ESTIMATING THE POTENTIAL ENERGY YIELD FROM THE USE OF WOODY INVASIVE SPECIES AS FEEDSTOCKS FOR BIOMASS GASIFICATION IN SOUTHEAST MICHIGAN

by

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Abstract

Small-scale biomass gasification presents a promising opportunity for distributed renewable energy generation, particularly in rural areas. The use of woody invasive plant species as feedstocks facilitates this generation without the reliance on dedicated energy crops or agricultural residues from monocultures, particularly in Michigan. Further, an opportunity is created to manage the ecological harm caused by woody invasive plant species while simultaneously co-producing biochar, which has the potential to sequester carbon and act as a soil amendment. The potential electrical energy yield from gasification must be understood and contextualized both with respect to the scale of impact, and a cost-benefit analysis. In this work, honeysuckle and buckthorn collected in southeast Michigan were used as separate feedstocks for biomass gasification. They were used in a small-scale Imbert gasifier and separate trials captured the percent composition of the produced syngas. The LHV for syngas produced using honeysuckle was found to be 6.6 ± 2.4 MJ/kg and 6.0 ± 1.8 MJ/kg for syngas produced using buckthorn. The gasification efficiency for the conversion of dry honeysuckle to syngas was 56 ± 23 % and 51 ± 18 % for the conversion of dry buckthorn to syngas. Finally, given assumptions about the amount of these species available in Michigan, a potential 0.34 – 0.37 TWh of energy could be yielded from honeysuckle or buckthorn respectively, enough to supply electricity to over 6,500 homes in the state for a year.

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1. Introduction

Invasive species can pose threats to ecosystems, by displacing the habitat of native species and decreasing localized biodiversity. Economically, it has been estimated that invasive species in the United States cause up to $120 billion annually in environmental damages [1]. Invasive plants can especially trigger widespread habitat change, given their ability to grow across vast areas, and that plants can comprise the habitat of entire ecological communities [2]. Within the state of Michigan, the Departments of Natural Resources, Environmental Quality, and Agriculture and Rural Development provide up to $3.6 million annually through the Michigan Invasive Species Grant Program [3]. These grants are provided to projects which aim to prevent and control the spread of invasive species within the state [4]. Two woody invasive plant species found in Michigan, honeysuckle[1], and buckthorn[2], are the focus of this work.

These two species, given their availability and regular removal from the grounds of the University of Michigan Matthaei Botanical Gardens (MBG) were selected as feedstock candidates for biomass gasification. Honeysuckle and buckthorn are also widely found across the state of Michigan. Distribution maps created by the Midwest Invasive Species Information Network (MISIN) show a combined 1,096 reported observations of amur and tatarian honeysuckle in Michigan since 2000, and the species have been observed in 29 and 64 of Michigan’s 83 counties respectively, according to data from the University of Georgia Center for Invasive Species and Ecosystem Health [5,6]. These data show that amur honeysuckle has been observed particularly in the southeast region of Michigan, while tatarian honeysuckle has been observed uniformly across all regions. MISIN data show over 9,000 combined reported observations of common and glossy buckthorn across the state since 1981. The University of Georgia Center for Invasive Species and Ecosystem Health records show common buckthorn has been observed in 54 of Michigan’s 83 counties, while glossy buckthorn has been observed in 57. Additionally, both species have been observed particularly in the Upper Peninsula and southeast portion of the Lower Peninsula.

Both honeysuckle and buckthorn are woody biomass species, a category of feedstock that has been researched and is commonly used for biomass gasification [7]. Gasification also co-produces biochar, which the larger research group for which this work is a part of is interested in for its ability to sequester carbon and potential to create a circular economy within rural agricultural communities. Therefore, gasification was motivated to be the target technology of this work.

More generally, biomass gasification provides flexibility as a means of electricity generation, given the variety of feedstock options it can accommodate. Factors related to the choice of feedstock such as moisture content or volatile compound content can impact the resulting energy potential [8,9]. Previous analyses on the performance metrics of gasifiers and the resulting syngas composition have been done using feedstocks such as coconut shells, rice husks, coffee husks, corn straw, and various woody biomass species [9,10,11,12]. Some exploration has been done to understand the bioenergy potential or gasification performance of using invasive species as a feedstock on small scales, but little of this work has been in the context of the midwestern U.S. [13,14,15,16]

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[1] For this work, “honeysuckle” is assumed to include only amur honeysuckle (*Lonicera maackii*) and tatarian honeysuckle (*Lonicera tatarica*).

[2] For this work, “buckthorn” is assumed to include only common buckthorn (*Rhamnus cathartica L.*) and glossy buckthorn (*Frangula alnus*).

Electricity generated from biomass holds the advantage of being a near-dispatchable source of baseload electricity, in contrast to the intermittency of other renewables like solar and wind. In the United States, only 1.4% of utility-scale electricity in 2019 was generated from biomass, 1.0% specifically from wood [17]. Modeling of a high penetration renewable electricity future for the U.S. has shown feedstock availability and cost to be major drivers in the deployment of electricity generation from biomass [18]. In 2018, wood solids - primarily from forestry, lumber, and paper industries - were the largest source of feedstock used in biomass electricity generation in the U.S. This feedstock, along with municipal solid waste and landfill gas, accounted for more than 94% of electricity generated from biomass in that year [19]. Dedicated energy crops and agricultural residues remain as options for increasing feedstock availability, particularly for biomass electricity generation technologies which utilize dry feedstock, such as gasification.

Dedicated energy crops and agricultural residues are abundant in the midwestern portion of the U.S. However, competition for land use is a common criticism against the widespread use of dedicated energy crops. In exploration of the potential of agricultural residues within Michigan specifically, 7,220,000 metric tons of sustainably removed agricultural residues were assessed to be available for bioenergy production in 2030 [20]. The same research indicates that these residues would predominantly be sourced from corn and wheat crops. Corn and wheat are both current monoculture crops, and given their consistent subsidies in the farm bill, drastic policy changes would be required for their production practices to shift to more sustainable methods on a state or national level [21]. This obstacle, coupled with the lack of deployment of advanced gasification technologies in the U.S., results in a need to understand the potential for electricity generation via biomass gasification on a decentralized scale, utilizing alternative sources of feedstock.

Furthermore, the state of Michigan has recently committed to the statewide goal of transitioning to carbon neutrality by 2050 [22]. Achieving this goal from an energy standpoint will require an array of solutions targeted to the resources available in the state. Rather than eliminating sources of invasive species through prescribed burns or allowing piles of manually cut branches to decompose, this work aims to understand the potential energetic value that these sources of plant residue can provide, via utilization as feedstocks for a small-scale Imbert gasifier. Specifically, this work seeks to calculate the potential electrical energy yield as well as the efficiency of the gasifier used to produce the syngas and contextualize the energy potential with respect to the scale of impact.

2. Methods

2.1 Gasifier Construction

For this work, a downdraft Imbert gasifier run on a batch system was constructed following detailed instructions in an educational guide meant for readers to replicate and operate the technology on their own properties [23]. This gasifier was built by the authors as part of their energy technology demonstration work. The dimensions of the gasifier were approximately 48” long by 36” wide and 65” tall. The final built design is shown below in Figure 1.

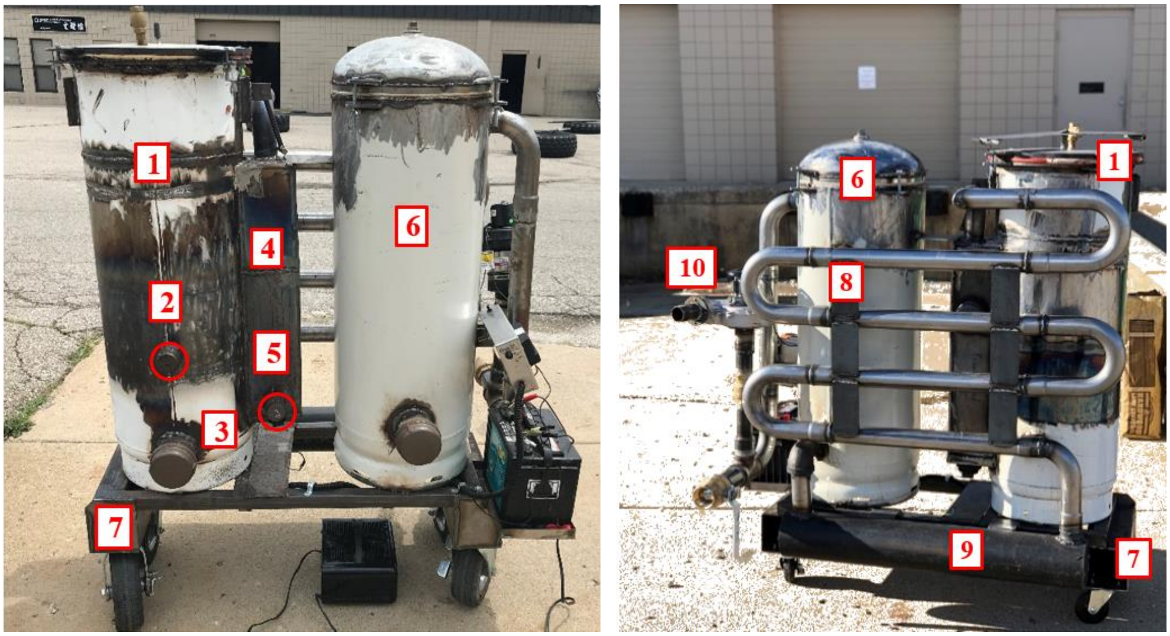

Fig. 1. The front (left) and back (right) of the Imbert gasifier constructed for this work. Components are labeled as follows: (1) Reactor tank (2) Ignition port (3) Biochar collection port (4) Heat exchanger (5) Air inlet (6) Filter tank (7) Skid (8) Cooling tubes (9) Condensate collection tank (10) Outlet pipe

For this design, air acts as the gasifying medium. Within the reactor tank is a hearth, where air is injected from the inlet across a layer of charcoal through jets. The hearth was sized according to the build guide instructions so that the gasifier could operate alongside a generator with a 1,000 cc engine displacement [23]. The design of the gasifier was validated after successful pre-experimental trials produced flammable syngas using pelletized hardwood as a feedstock. A blower was connected to the gasifier between the outlet of the filter tank and the outlet pipe. A ball valve below the blower allowed for the passage of syngas to the blower to be controlled. A motor was attached to the underside of the skid, which was connected to a grate just above the biochar collection port inside the reactor tank. Also attached to the skid was a 12 V deep cycle battery connected to a control box with electronics that supplied power from the battery to the blower and grate motor. The blower ran constantly to allow the syngas to flow through the gasifier, and the motor shook the grate every two minutes to allow biochar particles to fall into the collection port and avoid feedstock bridging. At the top of the filter tank three round, foam particulate filters were stacked each approximately 1” thick with decreasing pore size from bottom to top. The rest of the tank was filled with straw as a medium for removing tar and particulates from the syngas.

2.2 Feedstock Collection and Preparation

Both honeysuckle and buckthorn branches for this work were collected from the MBG, part of the University of Michigan in Ann Arbor, Michigan. Staff at MBG are constantly implementing a plan throughout the year to remove invasive species from the grounds. Removal of honeysuckle and buckthorn is a labor-intensive process which consists of cutting and stacking the branches into piles. These piles are then put through a chipper, so the chips can be used as mulch. Staff then return to the area where the branches were removed and spray a 50% glyphosate solution on the stumps to kill them and/or prevent them from resprouting [24]. For this work, honeysuckle and buckthorn branches were collected from piles that had not yet been chipped and were cut into circular disks using a circular saw, making sure to store in containers separated by species. The disks were approximately 1”- 2” in length, and 1” – 3” in diameter, which can be seen in Figure 2. All feedstock was stored in a dry hoop house, so as not to retain moisture.

Fig. 2. Samples of dry, cut honeysuckle (left) and buckthorn (right) used as feedstock for gasification trials.

2.3 Gasification Trial Setup

Operation of the gasifier was done following a standard operating procedure written after validating the design through pre-experimental trials (see supporting information). The gasifier was placed outdoors on a flat surface for each experiment. Before experimental trials began, the filter candle within the gasifier was filled with fresh straw, and the foam particulate filters were washed out with water, and then dried. If more than 50% of the straw filter was covered in tar or particulates before the beginning of any experimental trial, the filter was replaced with fresh straw.

Because the feedstock was stored in a dry hoop house and kept away from rain, the moisture content of the wood remained below 25%. For each trial, the moisture content was verified to be below 25% through moisture measurements taken on 10 pieces of feedstock, chosen at random. Using a handheld pin-type moisture meter, measurements were taken from both the outside, and in the center of the cut face of each piece of feedstock.

The reactor tank of the gasifier was filled with charcoal – either created during the previous trial or topped off with lump, hardwood charcoal – up to 10.5” from the top of the tank for each trial. The dry feedstock was then placed into a bucket and the mass calculated with a handheld scale before being recorded and then poured on top of the charcoal in the gasifier reactor tank. The top of the reactor tank was then sealed.

2.4 Gas Analysis

To capture the composition of the produced syngas from the gasifier, a PGA 3510 Portable Multi-Gas IR Analyzer from Super Systems, Inc. was used. The analyzer records the percentages by mass of CO, CO_2, CH_4, O_2, and H_2 in the syngas. The remaining mass percentage of the syngas was assumed to be composed of N_2. Figure 3 illustrates the different components of the analyzer.

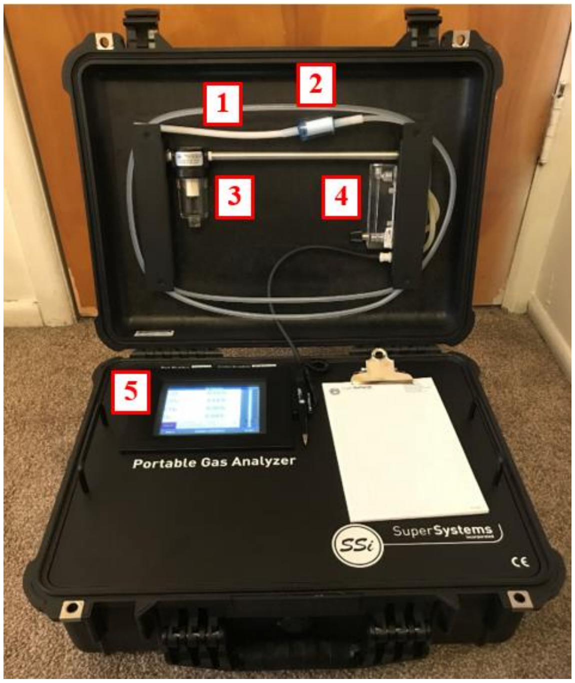

Fig. 3. The gas analyzer used to record the percent composition of the syngas produced from honeysuckle and buckthorn. Components are labeled as follows: (1) Inlet tube (2) In-line particulate filter (3) Bowl filter (4) Flow scope (5) Touch-screen display

The analyzer was calibrated weekly, as recommended by the manufacturer [25]. First, the analyzer was calibrated using a span gas with a composition shown in Table 1.

Table 1. Composition of the span gas used to calibrate the gas analyzer

Component	Percent Composition (by mass)
CO_2	9.99 %
CH_4	4.99 %
CO	10.01 %
H_2	15.05 %
N_2	Balance (59.96 %)

After completion of a span calibration, the analyzer was then zero calibrated in ambient air with the use of a CO_2 scrubber.

The produced syngas exiting from the outlet pipe of the gasifier was tested for flammability using a butane torch. Flammability indicates that the gas could be used as fuel in a generator. Once flammable, the flame was extinguished by closing and then immediately re-opening the ball valve to the gasifier outlet pipe (directly below the blower). The inlet tube of the gas analyzer was then placed into the outlet pipe of the gasifier to a depth of 5” - 6”, as shown in Figure 4.

Fig. 4. Set up for collecting data on the composition of the produced syngas.

Three trials were run for each species of feedstock. A clean in-line particulate filter was placed on the gas analyzer for each trial. Once the analyzer was placed inside the gasifier outlet, and composition readings appeared to reach an equilibrium, gas composition data was collected for 10 consecutive minutes with the analyzer pump turned on and kept within the range for proper operation, as specified by the manufacturer. The analyzer was then removed from the gasifier for 20 minutes, with the pump remaining on until the analyzer readings returned to ambient levels. Most gas analysis trials lasted approximately three hours, at which point the gasifier was shut down.

Due to operational realities with a laboratory-constructed gasifier, some data collection periods lasted longer than others. The gasifier battery would drain during experiments, and occasionally impact the power running to the blower, which would then change speed and cause changes in the syngas composition, causing it to lose flammability. Data collection would then not resume until the battery was recharged and the syngas was shown to be flammable. Generally, each experiment was limited to the hours of operation of the makerspace where the gasifier was run and stored. Factors such as this, in addition to weather (given the experiments were run outdoors) and technical difficulties were adjusted to, resulting in some variations in experimental length and data collection time. Data collected during times when the syngas was not combustible were disregarded. 148 data points were collected for the composition of the syngas produced from each feedstock.

2.5 Lower Heating Value Calculations

The lower heating value of the syngas produced from both honeysuckle and buckthorn was calculated using Equation 1.

Eqn. 1. $LHV_{syngas} = (y_{CO} * LHV_{CO}) + (y_{H_2} * LHV_{H_2}) + (y_{CH_4} * LHV_{CH_4})$

$$y_i = \frac{m_i}{m_{syngas}}$$

Only the portions of the syngas that can be used as a fuel source for a generator were included, where y_i is the percent mass of any of the fuel components of the syngas. The percent mass of each gas species for syngas from a given feedstock was averaged across all data collected from trials run with that feedstock. The lower heating values of CO, H_2, and CH_4 used in these calculations were 10,100 kJ/kg, 119,950 kJ/kg, and 50,020 kJ/kg respectively [26,27].

The lower heating value is reported per unit of mass because the gas analyzer records percent mass compositions of the syngas. However, other literature reports lower heating values per unit of volume. To compare the resulting lower heating values of this work with the work of others, the lower heating values were converted to a unit of volume basis by first assuming that the gas components are approximated as ideal gases. Therefore, the molar volume of the components can be calculated by Equation 2.

$$\textbf{Eqn. 2. } V_m = \frac{RT}{P}$$

The average recorded temperature of the syngas at the outlet pipe was 50.50 ± 0.50 °C. The pressure of the gas at the outlet pipe was 1 atm. Knowing the molar volume, the lower heating value of the syngas components can be converted to a volume basis through Equation 3.

$$\textbf{Eqn. 3. } LHV_i \left[\frac{MJ}{m^3}\right] = (LHV_i \left[\frac{MJ}{kg}\right])(M_i)(\frac{1}{V_m})$$

M_i represents the molar mass of the i^{th} component of the syngas.

2.6 Gasifier Efficiency Calculations

The efficiency of the gasifier was calculated using Equation 4.

$$\textbf{Eqn. 4. } \eta_{gasifier} = \frac{E_{syngas}}{E_{feedstock}} = \frac{LHV_{syngas}*(mass_{syngas})}{LHV_{feedstock}*(mass_{feedstock})} = \frac{LHV_{syngas}}{LHV_{feedstock}} * GR$$

An ultimate analysis on the two feedstocks used in this work was not done, so the lower heating value of both species is assumed to be 18.03 MJ/kg (dry basis). This value corresponds to the lower heating value found for silver wattle (*Acacia dealbata*), another woody invasive shrub [28]. The heating value assumed is also similar to values found for other woody crops and forest residues [29].

In Equation 4, GR is the gasification ratio, or the ratio of the mass of syngas to the mass of feedstock. The necessary equipment for capturing and measuring the mass of the produced syngas was not available for this work. Therefore, a gasification ratio of 1.53 ± 0.28 $\frac{kg_{syngas}}{kg_{feedstock}}$ is assumed, which is the average gasification ratio for a downdraft type gasifier calculated between using wood chips and pellets as feedstock [30].

2.7 Syngas Energy Content Calculations

The energy content in kWh of the produced syngas from a given feedstock for one trial was calculated using Equation 5.

$$\textbf{Eqn. 5. } E_{syngas} = \frac{(LHV_{feedstock}*m_{feedstock})}{\eta_{gasifier}} * \frac{1\ kWh}{3600\ kJ}$$

The average mass of feedstock used in a gasification trial with honeysuckle was 17.1 ± 1.9 lbs. (7.8 ± 0.9 kg), and 15.0 ± 6.4 lbs. (6.8 ± 2.9 kg) for a trial run with buckthorn.

3. Results

The average composition of the syngas produced both from honeysuckle and buckthorn is reported in Table 2.

Table 2. Percent composition by mass of syngas produced using both feedstocks

	Honeysuckle Syngas	Buckthorn Syngas
CO:	7.83 ± 1.41 %	7.32 ± 1.57 %
CO_2:	9.85 ± 0.73 %	9.39 ± 1.05 %
CH_4:	1.25 ± 1.20 %	0.67 ± 0.58 %
O_2:	8.31 ± 1.00 %	8.13 ± 1.40 %
H_2:	4.35 ± 1.93 %	4.11 ± 1.46 %
N_2:	68.41 ± 2.94 %	70.37 ± 2.83 %

Syngas produced from both feedstocks were found to be predominantly composed of N_2, followed by CO_2, and O_2. The useable fuel content of the honeysuckle syngas sums to 13.43% by mass, and 12.10% by mass of the buckthorn syngas. Some values, particularly measurements for the percent composition of CH_4, show large uncertainty. This uncertainty indicates the need for future trials to be conducted to add to the sample size and increase the precision of the measurements. The percent composition by mass values were converted to mole fractions, which under the assumption of the ideal gas law are equal to volume fractions. The volume fractions of the syngas components produced from honeysuckle and buckthorn are reported alongside literature values from the gasification of woody biomass species for comparison in Table 3.

Table 3. Percent composition by volume of syngas produced using both feedstocks compared to values from other work on the gasification of woody biomass species.

	Honeysuckle Syngas	Buckthorn Syngas	Biomass Producer Gas [31]	Pine/Mixed Hardwood Chips Syngas [32]	Pelletized Pine Syngas[3] [33]
CO:	5.13 ± 1.82 %	4.91 ± 2.96 %	22.10 %	20.00 %	16.57 %
CO_2:	4.11 ± 1.29 %	4.01 ± 2.30 %	10.20 %	1.20 %	13.37 %
CH_4:	1.43 ± 1.44 %	0.78 ± 0.81 %	1.70 %	3.00 %	2.70 %
O_2:	4.77 ± 1.57 %	4.77 ± 2.81 %	-	-	0.50 %
H_2:	39.7 ± 21.4 %	38.3 ± 25.5 %	15.20 %	19.00 %	12.30 %
N_2:	44.9 ± 13.9 %	47.2 ± 26.7 %	50.80 %	-	53.42 %

The lower heating value of each fuel component of the syngas is reported in Table 4, along with the overall lower heating value of the syngas.

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[3] Syngas also reported to contain 1.15 mol % (assumed to equal vol % under the ideal gas law) higher hydrocarbons on a dry basis.

Table 4. Lower heating values of the fuel components for each syngas as well as overall weighted heating value.

	LHV_{CO} *[MJ/kg]*	LHV_{CH_4} *[MJ/kg]*	LHV_{H_2} *[MJ/kg]*	LHV_{syngas} *[MJ/kg]*	LHV_{syngas} *[kWh/kg]*
Honeysuckle Syngas	0.79 ± 0.14	0.62 ± 0.60	5.2 ± 2.3	6.6 ± 2.4	1.84 ± 0.66
Buckthorn Syngas	0.74 ± 0.16	0.34 ± 0.29	4.9 ± 1.7	6.0 ± 1.8	1.67 ± 0.49

Both feedstocks produced a syngas with a similar lower heating value. These lower heating values were converted to a volume basis and are reported alongside literature values from the gasification of woody biomass for comparison in Table 5. Also reported for comparison is the lower heating value of natural gas, which in 2019 fueled 30% of Michigan’s electricity generation [34].

Table 5. Lower heating values for each syngas compared to those found in literature for the gasification of woody biomass.

	Honeysuckle Syngas	Buckthorn Syngas	Pine/Mixed Hardwood Chips Syngas [32]	Biomass Product Gas [35]	Woody Biomass Syngas [36]	Natural Gas [37]
LHV [MJ/Nm³]	4.59 ± 1.66	4.25 ± 1.26	6.00	4.00 – 7.00	3.80	32 - 38

Using Eqn. 4, the efficiency of the gasifier in converting the chemical energy embodied within the feedstock to chemical energy embodied within the syngas was found to be 56.3 ± 22.7 % for the gasification of honeysuckle, and 51.0 ± 17.7 % for the gasification of buckthorn. These values are compared to literature results for the efficiency of a downdraft type gasifier in Table 6.

Table 6. Efficiency values for the gasification of each feedstock compared to those found in literature for the gasification of woody biomass/agricultural residues in a downdraft type gasifier.

	Honeysuckle	Buckthorn	Woodchips/ Pellets [30]	Woody Biomass [38]	Corn Cobs [39]
Gasification Efficiency [%]	56.3 ± 22.7	51.0 ± 17.7	68.8 ± 8.29	69.0 – 72.0	66.0 – 68.0

Given the efficiency of the gasifier, the energy content of the produced syngas can be calculated using Eqn. 5. For one gasification trial of honeysuckle, the energy content of the syngas is 21.94 ± 9.19 kWh and 17.38 ± 9.60 kWh in the produced syngas from one gasification trial of buckthorn.

4. Discussion

Buckthorn and honeysuckle are often found growing together in an ecological community; land managers often view their presence as a single problem to be treated [40]. Given this growth pattern, and the similarity in resulting lower heating value of the two species, both could be treated as a single source of available feedstock for biomass gasification. Using both species as feedstock simultaneously would not drastically alter the composition of the produced syngas, allowing for increased flexibility with a source of energy generation. Additionally, the resulting fuel would have a consistent lower heating value, avoiding disruptions in the amount of electricity that the fuel could generate.

Compared to the findings of other work, the syngas produced from honeysuckle and buckthorn contained a higher percentage by volume of the three combined fuel components. However, when broken down by individual species composition, the syngas produced in this work contained smaller percentages by volume of CO, and a larger percentage by volume of H_2. A higher percentage by volume of H_2 could be attributed to the moisture content of the feedstock, which would produce H_2 from water vapor in the reduction stage of the reactor. Future study is needed to understand the relationship between feedstock moisture content and the resulting syngas composition, or to identify other sources of H_2 production.

Ultimately, the resulting lower heating value of the syngas produced from buckthorn and honeysuckle is within range of similar values found from the gasification of other woody biomass species. Future trials should be run to increase the precision of the gas composition and outlet temperature measurements, and other experimental parameters should be tested to understand their impact on the resulting lower heating value of syngas produced from these two invasive species. A method for capturing the mass of the produced syngas should be incorporated into the experimental design, to validate the assumed gasification ratio.

When compared to natural gas, the syngas produced from honeysuckle and buckthorn in this work has a much smaller lower heating value. The dependence on natural gas as an electricity generation source in Michigan stems from a low cost, high heat content, and need for a baseload source of electricity in a state where the climate necessitates both heating and cooling of buildings. As the state seeks to achieve carbon neutrality in the coming decades, it will need to balance the demand for a reliable baseload source of electricity with relying on a portfolio of fuel sources that are less environmentally detrimental. On a smaller scale, biomass gasification could be utilized by an individual or community rather than natural gas, which would offset emissions from avoiding the use of electricity from the grid. In a complete life cycle assessment comparing the emissions from generating electricity via the gasification of invasive species to the emissions from generating electricity from the Michigan grid, the emissions associated with constructing the gasifier, spraying glyphosate on the cut shrub stumps, and carbon sequestered within the produced biochar would need to be accounted for.

The geographical spread of honeysuckle and buckthorn makes them advantageous for use as feedstocks for biomass gasification. The widespread distribution of these species implies that they would not need to be transported a large distance from harvest site to gasification site. The economics associated with the transportation distance of feedstock has been shown to be factor in the adoption of this technology [41]. To understand the potential energy yield at a state-wide level from gasifying these species, future work is necessary to quantify the total harvestable biomass of honeysuckle and buckthorn in Michigan. Reported observations of these species in the state are not always accompanied by an exact area or aboveground biomass value. At a local scale, the MBG has a web mapping application which lists area measurements for boundaries of invasive shrub management, but these are not broken down by species type. Additionally, tonnage of invasives removed on the property is not tracked [42]. For the purposes of this work, an estimate of the total amount of honeysuckle and buckthorn available in Michigan was assumed to be equal to the amount of biomass from one growing season for three invasive species across all Great Lakes coastal wetlands. Carson et al quantified this value to be 659,454 metric tons of invasives [43]. This amount of biomass has the potential to yield a syngas with an energy content of 1.86 TWh, assuming the biomass was entirely honeysuckle, or 1.68 TWh, assuming the biomass was entirely buckthorn. With an assumed generator efficiency of 20%, the resulting total delivered electrical energy is estimated to be 0.37 TWh, again assuming the biomass was entirely honeysuckle, and 0.34 TWh assuming the biomass was entirely buckthorn [30]. Given that the 2018 annual energy consumption for the Michigan residential sector was 788 trillion Btu (2.31×10^{11} kWh) and that there are 4.53 million housing units in the state, the total delivered electrical energy from the gasification of these two invasive species is enough to meet the demand for 6,600 – 7,300 homes, assuming the entire available biomass was comprised of all buckthorn or all honeysuckle, respectively [44,45].

This work has explored how communities in Michigan would be able to use honeysuckle and buckthorn as locally sourced feedstocks for biomass gasification, enabling a decreased dependency on a state electricity grid that currently heavily utilizes fossil fuels. Furthermore, the choice of feedstock would provide a productive use for species that are otherwise ecologically damaging, creating a circular economy opportunity.

5. Conclusions

The use of invasive species such as honeysuckle and buckthorn as feedstocks for biomass gasification provides the opportunity to transform woody residues that are already being removed from ecosystems into renewable energy, as opposed to being combusted or composted into the open air, which generates some greenhouse gas emissions. The syngas produced from the gasification of these species was comprised by mass mostly of non-fuel components such as N_2, CO_2, and O_2. On a mass basis, the syngas produced from honeysuckle was found to have a slightly higher percent composition of fuel components, as well as a higher lower heating value than the syngas produced from buckthorn. The lower heating values of both syngases on a volume basis were within the range of similar values found from literature. Lastly, the gasification efficiency was found to be lower than values found in other studies on the gasification of woody biomass.

Constraints associated with the COVID-19 pandemic and level of accuracy of equipment used did impact the accuracy and completeness of this work. Time was a factor in coordinating the calculation of the lower heating value of the specific feedstocks used for this work, and so an estimate from literature was used. Additionally, specific moisture content results of the feedstock are not reported because of the lower bound of moisture content that the meter is able to report. These limitations are being addressed as this work aims to be published. Despite these drawbacks and subsequent results of the syngas composition and gasification efficiency, the gasification of woody invasive plant species remains a promising option for decentralized generation, particularly in rural areas where these feedstocks are easily accessible. The potential energy yield from gasifying the total assumed amount of honeysuckle and buckthorn available in Michigan is 0.34 – 0.37 TWh. While this amount of energy only represents a small percentage of the state's annual energy consumption, it is enough to meet the annual electricity demand for a non-trivial number of homes. At a distributed level, there is a case for generating electricity using from invasive species, while fostering ecosystems where native plants are better suited to thrive.

Ultimately, it is unlikely that these invasive species will ever be fully eradicated, and gasification provides only a short-term solution for harnessing value from these underutilized feedstocks. The benefits of producing energy via gasification of invasive species should not lead to an energy system that ultimately incentivizes their growth. Additionally, the biochar co-produced during gasification should be utilized to store carbon from feedstocks back into the soil they were grown from. Biochar has been researched to have soil amending properties, and so in this way a circular economy is formed where the use of biochar can assist in the growth of new feedstock.

To make transformative progress in the challenge to decarbonize global electricity sectors and mitigate the effects of climate change, solutions will be necessary on a systems-level scale. While the framework for creating change at that scope is being laid, there is an immediate opportunity to begin producing renewable energy at a localized level, particularly through gasification of feedstocks also found locally. This work has illustrated that in Michigan, invasive species like honeysuckle and buckthorn represent a currently underutilized local source of feedstock for biomass gasification.

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