Standard" or "Utility" grades it would not qualify for the higher value "Premium" grade that is sold for residential use at $250-$300/ton ($18-$22/MMBtu). Given the potential variability of ash content at harvest it is not likely that even a standard grade pellet could be guaranteed. Beneficiation techniques have been developed to reduce foreign matter from whole tree chips to less than 2%.[20] As yet there are no commercial systems and the extra cost of cleaning may be too high for the intended market. A Russian olive or saltcedar pellet may be suitable for small scale or industrial boilers that can burn fuel with 6% ash fuel. A "Utility" pellet (<6% ash) would sell in bulk for $160-$180/ton ($12-$13/MMBtu).

Table 4-2. Residential/Commercial Densified Fuel Standards

	Residential/Commercial Densified Fuel Standards See Notes 1 - 3		
Fuel Property	PFI Premium	PFI Standard	PFI Utility
Normative Information - Mandatory			
Bulk Density, lb./cubic foot	40.0 - 46.0	38.0 - 46.0	38.0 - 46.0
Diameter, inches	0.230 - 0.285	0.230 - 0.285	0.230 - 0.285
Diameter, mm	5.84 - 7.25	5.84 - 7.25	5.84 - 7.25
Pellet Durability Index	≥ 96.5	≥ 95.0	≥ 95.0
Fines, % (at the mill gate)	≤ 0.50	≤ 1.0	≤ 1.0
Inorganic Ash, %	≤ 1.0	≤ 2.0	≤ 6.0
Length, % greater than 1.50 inches	≤ 1.0	≤ 1.0	≤ 1.0
Moisture, %	≤ 8.0	≤ 10.0	≤ 10.0
Chloride, ppm	≤ 300	≤ 300	≤ 300
Heating Value	NA	NA	NA
Informative Only - Not Mandatory			
Ash Fusion	NA	NA	NA

Source: Pellet Fuels Institute, www.pelletheat.org

[20] Forest Concepts, LLC., 3320 W. Valley Hwy. N., Ste. D110, Auburn, WA 98001 www.forestconcepts.com

A mobile pellet mill was considered in the original plan for the MRWC bioenergy project. Mobile operation does not seem to be a practical conversion method of making a good quality pellet because of the requirements for material handling, sizing, and drying. Modular or prefabricated plants are available at the small scale.[21] A 1,000 lb/hr plant would produce about 500-600 tpy on a single shift and cost $500,000. A 1 tph system would produce about 1,200 tpy on a single shift, or 2,400 tpy on a two shift basis, and cost $1,000,000. A 4-6 tph pellet mill, like the one shown in Figure 4-3, would produce more than 30,000 tons per year and cost about $7 million. Operating costs for pellet mills are from $60-$100/ton not including the cost of packaging and raw materials. Cost for pellets at plants in the Northwest and Mountain regions are $147-175 FOB.[22] Residential pellets retail for $250-$300 ton.[23] If harvest costs are $300/ton and processing costs are $60 to $100/ton, then pellets from invasive species would cost $360-$400/ton FOB. They would not compete with bulk or retail pellets unless harvest costs are offset by funding from other sources.

Figure 4-3. Industrial Pellet Mill

A. Pellet Mill Dryer 4 TPH 30,000 tpy

B. Pellet Mill 4 TPH 400 HP

[21] A typical supplier for small pellet mills is ExFactory www.exfactory.com

[22] March 2012 Market Update, Pellet Fuels Institute Newsletter 2011-2012 Issue #4www.pelletheat.org

[23] Commercial markups are about 35% for wood pellets.

4.3 Torrefied Wood

Torrefaction is a method to prepare fuel for industrial use.[24] It is an industrial process that requires drying and heating biomass to 285^{0}C (545^{0}F) in the absence of air. Moisture is evaporated. Some of the volatile carbon, such as the hemicellulose, is also driven off. About 30% of the volatiles including moisture and carbon are lost, which equal about 10% of the weight of the raw wood. The remaining carbon is partially charred and has a heating content of about 11,000 Btu/lb compared with dry wood at 8,300 Btu/lb. Torrefied wood is reported to be easy to grind and densify. Torrefied pellets could be transported and co-fired in a coal boiler. Production costs have not been validated and a value has not been established for torrefied wood because there are few commercial facilities.

Coal plants consume fuel at the rate of about 11 MMBtu/MWh. A 100 MWe coal plant requires 1100 MMBtuh fuel. If it cofired torrefied wood at 20% it would need 220 million Btuh or 10 tons of torrified pellets per hour at 22 MMBtu/ton. That would require about 90,000 tons of wood from the eradication programs and an investment of $20 million for a plant to make the torrefied wood. Utilities buy fuel on a "burner tip" basis. Coal at $124/ton delivered from Wyoming costs $4-$6/MMBtu. It is not likely that the useful value of the torrefied pellet would be greater than $10/MMBtu or about $220/ton delivered to a coal plant, which is less than the cost to harvest the wood.

Figure 4-4. Torrified Wood Pellets

Source: T.R. Miles. Technical Consultants, Inc.

[24] S. J. Sokhansanj, J. Peng, X.Bi Lim.2010.Optimum Torrefaction and pelletization of biomass feedstock . TCS 2010 Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products, Iowa State University, Ames, Iowa September 21-13, 2010

4.4 Charcoal

Saltcedar has been used to make a good quality lump charcoal in small scale experiments.[25] Table 4-3, Figure 4-5. It has been sold in small quantities in New Mexico for about $0.70/lb ($7/10 lb bag, or $1,400/ton). Lump charcoal technologies are most advanced in Brazil. Current high technology kilns can produce about 1400 tons of charcoal per month from 50,000 tons of wood per year at a plant cost of about $2 million.[26] Afterburners prevent pollution. Markets for lump charcoal would have to be determined. Although the value of lump charcoal is high there are many producers. Much of the lump charcoal in the U.S. is supplied from Mexico.

Table 4-3. Properties of Charcoal

Fuel, boiler	Saltcedar	Mesquite	Ponderosa	Oak Encino
Heating Value Bt/lb	12,674	13,152	13,180	13,633
Fixed Carbon, %	73.17	76.12	70.46	80.83
Volatile Matter	20.76	18.17	26.02	14.28
Ash	2.78	2.97	1.30	2.63
Drying Loss	3.29	2.74	2.22	2.26

Source: www.scizeri-nm.org/ZERI/_PDF/chartfinalmad.pdf

[25] Dykstra, op. cit. and Sustainable Communities Zero Emissions Research & Initiatives, New Mexico http://www.scizeri-nm.org/ZERI/_PDF/chartfinalmad.pdf

[26] R. Miranda, A. Pimental. T. Miles, 2011. Review of Power Cogeneration Technologies for Charcoaling and their Potential Application in Sub-Saharan Africa. Report to the World Bank. May.

Figure 4-5. Saltcedar Lump Charcoal

A. Kiln charred saltcedar. (Sustainable Communities/ZERI, New Mexico)

B. Bagged charcoal for sale. (www.scizeri-nm.org/ZERI/charcoal.asp)

4.5 **Biochar**

Forest residues and chips from eradication programs can be converted to bulk charcoal in pyrolysis kilns to produce biochar. Biochar is defined by the International Biochar Initiative as solid material obtained from the carbonization of biomass. It is "1) added to soils with the intention to improve soil functions; and 2) produced in order to reduce emissions from biomass (that would otherwise naturally degrade to greenhouse gases) by converting a portion of that biomass into a stable carbon fraction that has carbon sequestration value."[27]

During pyrolysis biomass is heated in a retort to 400^{0}C-600^{0}C (752^{0}F-1112^{0}F).[28] Heat is applied externally in the absence of air, like in torrefaction, so that the carbon does not ignite. Low temperature pyrolysis is suited to wood like saltcedar because the nitrogen, sulfur or extractive components will be largely retained in the charcoal and will eventually be made available to plants through the action of micro-organisms that inhabit the charcoal when it is placed in the soil. Bark, leaves, sand, or clay that is picked up during harvest will just add nutrients to the biochar.

[27] International Biochar Institute www.biochar-international.org

[28] M. Garcia Perez, 2011. Methods for Producing Biochar and Advanced Biofuels in Washington State. Washington Department of Ecology Publication Number 11-01-017.

The technology of using charcoal in soils with low carbon content has existed since 1000 BCE but the current use of biochar in soil is recent and markets and applications are just now emerging. Standards for production and best practices for use are being developed. Biochar markets can be identified in agricultural crop production, horticultural crop production, turf management, and stormwater and erosion control. Biochar has been demonstrated as a suitable substitute for vermiculite in specialty horticultural crops. Current values for biochar range from $0.10/lb, or $200/ton, for agricultural uses to $1.00/lb, or $2,000/ton, for green roof and stormwater applications. The average sale is for about $0.40/lb or $800/ton.

Current use is limited by production. There are several small scale and pilot systems producing as little as one half ton per day or 125 tons per year. There are no large scale production facilities. There have been some small mobile demonstrations for production of biochar and bio-oil.[29] [30] Small plants are in commercial operation in Colorado and Idaho.[31] These systems have limited production but may be suitable for a small eradication program.

If the cost to carbonize wood from the eradication program is $60/ton then at 4 tons per acre the marginal cost of carbonization would be $240/acre. Approximately 1.2 tons of biochar could be produced from 4 tons of wood that could be used as amendment to improve the fertility of low carbon, or poor quality, soils and to sequester carbon. If the cost of eradication is added at $1200/acre then the total cost of eradication, soil improvement and carbon sequestration would be $1,440/acre. Table 4-4.

[29] D. Dumroese et. al. 2010. Can portable pyrolysis units make biomass utilization affordable while using bio-char to enhance soil productivity and sequester carbon? www.treesearch.fs.fed.us/pubs/37322

[30] Biochar Products, Halfway, OR www.biocharproducts.com

[31] Biochar Solutions, Carbondale, CO. www.biocharsolutions.com

Table 4-4. Cost of Treatment Including Biochar

Cost of Treatment	**$/ton**	**Tons/acre**	**$/acre**
Wood	$300	4	$1200
Carbonization	$60	4	$240
Total cost	$360		$1440
Biochar	$1200	1.2	$1440
$/ton **$CO_2$** [32]	$480	3	$1440

If biochar is produced for sale the total cost would be $1,200/ton or $0.60/lb ($1,440/1.2 ton biochar/acre) which is probably higher than the value of most applications. Carbonization of 4 tons of wood will produce approximately 20 MMBtu. If the char is valued at $0.40/lb and the heat was used in a boiler or greenhouse furnace the heat would cost about $24/MMBtu.[33] Combined heat and biochar could obtain savings when fuel oil is $4/gallon (or propane is $2.50/gal) and there are suitable markets for the char. Figure 4-6.

[32] Assume 2.5 tons of CO2 sequestered by 1 ton of biochar.

[33] Total cost $1,440/acre less biochar value of $960 ($0.40 x 1.2 tons/acre) = $480/acre/20 MMBtu= $24/MMBtu.

Figure 4-6. Biochar

A. Biochar furnace (right) converts wood to biochar and heat for a greenhouse heater (left). Est. value $35/MMBtu
(Whitfield Biochar Furnace)

B. Biochar replaces vermiculite (left) in growing media for tree seedlings. Est. value $800/ton
(Calforest Nurseries)

5.0 Conclusions and Recommendations

Bioenergy solutions for the eradication of saltcedar and Russian olive are likely dependent on the cost of production, the logistics of supply, and the value of markets rather than on their physical or chemical characteristics.

The potential to supply small heating boilers should be investigated. A tree service chipper might be sufficient to supply enough fuel for a small boiler to replace fuel oil or propane.

Wood from Russian olive or saltcedar is not likely to be competitive as a pellet fuel unless as is reduced and production costs are offset by funding from other sources.

Since large boilers rarely burn a single fuel these relatively clean fuels could be combined with other biomass or coal but the delivered cost of wood must be acceptable to the utility. If there is an opportunity to burn wood from an eradication program in a nearby boiler, then wood from saltcedar and Russian olive should be test burned for extended periods in large quantities. The large scale and high processing costs of torrefaction are not likely to make it a competitive process for saltcedar and Russian olive.

The potential to carbonize these fuels for use as a soil amendment should be investigated. Carbonization offers a means of improving poor quality soils and sequestering carbon. If suitable markets can be found for biochar and heat then combined heat and biochar could potentially recover the costs of treatment and provide heat savings.

Appendix A. List of Abbreviations and Acronyms

BDT Bone Dry Ton
BTU British Thermal Unit (MBtu, thousand Btu ; MMBtu, million Btu)
CE Conversion Efficiency (fuel to heat)
CHP Combined Heat and Power
Cord 80 ft3 of solid wood
DB Dry Basis (wet weight –dry weight/dry weight)
EMC Equilibrium moisture content
FOB Purchased at seller's premises. Buyer pays shipping costs
GHV Gross Heating Value (also Higher Heating Value)
Gpy Gallons per year
HHV Higher Heating Value
KBtu Thousand Btu
KWe Kilowatts, electric
KWt Kilowatts, thermal
MC Moisture Content (e.g. MC20 20 % moisture)
MMBtu Million Btu
MRWC Missouri River Watershed Coalition
MWe Megawatts per hour electrical capacity
MWh Megawatt hour, 1000 kilowatt hours
NHV Net Heating Value
OD Oven Dry (weight)
ODT Oven Dry Ton
O&M Operating and Maintenance
OWB Outdoor Wood Boiler
PV Present Value
RHV Recovered Heating Value
Therm Heating unit for natural gas = 100,000 Btu
Unit A shipping volume of 200 ft3
USFS United States Forest Service
WB Wet basis (wet weight-dry weight/wet weight)