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A life cycle inventory for switchgrass fuel pellets

A Final Report Submitted to

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Final Report Components

- ***Abstract***

This study developed a cradle-to-gate life-cycle inventory (LCI) data for switchgrass fuel pellets potentially manufactured in the US southeast. Because there are no current manufacturers of switchgrass pellets, inventory data were based on field trials of the cultivation and harvest of switchgrass data (or yield and energy inputs data) combined with data from a separate study of wood pelletization. Energy inputs for cultivation and harvest of switchgrass were collected by survey from switchgrass farmers in east Tennessee and represent cultivation and harvest data for years 2008, 2009, and 2010. Data for pelletization were taken from a report on wood pellet manufacturing in the US southeast. All raw materials and emissions were assigned to the switchgrass pellets. No co-products were produced. An impact assessment was conducted using the TRACI 2.0 model. 4.1 GJ of fossil energy inputs were required to produce 1.0 Mg of switchgrass pellets that contain 18.0 GJ of potential bioenergy. Switchgrass crops require relatively little energy and inputs for the cultivation and harvest processes; the majority of the environmental burdens are associated with drying and pelletizing the raw material.
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- ***Executive Summary***

  A wide array of new bio-based fuels, chemicals and materials are being developed. Holistic environmental assessment of these new products in needed to ensure that their production, use and disposal are sustainable. This study developed a life cycle inventory for switchgrass fuel pellets produced in the US southeast. This measures the total energy and material inputs, and total product and waste outputs, associated with the growing and processing of switchgrass. The results of this study show that switchgrass is a very low-impact alternative to fossil fuels such as natural gas.

- ***Final Report (core components)***

Introduction

There are a number of factors motivating the development of bio-fuels and bio-products: high petroleum prices, a desire for energy independence, the need for rural economic diversification and concern about the environmental impacts of using fossil carbon sources. With regard to the last point, products and fuels made from plants inherently have environmental advantages: they are renewable and solar-powered, and their use is carbon-neutral with respect to greenhouse gas concentrations and global climate change. However, there is growing debate about these potential environmental benefits and more attention is being paid to the amount of fossil carbon resources consumed in the production and processing of bio-energy and the potential tradeoffs (e.g. between food and fuel) involved. While the environmental advantages of bio-based resources remain important, they can no longer be assumed – they must be demonstrated, using generally accepted methods. Life cycle assessment (LCA) is the standard method for evaluating the environmental impacts of processes and products [1].

Switchgrass (*Panicum virgatum L.*) is a grass indigenous to Central and North America. In the southeastern United States (SE), this perennial crop has a growing season from May through September and can reach up to eight feet tall. Switchgrass and other crops are being considered as new sources for bio-energy and bio-products. Because these crops are harvested seasonally and are bulky to handle and transport, pelletization may be necessary as a primary processing step. Pellets are dry, dense, easily-handled and stable in long-term storage. Pellets are burned directly for fuel or can be an initial processing step in a biorefinery or bio-fuel conversion

process. Wood pellets are an established fuel product that is growing in importance in the US and abroad, driven by rising fuel prices and demands for green energy sources. Switchgrass pellets have the potential to join wood pellets in this growing market. A study by Sultana and Kumar [2] evaluated and ranked biomass feedstock-based pellets with a multi-criteria assessment model based on environmental, economical, and technical factors naming wood pellets the best among the five alternatives evaluated, closely followed by switchgrass pellets. Particularly in the SE, interest in switchgrass has been established and is currently being cultivated and harvested for energy and research purposes [3].

Some LCA data on switchgrass or similar crop pellet production have been published for Canadian and European contexts [4-7, 29, xx5]. This study focuses on the southeastern United States. The data are intended for analyses of pelletized biofuels and for related products (e.g. when switchgrass or pellets are a component of a bio-refinery).

The goal is to develop an inventory of the inputs and outputs associated with the production of switchgrass pellets in the southeastern United States. Results can be used in lifecycle inventory assessment and interpretation phases to identify major sources of environmental impacts and to compare the environmental impacts of switchgrass pellets with other energy sources. The output of this study is intended for use by researchers and practitioners as an input to the life cycle analysis (LCA) of biomass materials. Because there is currently no commercial production of switchgrass pellets, this life cycle inventory is based on data from field trials of the cultivation and harvest of switchgrass, combined with a wood pellet manufacturing life-cycle inventory [8]. The primary data for the cultivation and harvest of switchgrass were collected by a survey of participating farmers.[1]

Methods

This is a cradle-to-gate life cycle inventory of switchgrass pellets and includes data from the cultivation and harvest of switchgrass plantations that have been established in east Tennessee as part of the University of Tennessee Biofuels Initiative (UTBI).[2] Initiated by a $70.5 million dollar state investment, this initiative has been charged with developing a cellulosic biofuels industry in Tennessee. Part of this approach was to hire farmers to grow switchgrass as well as the creation of a pilot bio-refinery located in Vonore, TN. Raw material transportation values to a pelletization plant are assumed. Because no commercial switchgrass pellet mill data are available, data from a survey of wood pelletization mills in the US southeast was used [8]. Cultivation and harvest data were collected by survey sent to switchgrass farmers. The crop stands ranged from first-year to mature, third-year stands. Because inputs (primarily fertilizer treatments) decrease after stand establishment, and yields increase, the data were averaged and weighted over a ten-year period (the assumed stand rotation).

Sixty one switchgrass farmers contracted with the University of Tennessee's Biofuels Initiative were contacted and sent a production data survey from September to December 2010.The surveyed farmers operated switchgrass farms primarily in the southeastern region of Tennessee (Vonore, TN). Another gate-to-gate LCI was conducted on the hardwood flooring residues pelletization process using a similar survey method sent to operating pellet mills in Alabama, Kentucky, Tennessee, Virginia and West Virginia [8]. SimaPro LCA modeling software [9] calculated the overall cradle-to-gate emissions of switchgrass pelletization using a network of

[1] This survey is located at http://www.renewablecarbon.org/PDF/sg_survey.pdf.
[2] http://www.generaenergy.net/faqs/ut_biofuels_initiative.aspx

related inventories associated with inputs for both the cultivation and harvest of switchgrass (resource harvesting) and the pelletization process (gate-to-gate). The US LCI Database [10] was the main secondary LCI data source.
We chose to use the wood-pellet value because it is based on actual, regional commercial productionof a similar material. The procedures and report of this study follow the standards in ISO 14040 [1] and 14044 [26]. The procedures and report also follows the research guidelines for life cycle inventories used by other researchers in the CORRIM group [11].
The cradle-to-gate manufacture of switchgrass pellets comprises the following processes: cultivation and harvesting of switchgrass, transportation, drying, hammer-milling, pelletizing, cooling and stored (bagged or in bulk). This study did not include bagging in the system boundary and evaluated the system as if it were to be prepared for bulk storage.

Unit process and system boundary
The processes described in **Error! Reference source not found.Error! Reference source not found.**Figure 1 are the basic flows within the system boundary for the cradle-to-gate LCI of the switchgrass pellet-manufacturing model. The functional unit was one Mg (1 tonne = 1000 kg = 2200 pounds) of switchgrass pellets (5% moisture content). The following describes each of the manufacturing processes:

1. *Switchgrass*
    - **a.** *Cultivation and Harvest*. Switchgrass is grown as a perennial crop, with each stand lasting for ten years before reestablishment. In the SE, cultivation and harvesting usually takes place during mid- to late-fall. During growth fields were plowed, fertilized, seeded and maintained to control for weeds with pesticides. No irrigation was used. During harvesting, the switchgrass is cut, field-dried, baled and loaded onto tractor-trailer trucks for transport. Farmers in our study used switchgrass farming recommendations from the University of Tennessee's Biofuels Initiative.[3]
    - **b.** *Transportation*. After baling, switchgrass is loaded onto tractor-trailer trucks and transported to pellet mill for storage and processing.
    - **c.** *Storage***.** In a projected model of a switchgrass pelleting facility, raw material would be transported by truck to the pellet mill. The raw material would then be stored in a dry facility on-site. Inputs for raw material collection included diesel fuel and/or liquid propane gas for transportation and/or handling.
    - **d.** *Drying*. Raw materials for pelletizing usually require drying to about 10% moisture content.
2. *Pelletization*. Because we were unable to collect data for the pelletization process, this study treated pelletization as a single process from the Reed et al. study [8]. Pelletization includes, 1) size reduction, 2) pelletizing and 3) cooling processes.
    - **a.** *Size reduction*. Once the material is collected, it is broken down into small, uniform particles (~2 mm) using a hammer mill. The hammer mill is operated by electric motors.

[3] http://economics.ag.utk.edu/publications/bioenergy/SP701-A.pdf

b. *Pelletizing.* Pellets (~6mm diameter and 25mm long) are extruded using machinery that is similar to the equipment used to form feed pellets for the agriculture industry. Pelletizers use large electric motors to extrude the pellets through steel dies. High pressure (~300 Mpa) and temperatures (~90˚C) soften lignin and binds the switchgrass particles together to make uniform and consistent pellets. While no adhesives are required for this process, small amounts of lubricants and water are sometimes added to improve processing.

c. *Cooling.* The pellets are hot when they emerge from the pelletizer. They are stored in a hopper and allowed to cool under ambient conditions before further handling, transportation and storage.

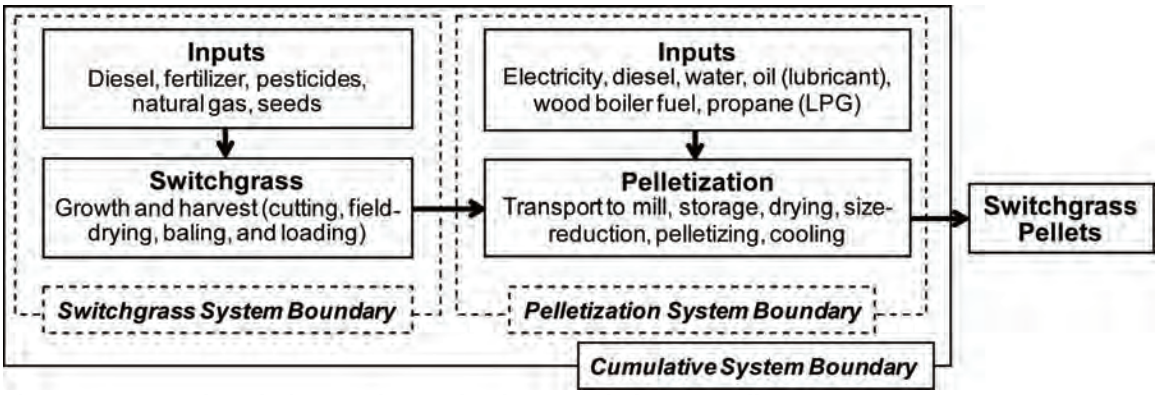

Figure 1 System description for the production of switchgrass pellets

2.2. Assumptions

The data collection, analysis, and assumptions followed the protocol defined in "Consortium for Research on Renewable Industrial Materials (CORRIM)—Research Guidelines for Life Cycle Inventories" [11]. Additional conditions include:

- All data from the switchgrass farmer survey were weight averaged over a period of ten years to account for input and yield variations over the ten year life of the stands [5]. The input and yield values reported for year 3 were assumed to be the same for the subsequent seven years.
- The seeding rate (only for the first year) was assumed to be 7.8 kg/ha (7lbs per acre) [14, 15]. The associated impacts associated with seeds come from the seed input we used.
- We did not consider storage facility, pellet facility, or farming machinery construction in this study.
- Transportation was based on an assumption of 80.5 km (50 mile) average haul with an 18.2 Mg load (40,000 pounds).
- Switchgrass typically dries on the field to 20%MC or less before being baled and shipped to the plant for drying [12]. Drying inputs (natural gas) of the switchgrass prior to pelletization was estimated by an expert in the area of biomass processing (Gary Follmer, M-E-C Company, 2012, pers. comm., March 15) as 721 MJ per tonne to dry switchgrass

to 10% moisture content, requiring 23.7 cubic meters of natural gas combusted at 80% efficiency [13].

- The pelletization process for dry switchgrass was assumed to be the same as for pelletization of wood processing residues, as reported by Reed et al. [8]. The process of pelletizing switchgrass will change the density of the biomass raw material and will evaporate some moisture. Therefore, it was assumed that 0.95 Mg of oven-dry switchgrass is required to produce one Mg of pellets with a final product moisture content of 5%.
- We assumed 100% yield of pellets from the raw material and that no raw material was lost as dust and that all poorly formed pellets or fine particles are recycled in the system. However, Jannasch, Quan and Samson [4] speculated that 95% yield might be more realistic, due to the loss of raw material during processing.

Life cycle impact assessments (LCIA) were performed using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2) [16]. TRACI is a midpoint-oriented methodology developed by the U.S. Environmental Protection Agency specifically for the United States. Nine impact categories were examined including global warming potential (kgCO2-eq), acidification potential (H^+ moles-eq), carcinogens (kg benzene-eq)), non-carcinogens (kg toluene-eq), respiratory effects (PM 2.5-eq), eutrophication potential (kg N-eg), ozone depletion (kg CFC-11-eq), ecotoxicity (2,4-D-eq), and smog potential (kg NOx-eq).

Results

Life Cycle Inventory

Of the sixty-one farmers surveyed, twelve (19%) responded with complete data in terms of switchgrass production, seed rate, fuel use, and herbicide & pesticide inputs. The survey was sent out in 2010 and represents cultivation and harvest data for 2008, 2009, and 2010. Usable responses were collected from twelve farmers with data on 152 ha, or about 7% of the 2090 ha in switchgrass production. The survey responses for wood pellet manufacturers represented 2009 production data from approximately 25% of the total number of operating mills in the SE. The only available production data estimated total production in the Southeast region in 2008 at 591,872 tonnes [17]. The total production of responding pellet mills were 303,912 tonnes of pellets a year or about 51%.

The switchgrass yield data collected in our survey (13.9 Mg/ha) were consistent with published data [4] but reported inputs (e.g. electricity) were less. However, the reported data on the pelletization process are consistent with energy consumptions valued reported in other studies [18-24]. The weighted-average electrical usage reported per functional unit (0.907 Mg) of wood pellets was 132 kWh [8] is significantly more than values estimated in some publications related to switchgrass pelletization [5].

The inputs per functional unit (1.0 Mg) were calculated based on an average switchgrass yield of 13.9Mg per ha per year (oven-dry). Variation in the reported inputs was high, in part because of differences in the ages of the switchgrass stands (see CV; Table 1). Of the material inputs for the cultivation and harvest of switchgrass, the most significant is nitrogen fertilizer. Other inputs include diesel, phosphorous fertilizer, pesticides, herbicides and surfactant. The most significant

input for pellet-making operations in the Southeast is electricity. Other fuels used for equipment (i.e. tractors, trucks, forklifts) include diesel fuel, and liquid petroleum gas (LPG). Other raw material inputs used in the manufacture of wood pellets are water, oil, and grease. Water is used to adjust the moisture content and oil and grease are used for lubrication during the pelletizing process.

Table 1 Cradle-to-farm gate inputs for 1.0 Mg of switchgrass (oven-dry basis) in the US southeast.

Inputs	*Units*	*Average Value*[1]	*Coefficient of Variation*[2]
Diesel (tractor use)	L	3.98	46%
Nitrogen (fertilizer)	kg	4.77	84%
Phosphorous (fertilizer)	kg	0.49	224%
2, 4-D (pesticide)	L	0.05	219%
Glyphosate (herbicide)	L	0.05	213%
Surfactant	L	0.03	332%
Seed[3]	kg	0.56	n/a

[1]Average value is the weighted average over a 10-year switchgrass stand rotation, where inputs and yields are assumed to be constant in years 3-10.
[2]Coefficient of variation is standard deviation/average of the reported data, without any weighting for stand age.
[3]Seed input values were not reported by the farmers. The value listed here is from the literature

Pelletization primarily has energy and switchgrass inputs and only one output—switchgrass pellets. Finished pellets contain about 5% moisture content, so the switchgrass input is only 0.95 Mg of oven-dry switchgrass to produce 1.0 Mg of switchgrass pellets (Table 2.)

Table 2 Farm gate-to-mill gate inputs for 1.0 Mg of switchgrass pellets (5% moisture content) in the US southeast.

Input	*Units*	*Value*
Switchgrass (oven-dry basis)	Mg	0.95
Diesel-powered truck (switchgrass transportation to pellet mill)	tkm	84.28
Natural gas (swichgrass drying)	m^3	27.09
Pellet Manufacturing[1]		
Corn oil (lubricant)	L	1.38
Ground water	L	23.91
Electricity	kWh	145.67
Liquid petroleum gas	L	0.09

Wood residues to boiler	kg	33.04
[1]Based on the inventory for the pelletization of wood processing residues (8).		

Pelletization does not create a solid waste stream. All residues are recycled in the pelletization process and air-borne particulate emissions (dust) are assumed to be insignificant. Because on-site air, water and solid waste emissions are insignificant, the emission data here (Tables 3 & 4) are those associated with growth, harvest and transport of the switchgrass, as well as those associated with the production of the other pelletization inputs (electricity and corn oil). Because electricity is the primary energy for pelletization, the source of the fuel used for electricity generation is important in determining the environmental impacts of pellet making. In the eastern United States, the primary fuel sources for electricity are coal, nuclear energy and natural gas [27]. The cumulative life-cycle emissions associated with pelletization (including particulates; Table 3) are pre-gate (i.e. those associated with switchgrass and electricity production). There are no emission control measures employed during pelletization and there are no emissions to soil in this inventory.

Table 3 Cradle-to-mill gate emissions to air for 1.0 Mg of switchgrass pellets (5% moisture content) in the US southeast.

	Switchgrass growth and harvest	Switchgrass transport, drying and pelletization	Cumulative (growth, harvest, transport, drying and pelletization)
Substance	*kg*	*kg*	*Kg*
CO2 (fossil)	4.07	168.27	172.34
CO2 (biomass)	0.06	2.04	2.10
NO_x	0.02	0.40	0.42
SO2	0.11	1.19	1.30
Sox	0.01	0.03	0.04
Methane	0.06	0.50	0.56
Particulates (unspecified)	0.00	0.07	0.07
Volatile organic compounds (VOC)	0.00	0.03	0.03

Table 4 Cradle-to-mill gate emissions to water for 1.0 Mg of switchgrass pellets (5% moisture content) in the US southeast.

	Switchgrass growth and harvest	Switchgrass transport, drying and pelletization	Cumulative (growth, harvest, transport, drying and pelletization)
Substance	*kg*	*kg*	*kg*
Biological oxygen demand (BOD)	0.01	0.02	0.03
Suspended solids	0.05	0.12	0.16
Chemical oxygen demand (COD)	0.01	0.04	0.05
Chloride	1.25	3.92	5.18

Discussion

Pelletization converts a potential fuel or raw material for products into a more convenient form, thus it is interesting to analyze the additional environmental impacts that are associated with this convenience.

For the pelletization process alone, electricity production contributes the most to the total impact for five of the TRACI-defined impact categories (global warming, acidification, carcinogenics, respiratory effects, and smog) [8]. Impacts associated with switchgrass cultivation and harvest are most important for four of the categories (non-carcinogenics, eutrophication, ozone depletion, and ecotoxicity). Impacts associated with drying the feedstock (natural gas) are considerable in every impact category except for eutrophocation and smog. (Figure 2). Switchgrass cultivation and harvest contributes nearly all of the impact towards eutrophication and ozone depletion which is due to run-off and emissions associated with fertilizers.

The primary input for the cultivation and harvesting of switchgrass is nitrogen fertilizer; however, impact assessment shows that other fuels and chemicals add to the environmental burden of this process. The primary input for manufacturing pellets is electricity and, because electricity is mostly generated from nonrenewable and fossil fuels, this input significantly impacts the carbon balance of switchgrass pellets.

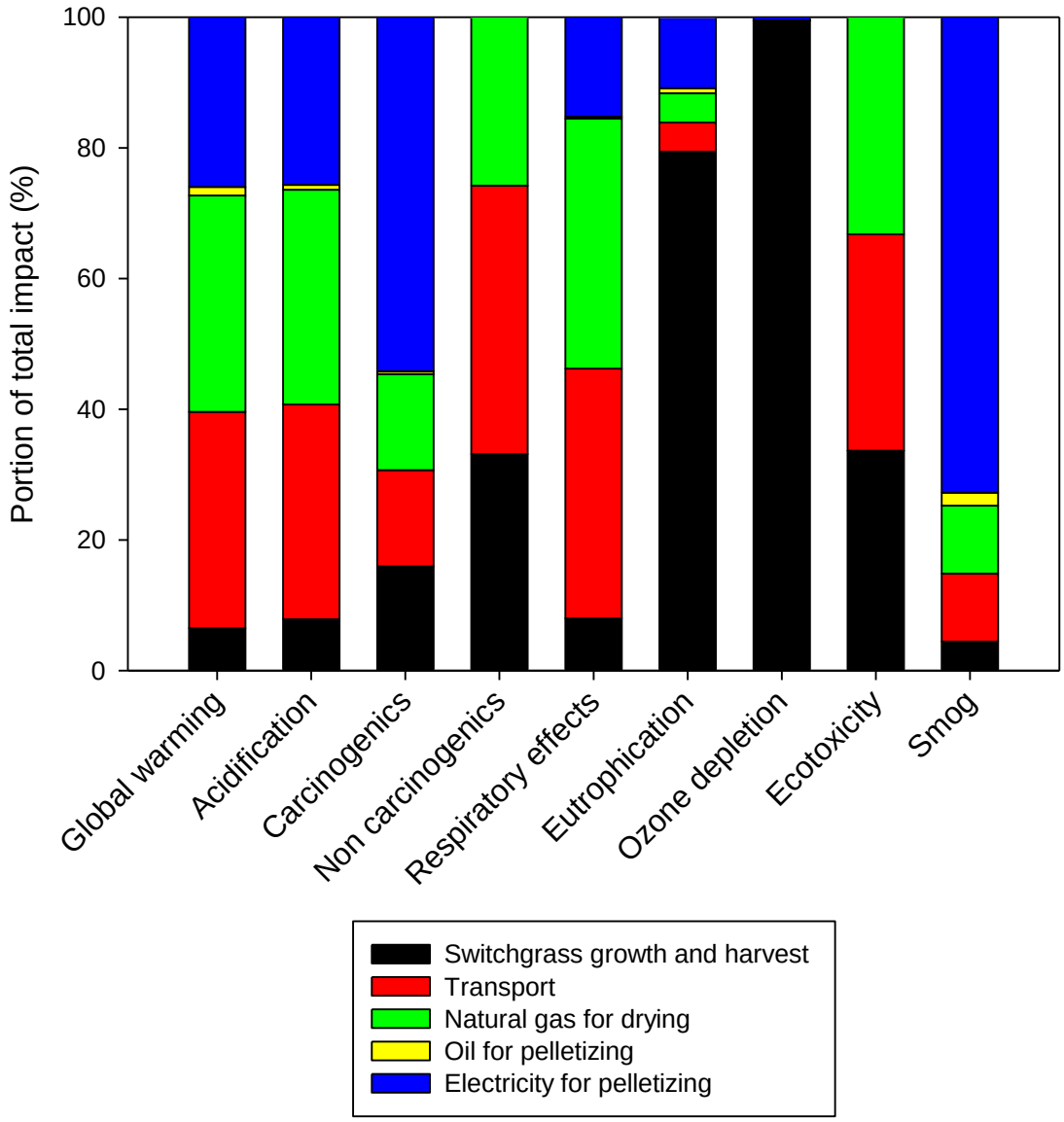

Figure 2 Impact categories showing relative contribution of the inputs

Biomass energy sources are sometimes considered to be 'carbon-neutral' [29, 30] for accounting purposes because the carbon dioxide (CO_2) released during energy production is offset by CO_2 adsorption during photosynthesis (e.g. [16]). However, some fossil energy inputs are required for the production of most bio-fuels. The fossil energy required for the production of switchgrass pellets was calculated from the inventory data tabulated by Sima-Pro and weighted for their energy content (higher heat value). This analysis revealed that switchgrass pellets are very 'fossil-fuel efficient'; i.e. the amount of fossil fuel used to generate the pellets is small compared with the potential bioenergy in the pellets (Figure 3). In the present study, embodied energy is referred to as the energy used or consumed to make the product from crade-to-gate.

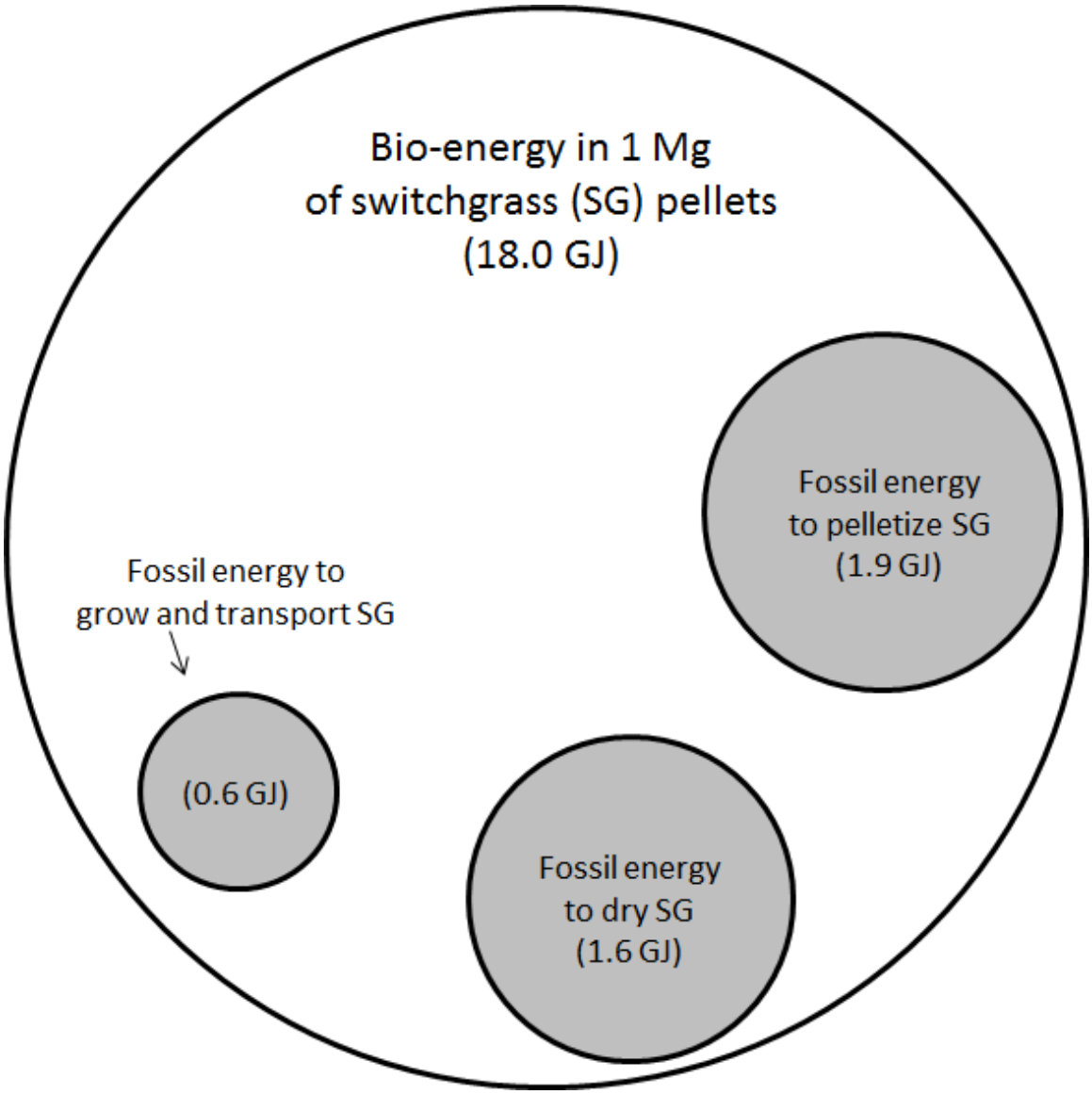

Figure 3 Potential bio-energy and embodied fossil energy in one ton of switchgrass pellets. Bio-energy content value from FPL 2004 [12].

Because of the high net bio-energy content of switchgrass pellets, the use of switchgrass for fuel would offer a significant global warming potential advantage over fossil fuels such as natural gas (Figure 4). This life cycle assessment scenario assumes equivalent combustion efficiencies (80% [13]) and includes biogenic carbon dioxide emissions and absorption. The results suggest a reduction in global warming impact of over 80% for switchgrass pellets versus a natural gas alternative. The Energy Independence and Security Act of 2007 requires a cellulosic biofuel to provide a 60% reduction in greenhouse gas emissions versus fossil fuel alternatives [30]; however this calculation involves consideration of land-use change impacts that were not considered here.

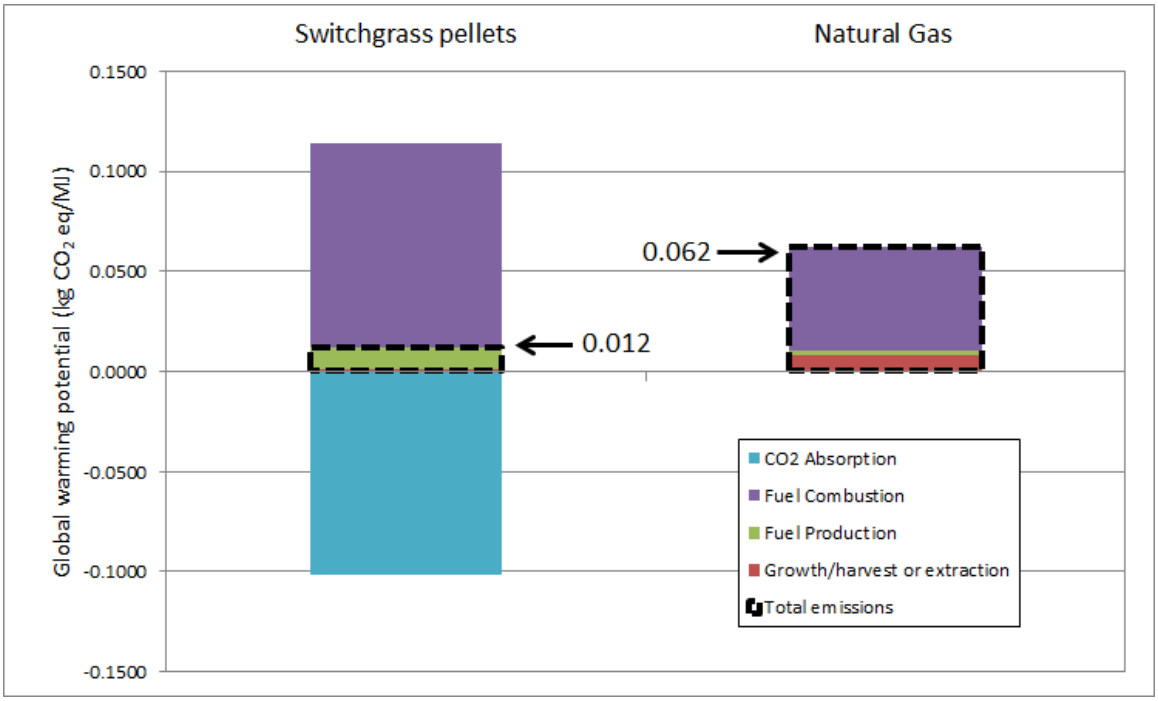

Figure 4 The global warming potential of switchgrass pellets and natural gas fuels, by life stage. Transportation of the fuels to the combustion facility is not considered.

Sensitivity Analysis

The electricity input to the pelletization process contributes significantly to the environmental impacts of producing switchgrass pellets, thus it is interesting to explore the impact of different potential electricity sources. For our study, the electricity input used was based on an Eastern United States grid mix which is primarily coal-based. If a different US source is selected, impact categories show varying results. Figure 5 shows the comparison between US eastern grid mix, US western grid mix, and US Texas grid mix. From this figure, it is evident that producing switchgrass pellets in a US western grid mix would have a lesser impact in all categories. Comparatively, producing in the US Texas grid mix would have the highest impacts in five of the nine categories (Global Warming, Acidification, Non-cardinogenics, Respiratory effects, and Ecotoxicity). US Eastern grid mix has a higher smog impact than the others and all three grid mixes have relatively the same ozone depletion impact.

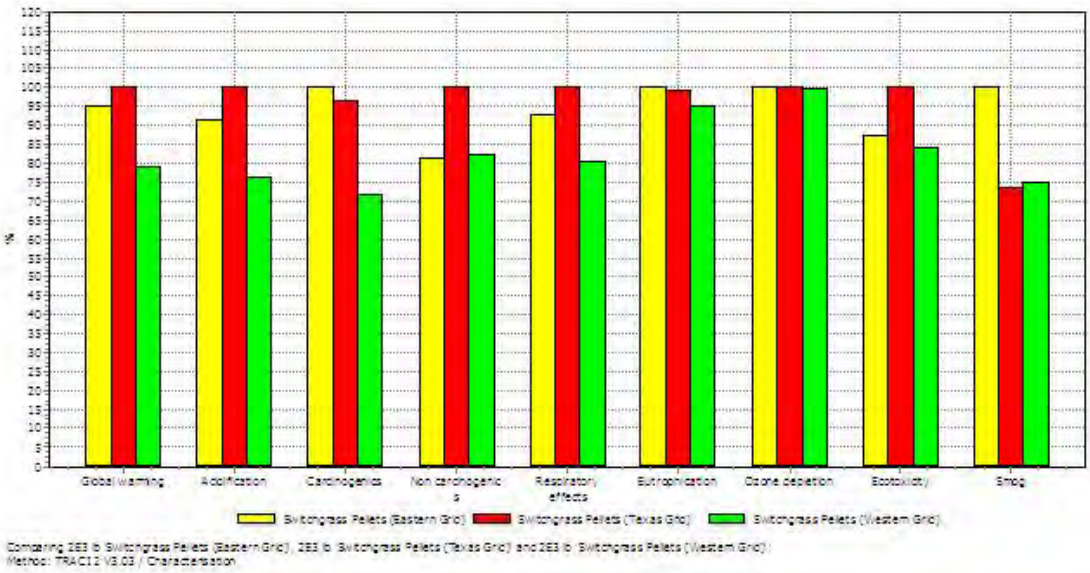

Figure 5 A sensitivity analysis and comparison between US eastern grid mix, US western grid mix, and US Texas grid mix

The difference in generation sources among these three grid mixes help explain why the US western grid mix has less impacts. For the US Texas grid mix the primary source for electricity generation is natural gas (50%) followed by coals (~35%), nuclear (~12%) and others (~3%). For the US Eastern grid mix the primary source for electricity is coals (~58%) followed by nuclear (~22%), natural gas (~10%), and others (10%). While the US western grid mix does heavily rely on coal (~32%) and natural gas (~23%) for electricity generation, it also uses a significantly higher proportion of hydropower (~27%) among other renewables (~18%).

Limitations

As with all LCIs and impact assessments, the conclusions that can be drawn are influenced by the underlying assumptions. This study focused on a particular method of growing and harvesting switchgrass (for the use of a pilot switchgrass bioenergy refinery and research) in a particular location (southeast Tennessee). The pellet operations surveyed used results from mills attached to hardwood flooring facilities. Results for mills that use other resources—particularly those that require additional drying as part of the pellet making process—will be different [20]. The study that established the inventory for the pelletization process was also heavily influenced by the local electrical generation source (mostly coal). Mills in other areas (for example areas that rely on mainly hydropower for electrical generation) will produce different GWP results from those calculated in this study. Our sensitivity analysis above explores impacts of electricity from two other grids using different electricity sources.

This study involved a cradle-to-gate life-cycle analysis of switchgrass pellets therefore environmental impacts beyond the mill gate could be important but were not included, e.g. when transportation to markets in Europe are considered [31]. However, this study provides an initial scenario that can be added to or altered for future studies.

Conclusions

Data from a survey of switchgrass farmers was combined with an estimate for drying energy and inventory data from the pelletization of wood residues. Life cycle inventory analysis of switchgrass pellets indicates that the potential bio-energy in the pellets is more than five times the total fossil energy used to create them. Switchgrass pellets, if used as a fuel in place of natural gas, would result in an >80% reduction in global warming potential. A sensitivity analysis using different US grid mixes shows that switchgrass pellets produced in the western electricity grid would have fewer impacts to all nine impact categories. Switchgrass pellets produced in a Texas grid mix would have the highest impacts in five of the nine impact categories.

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- ***Acknowledgment***

"Support for this research was provided by a grant from the Southeastern Sun Grant Center with funds provided by the U.S. Department of Transportation Research and Innovative Technology Administration (DTOS59-07-G-00050)."

- ***BASIC INFORMATION***

Date of Final Report: 3 April 2013

Project Title: **A life cycle inventory for switchgrass fuel pellets**

Principal Investigator Dr. Adam M. Taylor
Center for Renewable Carbon
Department of Forestry, Wildlife & Fisheries
University of Tennessee
2506 Jacob Drive
Knoxville TN 37919

All Co-Principal/Other Investigators *(Name, Title, Department, Institution, City/State)***:**
Daniel Reed, Doctoral Candidate, University of Tennessee, 2506 Jacob Drive Knoxville TN 37996, danielreed@tennessee.edu
Richard Bergman, Research Forest Products Technologist, USDA Forest Products Laboratory, Madison WI rbergman@fs.fed.us
David Harper, Associate Professor, University of Tennessee, 2506 Jacob Drive Knoxville TN 37996, dharper4@utk.edu
Don Hodges, Professor, University of Tennessee, 274 Ellington Plant Science Bldg Knoxville TN 37920, dhodges2@utk.edu

Collaborators *(Contact's Name, Title, Organization, City/State or Locations)***:**

Project Start Date: May 1, 2009

Project End Date: June 30, 2012

FINAL (ACTUAL) BUDGET

1. Actual Dollars Spent:

BUDGET ITEM	SUN GRANT $	COST SHARE $
a. Total Salaries & Wages		15,000
b. Fringe Benefits	1,963.24	
c. Supplies	14,653.42	
d. Equipment		
e. Travel	5,396.58	
f. Publications	25.88	
g. Other (Subcontractors, Consultants)	2,461.96	29,000
Total DIRECT COSTS (Sum of A-G)	37,554.60	44,000

Total INDIRECT (i.e. F&A) COSTS (IDC Usually = Total Direct Costs*.25)		
h. Graduate Student Tuition	36,362.43	
i. Permanent Equipment ($5,000 or More)		
j. Other Costs Not Requiring Indirect	10,591.56	
Total DOLLARS SPENT (Total Direct + Total Indirect + H + I + J)	75,996.74	

2. Describe all Cost Share:

   WoodLife Consulting. $9,000 in kind
   Kesco Solutions $10,000 in kind
   M-E-C $10,000 in kind
   PIs Hodges, Harper and Taylor, $5,000 each, in kind

Discussion Information

1. Project Summary (*maximum of 250 words*)
   This study developed a cradle-to-gate life-cycle inventory (LCI) data for switchgrass fuel pellets potentially manufactured in the US southeast. Because there are no current manufacturers of switchgrass pellets, inventory data were based on field trials of the cultivation and harvest of switchgrass data (or yield and energy inputs data) combined with data from a separate study of wood pelletization. Energy inputs for cultivation and harvest of switchgrass were collected by survey from switchgrass farmers in east Tennessee and represent cultivation and harvest data for years 2008, 2009, and 2010. Data for pelletization were taken from a report on wood pellet manufacturing in the US southeast. All raw materials and emissions were assigned to the switchgrass pellets. No co-products were produced. An impact assessment was conducted using the TRACI 2.0 model. 4.1 GJ of fossil energy inputs were required to produce 1.0 Mg of switchgrass pellets that contain 18.0 GJ of potential bioenergy. Switchgrass crops require relatively little energy and inputs for the cultivation and harvest processes; the majority of the environmental burdens are associated with drying and pelletizing the raw material.

2. How will the Results of this Research be Used?
   As a component of environmental impact analyses for biorefinery projects that involve switchgrass or similar feedstocks.
3. Outcomes/Products (Current and Anticipated)
   Posters and presentations (listed below). A peer-reviewed journal publication is in preparation.

4. For Each Objective, Discuss Accomplishments and Successes (Include Modifications)

5. Discuss Project Outcomes and Impacts

6. Provide a List and Complete Citation Since Project Inception of:

a) Peer-Reviewed Articles

i. Submitted:

ii. In Press:

iii. Published:

b) Books and Book Chapters

i. Submitted:

ii. In Press:

iii. Published:

c) Outreach Publications & Materials

i. Submitted:

ii. In Press:

iii. Published:

d) Website URLs or Other Electronic Outreach

i. Submitted:

ii. Published:

e) Oral & Poster Presentations

i. In Preparation:

ii. Presented:

Taylor AM et al. 2011. LCIs of wood and switchgrass pellets. Presentation at the Forest Products Society International Convention. June 20. Portland OR

Reed D. Life Cycle Assessment: A tool for decision makers Southern Forest Economic Workers, 2009 – Pinehurst, NC

Reed D. Policy Implications of Life Cycle Assessment: A Biofuels Example Texas State University International Graduate Research Conference, 2009 - San Marcos, TX

Reed D. Life Cycle Assessment: Wood and Switchgrass Pellets Texas State University International Graduate Research Conference, 2010 - San Marcos, TX

Taylor A, Reed D, Bergman R, Harper D, Hodges D. Cradle-to-Gate Life-Cycle Inventory of Switchgrass Fuel Pellets in the Southeastern United States, Poster presented at the Sungrant Conference. New Orleans. 2012

Daniel Reed, and A. M. Taylor. 2011. Life cycle inventories for wood and switchgrass pellets. Poster presented at the Life Cycle Assessment XI Conference in Chicago.

iii. Other

7. Licenses/Inventions (*provide complete citation as appropriate*)

a) In Preparation:

b) Disclosed:

c) Applied:

d) Obtained:

8. Name of Students Funded on Project, including Department, Institution, Thesis/Dissertation Title (*if applicable*), Degree Obtained (*if applicable*), and Program Area:

Student Name	**Department**	**Institution**	**Thesis/Dissertation Title**	**Degree Obtained/Date**	**Program Area**
Daniel Reed	FWF	University of Tennessee	Policy applications of lifecycle assessment	PhD. 2012	Natural Resources

9. Name and Institution/Agency/Company of Collaborators and/or Partners (Original and New)

10. Educational Programs Conducted *(including courses developed, indicate title, subject matter and audience*)

11. Internal and External Grants and Contracts Related to this Project since Project Inception (*provide complete citation*)

a) Proposals Submitted:

b) Proposals Funded:

12. Attach any Photographs, Data and Supporting Information You Deem Appropriate

Appendices (Optional)

- ***UT Ledger Report***

U110005 Sun Grant Center
R110515031 Internal DTOS5907G00050 CRC-Taylor

The University of Tennessee
LEDGER

Reporting Period: 03-01-2013 to 03-31-2013
Reporting Status: Final

Principal Investigator: Taylor, Malcolm M. Sponsor: US Department of Transportation Sponsor's Obligation: 77,316	Invoice Type: Cost reimbursement Net F&A: 8.0% of Modified total direct costs	Project Status: Not Postable Project Start: 05-01-2009 Project End: 06-30-2012

S O U R C E S & U S E S O F F U N D S

S O U R C E S O F F U N D I N G	Current Month	Budget	Cumlatv Actuals	Remaining
Sponsored Projects Billings		77,316	75,996.74	1,319.26
TOTAL SOURCES OF FUNDING		77,316	75,996.74	1,319.26

U S E S O F F U N D S	Current Month	Budget	Commitments	Cumlatv Actuals	Remaining
DIRECT COSTS		72,800		71,455.07	1,344.93
Facilities & Administrative Cost		20,528		21,302.22	774.22-
Facilities & Administrative Cost-Sharing		16,012-		16,760.55-	748.55
NET FACILITIES AND ADMINISTRATIVE COST		4,516		4,541.67	25.67-
TOTAL DIRECT AND F&A COSTS		77,316		75,996.74	1,319.26

DIRECT COST REMAINING AFTER EXPENSES & COMMITMENTS	1,221.54

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*****************************************************
*                W A R N I N G                      *
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*                                                   *
*  ●●●  Project is expired                          *
*                                                   *
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In accordance with university policy, I have reviewed the charges shown on this ledger and either verified their accuracy and appropriateness to this fund or identified and reported discrepancies for correction through proper channels.

_____

(signature of principal investigator)

Date: _____

B U D G E T vs A C T U A L S S U M M A R Y

	Current Month	Budget	Commitments	Cumlatv Actuals	Remaining
GTA, GA, GRA Salaries		35,000		36,362.43	1,362.43-
TOTAL SALARIES & WAGES		35,000		36,362.43	1,362.43-
TOTAL STAFF BENEFITS		4,952		1,963.24	2,988.76
Travel		6,000		5,396.58	603.42
Communication		1,000		25.88	974.12
Professional Services & Memberships		1,000			1,000.00
Supplies		10,700		14,653.42	3,953.42-
Grants & Subsidies*		14,148		10,591.56	3,556.44
Contractual & Special Services				2,461.96	2,461.96-
TOTAL OPERATING & EQUIPMENT		32,848		33,129.40	281.40-
TOTAL DIRECT COSTS OF THE PROJECT		72,800		71,455.07	1,344.93
Add Net Facilities and Administrative Cost (8.0%)		4,516		4,541.67	25.67-
TOTAL EXPENSES TO THE SPONSOR		77,316		75,996.74	1,319.26

* Costs in these categories are exempt from F&A charges.

S P O N S O R P A Y M E N T / I N V O I C I N G H I S T O R Y

Sponsor: US Department of Transportation

Invoice Type: Cost reimbursement
Invoice Frequency: Monthly

Total Not Invoiced		0.00
Invoices Collected to-Date	75,996.74	
Invoices Not Collected	0.00	
Total Invoiced to-Date		75,996.74
Total Expenses to-Date		75,996.74

Last Payment Posted On 03/31/2013
Last Invoice Posted On 08/24/2012

U N C O L L E C T E D I N V O I C E S

Posting Date	Invoice#	Days Old	Current	61-120 Days	121-180 Days	Over 180 Days	T o t a l

TOTAL INVOICED BUT *NOT* COLLECTED

If you have invoices over 120 days old, it may indicate a payment problem with your sponsor.

Expenses not re-imbursed by your sponsor ultimately will be charged to your department.