Waste Biomass Inventory to Support Renewable Energy Development

Technical Appendix

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Appendix A: Biomass Producing Facility Locations

Wastewater Treatment Plants

Biomass production type: WWTP Biosolids
Mapped as: Specific Locations (Point Source)

Field Explanations:

Field	Explanation
Unique ID	Unique facility ID
Fac_name	Name of facility
Perm_no	Permit number
District→ county	Location data
Lon/lat	Coordinates
MGrx/Mrgy	MIGeoref X and Y
Total_auth	Authorized flow per year
Dry_tons_s	Dry tons of WWTP sludge per year
Feedtype	Biomass reference code

Source: Michigan Department of Environmental Quality
Additional Work Needed: None
Notes: The original form of this list contained many more entries. Any facilities that were deemed smaller or of the wrong type (not a WWTP, or a WWSL), were deleted.

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Universities

Biomass production type: Food Waste
Mapped as: Specific Locations (Point Source)

Field Explanations:

Field	Explanation
Unique ID	Unique facility ID
Officialna	Name of school
Commonname	Common name
Awsid->addresstyp	Location Information
Street →std_zip	Locations
MGrx/Mrgy	MIGeoref X and Y
Lon/lat	Coordinates
Fdemail	Food department email of university
Population	# of students in student housing
Meals_d	Meals served per day
Food_yr	Amount of food waste per year
Feedtype	Biomass reference code

Source: Michigan Center for Geographic Imaging
Additional Work Needed: None
Notes: Includes every university and college in the state.

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Secondary Schools

Biomass production type:	Food Waste
Mapped as:	Specific Locations (Point Source)

Field Explanations:

Unique ID	Unique facility ID
Name	Name of school
Officialna	Official name
Street → zip4	Location data
MGrx/Mrgy	MIGeoref X and Y
Lon/lat	Coordinates
Adressid → actual grad	School info
Brkserv → Z_lun	Food data
Enroll	# of students
Meals_d	Meals served per day
Food_yr	Amount of food waste per year
Feedtype	Biomass reference code

Source:	Michigan Center for Geographic Imaging
Additional Work Needed:	None
Notes:	Includes every secondary school in the state.

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Hospitals

Biomass production type:	Food Waste
Mapped as:	Specific Locations (Point Source)

Field Explanations:

UniqueID	Unique record ID
Id	Hospital ID
Name	Name of the hospital
Telephone	Phone #
Address	Address
Address2	Suite #
State/county/city/ZIP	Location
NAICSdescr	Description of facility
geolinkId	?
X/Y	Lat/long
X/Y_migeo	MI georef cords
Beds	# of beds in hospital
Food_yr	Food waste per year
Feedtype	Biomass reference code

Source:	Michigan Center for Geographic Imaging
Additional Work Needed:	None
Notes:	This is every hospital in the state.

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Correctional Facilities

Biomass production type: Food Waste
Mapped as: Specific Locations (Point Source)

Field Explanations:

Unique ID	Unique facility ID
Facility_n	Facility name
Alternate_	Alternate facility name
comments	Comments about facility
UID	?
Dept_name	Name of department
Fac_type	?
Lat/long	Lat long coordinates
X/Y	MIGeoref
Addr/city/count/ state/zip/zip_ext	Location data
Jurisdicti	Jurisdiction
Population	# of inmates
Meals_per_	Meals served per day
Food_yr	Food waste per year
Feedtype	Biomass reference code

Source: Michigan Center for Geographic Imaging
Additional Work Needed: None
Notes: Includes every correctional facility in the state.

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Confined Animal Feeding Operations

Biomass production type: Animal Manure
Mapped as: Specific Locations (Point Source)

Field Explanations:

Unique ID	Unique facility ID
Designated	Name of facility
Permit_no_	????
Owner	Owner of facility
District → Zip_Code	Location information
Facility_1/2	Long/Lat
X/Y	MIGeoRef coordinates
Primary_sp	Animal type
Total_anim	# of animal units
Manure_y	Amount of manure per year
Feedtype	Biomass reference code

Source: Michigan Center for Geographic Imaging
Additional Work Needed: None
Notes: Includes all of the CAFOs in the state of Michigan.
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Animal Manure: Small Farms

Biomass production type:	Animal Manure
Mapped as:	County level data on # animals and amount of manure

Field Explanations:

Name	County Name
Commodity	Type of inventory
Year	Year inventory was compiled
District	District of ag census
Commcode	Commodity type
Manure_y	Amount of manure produced
Flag	Whether an average # over the district or original data for that county
Feedtype	Biomass Reference Code
DAIRY	
Type	Commodity type
Cows_head	# animal units total
Type_2	Additional product (milk)
Year_1	Year inventory on milk was compiled
Lbs_1000	1000s of lbs of milk produced per year
Dairy_cows	# animal units minus CAFO animals
CATTLE	
Cattle_all	Total # animal units
Cattle_min	# of animal units minus animals in CAFOs
HOGS	
Hogs_all_h	Total # animal units
Pigs_minus	# of animal units minus animals in CAFOs
CHICKENS	
Birds	Total # animal units
Chckens_m	# of animal units minus animals in CAFOs
SHEEP	
All_sheep	# animal units

Source:	National Agricultural Statistics Service
Additional Work Needed:	Specific Locations of these farms are desirable since it would allow the user to see exactly where the manure is coming from to account for transportation.
Notes:	The numbers for each county do not count the animals that are in CAFOs. Every layer has a field showing the # of animals with and without the CAFO animals. The amount of manure per county was calculated based on the non-CAFO number.

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Croplands

Biomass production type:	Crop residues or Energy Crops
Mapped as:	Raster showing acres of crops (Cropland Data Layer)
Field Explanations:	The raster shows acres of crops, and has a field designating what land use is on each raster data point
Source:	Michigan Center for Geographic Imaging
Additional Work Needed:	Determination if certain areas that might be used for "energy crops" are actually useful for this purpose.

Notes: This map shows the land use for the whole state.
The areas that are designated for use for the growth of "energy crops" are:

- Barren
- Fallow Cropland
- MLCD Barren
- MLCD Grassland
- Pasture Grassland

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Food Processors

Biomass production type: Food processing residues
Mapped as: Points of interest. Relative biomass data available at this time

Field Explanations:

Unique ID	Unique facility ID
Firstoflic	License #
Name	Facility name
Address1 -> Y	Location data
Pic_phone_	Facility Phone number
Operation_1	Operation code
Operation	Main facility operation
Sun_operat	Sub operation
Commodity	Food produced

Source: Michigan Department of Agriculture
Additional Work Needed: Data on the amount/type of biomass each facility produces
Notes: Mapped as points that will pop up in a query, but there is no data to be factored into energy calculations.

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Other

Biomass production type:	Various
Mapped as:	Points of interest. No biomass data available at this time

Field Explanations:		
	X	Mi Geo ref X
	Y	Mi Georef Y
	Unique ID	Facility unique ID
	Facname	Facility name
	Address→ ZIP	Location data
	Commodity	What this facility produces
	Waste Type	Type of waste produces
	Notes	Any other information about the facility
	Phonenum	Phone number of facility

Source:		
	Ethanol Facilities	Michigan Department of Agriculture and Corn Marketing Program Committee of Michigan, January, 2008
	Others	Google Maps and correspondence with project members.

Additional Work Needed:	Need to determine how much waste these facilities produce and its' characteristics are.
Notes:	Mapped as points that pop up in a query, but data not factored into energy calculations.

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Additional Sources

For Future Consideration

- Meat Processing Facilities
- Restaurants
- Crop processing facilities (sugar beets, soybeans, etc)

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Appendix B: Waste Biomass Amount/Type

Waste Water Treatment Plants Biosolids

Biomass type units: Dry tons Biosolids/yr
Biomass Reference Code: WWTPSlud

Variables:
Moisture % 90

Source Flow data: Personal Communication with Greg Mulder, Coffman Electric

Additional Work Needed: More accurate value for moisture content
More data on amount of biosolids

Notes: None

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Food Waste

Biomass type units: Tons food waste/yr
Biomass Reference Code: FoodWast

Variables:
Moisture % 90

Food/yr Calculations:

University: $$\frac{Meals}{day} * \frac{.3\ lbs\ food\ waste}{meal} * \frac{365\ days}{yr} * \frac{ton}{2000\ lbs}$$

Secondary Schools: $$\frac{Meals}{day} * \frac{.3\ lbs\ food\ waste}{meal} * \frac{180\ days}{yr} * \frac{ton}{2000\ lbs}$$

Hospitals: $$\frac{Meals}{day} * \frac{.3\ lbs\ food\ waste}{meal} * \frac{365\ days}{yr} * \frac{ton}{2000\ lbs}$$

Meals/day: $$\#\ beds * \%\ beds\ occupied * \frac{1\ patient}{bed/day} * \frac{3\ meals}{day}$$

Correction Facilities: $$\#\ inmates * \frac{3\ meals}{day/inmate} * \frac{.3\ lbs\ food\ waste}{meal} * \frac{365\ days}{year} * \frac{ton}{2000\ lbs}$$

Source:	Food Waste/Meal	Kirk, D. Michigan State University Cafeteria Food Waste Audit. 2006. Handel, B. V. Quantifying food residuals in campus cafeteria. Biocycle: Mar 2004. 43.
	University Food:	Correspondence with each university
	Secondary School Food:	Correspondence with Melanie Brummeler, Michigan Department of Education
	Hospital # of beds occupied:	Correspondence with Michigan Department of Community Health
	Correctional Facilities meals/day:	Department of Corrections

Additional Work Needed:

All: More accurate value for moisture content
All: More data on amount food waste at certain facilities
All: Amount of food waste is actually available for use.
Hospitals: more accurate information on the number of meals served/yr. Since this is based on a few assumptions, more accurate information could be obtained on amount of food waste for each hospital

Notes:	University:	Food data was obtained by emailing each university and asking for the number of meals they served per day.
	Secondary Schools:	Number of lunches and breakfasts served at many schools was obtained, which adds up to the number of meals per day. The school year was assumed to be around 180 days/yr for the entire state.
	Hospitals:	Assumed that 3 meals are served per day, that one patient occupies a bed per day, and that the state average of 85.17% of beds being occupied applies to every hospital

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Animal Manure: Confined Animal Feeding Operations

Biomass type units: Tons manure/yr

Biomass Reference Code:	DairyMan	Dairy manure
	CattlMan	Manure from cattle
	ChickMan	Chicken manure
	HogManur	Hog/pig manure
	TurkeyMa	Turkey manure

Variables:

Moisture %	Dairy	91.5
	Cattle	91.5
	Pigs	94.5
	Chickens	33
	Turkeys	33
Manure Yield per animal (lbs/animal/day)	Dairy	71
	Cattle	63
	Pigs	10
	Chickens	.22
	Turkeys	.90

Calculations: Manure/yr

$$\#\ animal\ units * \frac{lbs.manure}{animal\ /\ day} * \frac{365\ days}{year} * \frac{1\ ton}{2000\ lbs}$$

Source:	Manure/Animal /day	Manure Characteristics. MWPS-18 section 1.
	Locations of facilities	CGI
	Moisture %	Steffen, R., Szolar, O. and Braun, R. Feedstocks for Anaerobic Digestion. 1998. Institute for Agrobiotechnology, Tulln. University of Agricultural Sciences, Vienna. Kim, S., A. A. Agblevor, J. Lim. Fast pyrolysis of chicken litter and turkey litter in a fluidized bed reactor. Journal of Industrial and Engineering Chemistry, 15 (2009). 247-252.

Additional Work Needed: Specific info on amount of manure available from each facility

Notes: None

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Animal Manure: Small Farms

Biomass type units:	Tons manure/yr	
Biomass Reference Code:	DairyMan	Dairy manure
	CattlMan	Manure from cattle
	ChickMan	Chicken manure
	HogManur	Hog/pig manure
	SheepMan	Sheep manure

Variables:		
Moisture %	Dairy	91.5
	Cattle	91.5
	Pigs	94.5
	Chickens	33
	Sheep	33
Manure Yield per animal (lbs/animal/day)	Dairy	71
	Cattle	63
	Pigs	10
	Chickens	.22
	Sheep	4

Calculations: Manure/yr

$$\frac{\#\ animal\ units}{county} * \frac{lbs.manure}{animal\ /\ day} * \frac{365\ days}{year} * \frac{1\ ton}{2000\ lbs}$$

Source:	Manure/Animal /day	Manure Characteristics. MWPS-18 section 1.
	Census Data	National Agricultural Statistics Service
	Moisture %	Steffen, R., Szolar, O. and Braun, R. Feedstocks for Anaerobic Digestion. 1998. Institute for Agrobiotechnology, Tulln. University of Agricultural Sciences, Vienna. Kim, S., A. A. Agblevor, J. Lim. Fast pyrolysis of chicken litter and turkey litter in a fluidized bed reactor. Journal of Industrial and Engineering Chemistry, 15 (2009). 247-252.

Additional Work Needed: Locations of specific facilities. Also, specific information on some counties, rather than an average over the whole district.

Notes: None

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Cropland: Crop Residues

Biomass type units:	Tons crop residues/yr	
Biomass Reference Code:	CornStvr	Corn Stover
	Straw	Wheat Straw

Variables:

Moisture %	Corn Stover	15
	Wheat Straw	30

Corn composition: 67% of whole plant

Wheat composition: Used equation shown below, but could be a variable depending on area.

Crop Yield: Depends on the area in which the crop was harvested. Our data was from county level data from the NASS.

Calculations:

Tons Corn Grain (CG)/acre

$$\frac{Bushels\ CG}{acre} * \frac{56\ lbs}{bushel} * \frac{1\ ton}{2000\ lbs}$$

Tons Stover (CS)/acre

$$\frac{tons\ CG}{acre} * \frac{.67\ ton\ CS}{ton\ CG}$$

Tons straw/acre

$$\left(\frac{69.76\ lbs}{bushel\ wheat} * \frac{bushels\ wheat}{acre} + \frac{1067.7\ lbs}{acre}\right) * \frac{1\ ton}{2000\ lbs}$$

Source:

Crop Yields (bushels or tons/acre)	NASS
CS yield/CG	Shahab Sokhansanj, Engineering aspects of collecting corn stover for bioenergy . 2002. Biomass and Bioenergy. doi:10.1016/S0961-9534(02)00063-6
Wheat straw yield/acre	Kerstetter, J., J. Lyons. Wheat Straw for Ethanol Production in Washington: A resource, Technical, and Economic Assessment. 2001. Washington State University Cooperative Extension Energy Program.
Moisture % corn stover	A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover. NREL/TP-510-32438. 2002.
Moisture % Wheat Straw	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the Netherlands
Crop Weight/bushel	U.S. Commercial Bushel Sizes. http://www.unc.edu/~rowlett/units/scales/bushels.html

Additional Work Needed: All: Amount of crop is actually recoverable based on amount of residue is left on the field/used for other purposes

Sugar Beets: Pulp can be used as a source for energy but the facilities that produce it and the amount they produce has to be found first.

Soybeans: These are a substantial crop, and it is possible that residues are available from them.

Notes: Yield data was found by taking the overall production of crops for certain counties and dividing by the number of acres for that county to get the yield/acre. This data was not available for all counties from the NASS. The yield number is used in conjunction with the data from the cropland data layer to find the amount of crops available in an area.

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Cropland: Energy Crops

Biomass type units:	Tons energy crop/yr	
Biomass Reference Code:	CornGrai	Corn Grain
	SwitchGr	Switchgrass

Variables:

Crop Yield	Depends on the area in which the crop was harvested. Data was from NASS county level.	
Moisture %	Corn Grain	15
	Switchgrass	10

Calculations: Tons Corn Grain (CG)/acre

$$\frac{Bushels\ CG}{acre} * \frac{56\ lbs}{bushel} * \frac{1\ ton}{2000\ lbs}$$

Source:	Corn Grain Yield/acre	NASS
	Switchgrass Yield/acre	Barnes, R. F., C. J. Nelson, K. J. Moore and M. Collins. 2007. Biomass, Energy and Industrial Uses of Forages. Chapter 41 in: Forages, Vo. II, 6th ed. Blackwell Publishing.
	Moisture %: Corn Grain and Switchgrass	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the Netherlands
	Crop Weight/bushel	U.S. Commercial Bushel Sizes. http://www.unc.edu/~rowlett/units/scales /bushels.html

Additional Work Needed: All: Find out what idle land is actually useable.
Soybeans: consider them for growth as an energy crop

Notes: The yield data was found by taking the overall production of crops for certain counties, and dividing by the number of acres for that county, to get the yield/acre. This data was not available for all counties from the NASS. This yield number is used in conjunction with the data from the Cropland data layer to find the amount of crops available in an area. The energy crops are assumed to be grown on the “idle” land areas mentioned in Appendix A under the Cropland category.

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Appendix C: Transportation

General Equation:

$$\frac{140000\ Btu}{gallon\ petro\ diesel}_A * \frac{gallon}{5\ miles_B} * \frac{truck\ load}{80000\ lbs}_C * \frac{2000\ lbs}{ton}_D * \frac{1\ MBtu}{1000000\ Btus_E} = \frac{\frac{0.0007\ MBtus}{mile}}{ton\ biomass}$$

Explanation	A	Energy in diesel fuel	This value is constant
	B	Truck mileage	Depends on the type of truck being used. Variable
	C	Size of truck load	Depends on the type of truck and the density of the biomass. This value only changed in the case of energy crops, where better data was available. Variable
	D	Conversion	n/a
	E	Conversion	n/a

Sources:	A	Wikipedia. http://en.wikipedia.org/wiki/Diesel.	
	B	Harrigan, Time-Motion Study of Corn Silage Harvest Systems. Applied Engineering in Agriculture, Vol. 19(4). 389-395. 2003. Harrigan, personal communication with Sugar Beet Growers	
	C	Standard # (80000)	Personal communication with Dr. Chris Saffron, MSU, BAE
		Energy Crop #s	Deere and Co. 1993. Hay and Forage Harvesting. Chapter 9 in: Fundamentals of Machine Operation. Moline, IL.
	D	n/a	
	E	n/a	

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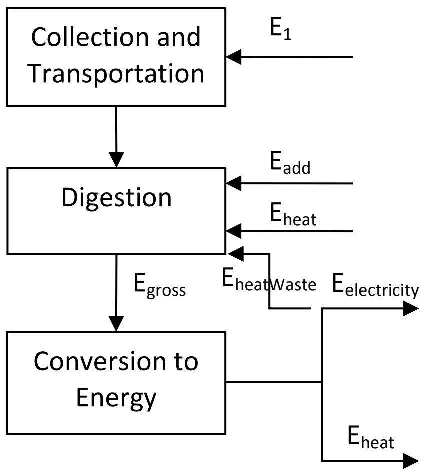
Appendix D: Conversion Technologies and Energy Produced

Anaerobic Digestion

Energy Balance Diagram



E_1: In the form of diesel fuel

E_2: Additional energy for digestion

E_3: Energy for heating

$E_{heatWas}$: Recycled heat from electrical conversion

E_{gross}: Gross energy available from biomass

$E_{(heat\ or\ electricity)}$=($E_{gross}$*conversion factor+ $E_{heatWas}$ -(E_1+E_2+E_3))

Biomass Sources Considered
- WWTP biosolids
- Food Waste
- Animal Manure (all varieties)
- Corn Stover
- Wheat Straw

Energy

E_1: Energy for Transportation. *See Appendix C.*

E_2: Additional energy requirement to run Digester (i.e. electrical)

General Equation:

$$\frac{MBTu}{dry\ ton}_A * .12_B$$

Explanation:			
	A	E_{gross}	This is the calculated amount of energy available from digesting the biomass
	B	Energy requirement %	A certain % of the energy produced that must be used to run the facility. Variable.

Sources:
- A n/a
- B Personal communication with project team

E_3: Energy needed to heat digester

General Eq.:

$$\frac{H2O\ lbs}{yr}_A * \frac{1\ Btu}{lb\ F}_B * (T_C - T_D) + \frac{dry\ lbs\ biomass}{yr}_E * \frac{X\ Btu}{lb\ F}_F * (T_C - T_D)$$

Explanation:			
	A	Mass H_2O/yr	This is the amount of water contained in the biomass. = Moisture% * amount wet biomass
	B	Specific heat of water	The amount of heat needed to raise the temperature of water

C	Temperature of reactor	Assumed to be 95 F
D	Ambient Temperature	The average yearly temperature of Michigan, 60 F
E	Dry tons biomass/yr	The amount of biomass with all water removed. = (1-Moisture %) * amount wet biomass
F	Specific Heat of Biomass	Assumed to be 1 if no other data was available

Sources:

- A n/a
- B The Engineering Toolbox online. Specific Heat Capacities. Available at www.Engineeringtoolbox.com.
- C Personal communication with Dr. Susie Liu, MSU, BAE.
- D n/a
- E n/a
- F The Engineering Toolbox online. Specific Heat Capacities. Available at www.Engineeringtoolbox.com.

E_{gross}

General Equation:

$$\frac{X\ m^3 biogas}{kg\ VS}_A * \frac{1\ mol\ biogas}{.0224\ m^3 biogas}_B * \frac{1000\ kg\ VS}{1.102\ ton\ VS}_C * \frac{Y\ mol\ CH4}{mol\ biogas}_D * \frac{890\ kJ}{mol\ CH4}_E * \frac{.875\ VS}{TS\ (dry\ ton)}_F * \frac{1\ MBtu}{1.055 * 10^6 kJ}_G$$

Explanation:

A	Biogas yield	Amount of biogas produced from anaerobically digesting substrate. Variable
B	Conversion Factor	For an ideal gas, the volume of one mol of substrate
C	Conversion factor	From kg to ton volatile solids (VS)
D	Methane Yield	Amount of biogas that is in form of methane. Variable
E	Heat of Combustion	From combusting methane to get heat
F	Percent total solid that is VS	Variable
G	Conversion Factor	n/a

Sources:

- A Steffen, R., Szolar, O. and Braun, R. Feedstocks for Anaerobic Digestion. 1998. Institute for Agrobiotechnology, Tulln. University of Agricultural Sciences, Vienna.
  Labutut, Rodrigo A. and Norm Scott. Experimental and Predicted Methane Yields from the Anaerobic Co-Digestion of Animal Manure with Complex Organic Substrates. 2008. Presented at the ASABE conference. Paper number 08.
- B n/a

C	n/a	
D	Same as (A)	
E	Felder, R. M., R. W. Rousseau. Elementary Principles of Chemical Processes. 3rd Edition. John Wiley and Sons, Inc., 2005.	
F	The Engineering Toolbox online. Specific Heat Capacities. Available at www.Engineeringtoolbox.com.	
G	n/a	

E_{heat}

General Equation:

$$\left(\frac{dry\ tons\ biomass}{yr}_A * \frac{.9\ yr\ on}{yr}_B * \frac{.75\ Btu\ useable}{Btu\ produced}_C * \frac{Gross\ MBtu}{dry\ ton\ biomass}_D\right) - \left(\frac{MBtu\ used}{dry\ ton}_E * \frac{.9\ yr\ on}{yr}_B * \frac{dry\ tons\ biomass}{yr}_A\right) - \left(\frac{MBtu\ for\ transport}{ton\ biomass/mile}_F * Miles\ travelled_G * \frac{tons\ biomass}{yr}_H\right) - \left(\frac{MBtu\ for\ heat}{yr}_I * \frac{.9\ yr\ on}{yr}_B\right)$$

Explanation:

A	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass
B	Online time of conversion	Amount of time in a year that the facility is running. Variable
C	Conversion efficiency of facility	Conversion efficiency for burning of methane to heat. Variable
D	Gross energy/dry ton biomass	E_{Gross}
E	Additional Energy Required	E_2
F	Transportation Energy	See Appendix C
G	Miles travelled from source to technology	From GIS tool
H	Wet tons biomass/yr	This assumes that the truck is moving the wet biomass, not dry
I	Energy for heating digester	E_3

Sources:

A	n/a
B	Personal Communication with project team
C	Personal Communication with project team
D-I	n/a

$E_{electricity}$ (and $E_{heatWast}$)

General Equation: Note: add in the waste heat that is recycled back to the digester to help keep heat it. User must have the option to select this or not, since some facilities are not able to recycle this heat. Also, the conversion efficiency to electricity is lower than that for heat, but the overall net energy equation is the same, minus this the addition of this term for electricity:

$$\frac{waste\ heat}{total\ heat\ produced}_A * \frac{heat\ recoverable}{waste\ heat}_B * \frac{Gross\ Energy}{dry\ ton\ biomass}_C * \frac{Dry\ tons\ biomass}{yr}_D$$

Explanation	A	Amount of heat available to recycle	1-electric conversion factor. This is the amount of energy lost as heat to the environment. Variable
	B	Heat Recoverable	The amount of (A) that is recoverable. Variable.
	C	Gross Energy	E_{Gross}
	D	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass

Sources:	A	Personal Communication with project team
	B	Personal Communication with project team
	C	n/a
	D-I	n/a

Additional Work

Gross Energy: number can also be calculated based on the COD, BOD, biogas generation value, or a few other variables. This data is known for sources that are currently not being considered.
Heat added: need more values for the specific heats of biomass
Heat recycled: need actual values for what can be recycled.
Conversion efficiency: need values for actual efficiency.
All: need to consider many more sources, such as food processing waste water, ethanol LFS, and others

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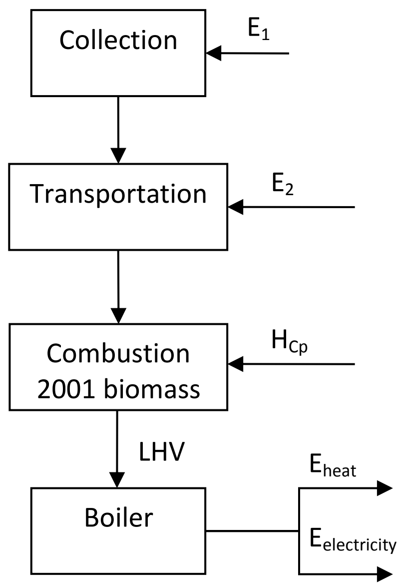
Combustion

Energy Balance Diagram



E1: collection

E2: In the form of diesel fuel

H_{Cp}: amount of energy needed to heat products to furnace temp

LHV: amount energy from combusting biomass

E(heat or elec)= conversion factor*(LHV-E1-E2-Cp)

Biomass Sources Considered

Corn Stover
Wheat Straw
Animal Manure (all varieties)
Food Waste

Reaction

$$aCxHyOz_s + bO2_g + eH2O_l \rightarrow cCO2_g + dH2O_v + eH2O_v$$

Combustion Process Flow Chart

$$reactants\ at\ 77\ F \rightarrow products\ at\ 77\ F \rightarrow products\ at\ furnace\ temp$$

Step one will release energy in the form of heat, based off the LHV of the biomass. Step two requires energy, to account for the furnace at its actual temperature. Note that the lower heating value LHV is used because the combustion of biomass leads to water in vapor form, requiring more energy.

Calculation of Mol Fractions and balanced stoichiometric equation

Mol fractions:	Divided mass fraction by summation of mass fractions of biomass.
Average molecular weight of biomass	C, H, O mol fractions multiplied by the atomic masses.
x, y, z	Mol fraction of C, H, O over mol fraction C
a, b, c, d, e	Balanced stoichimetric coefficients, assuming 1 mol biomass reacting

Source	Mass Fractions of biomass	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy

research Centre of the Netherlands

Energy

E_1: Collection Energy (only applies to crop residues)

General Equation:

$$\frac{X\ MJ}{kg}_A * \frac{947.1\ Btu}{MJ}_B * \frac{1000\ kg}{1.102\ dry\ tons\ corn\ stover}_C$$

Explanation			
	A	Energy for collection of residue	This is the amount of energy needed to collect the residue from the field and prepare it for transport. Variable
	B	Conversion Factor	n/a
	C	Conversion Factor	n/a

Sources:		
	A	Kim, S., B. E. Dale, R. Jenkins. Life cycle assessment of corn grain and corn stover in the United States. 2009. International Journal of Life Cycle Assessment. 14:160-174.
	B	n/a
	C	n/a

E_2: Transportation Energy. See Appendix C.

H_{Cp}: Energy needed to heat furnace to operating temperature. This number included adding the specific heat capacities for CO2 and H2O, as well as the Heat of vaporization of H2O. The reactor was assumed to have to heat from 77 F to 800 F . The final reactor temp is a variable

Source: Felder, R. M., R. W. Rousseau. Elementary Principles of Chemical Processes. 3rd Edition. John Wiley and Sons, Inc., 2005.

LHV

General Equation:

$$(0.3491_A * C\ \%_B + 1.1783_A * H\ \%_C + 0.1005_A * S\ \%_D - 0.1034_A * O\ \%_E - 0.0151_A * N\ \%_F - 0.0211_A * Ash\ \%_G) * \left(\frac{907.2\ kg}{ton}_H * \frac{947.1\ Btu}{MJ}_I * \frac{1\ MBtu}{10^6 Btu}_J\right) - \left(\frac{ton-mol\ H2O}{ton-mol\ biomass}_K * \frac{18934\ Btu}{lb-mol\ H2O}_L * \frac{2000\ lb-mol}{ton-mol}_M * \frac{1 Mbtu}{10^6 Btu}_N * \frac{1\ ton-mol\ H2O}{18.02\ ton\ H2O}_O\right)$$

Explanation			
	A	Equation from Channiwala	This is a number in the equation from Chaniwala
	B	C mass %	The mass % of C for the biomass Variable
	C	H mass %	The mass % of H for the biomass. Variable
	D	S mass %	The mass % of S for the biomass. Variable
	E	O mass %	The mass % of O for the biomass. Variable
	F	N mass %	The mass % of N for the biomass. Variable
	G	Ash mass %	The mass % of ash for the biomass. Variable
	H	Conversion	n/a
	I	Conversion	n/a
	J	Conversion	n/a

K	Mol fraction of H2O (based off of stoichiometric coefficient d)	The amount of water produced as a vapor from combusting the biomass
L	Heat of vaporization of H2O	Accounts for the water coming off as a vapor
M	Conversion	n/a
N	Conversion	n/a
O	Molecular Weight of H2O	n/a

Sources:

A Channiwala, S. A. and P. P. Parikh. A unified correlation for estimating HHV of solid, liquid and gaseous fuels. 2001. Fuel 81: 1051-1063.

B-G Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the Netherlands

Kim, S., A. A. Agblevor, J. Lim. Fast pyrolysis of chicken litter and turkey litter in a fluiized bed reactor. Journal of Industrial and Engineering Chemistry, 15 (2009). 247-252.

H-K n/a

L Felder, R. M., R. W. Rousseau. Elementary Principles of Chemical Processes. 3rd Edition. John Wiley and Sons, Inc., 2005.

M-O n/a

$E_{heat\ or\ electricity}$

General Equation:

$$\left(\frac{Dry\ tons\ biomass}{yr}\right)_A * \left(\frac{MBtu\ heat\ produced}{MBtu\ total}_B * \frac{MBtu\ produced}{dry\ ton\ biomass}_C - \frac{MBtu\ consumed}{dry\ ton\ biomass}_D\right) - \left(\frac{wet\ tons\ biomass}{yr}_E * \frac{MBtu}{wet\ tons\ biomass * mile}_F * miles_G\right) - \left(\frac{Tons\ Water}{Wet\ tons\ biomass}_H * \frac{Wet\ tons\ biomass}{yr}_E * \frac{MBtu\ to\ vaporize}{ton\ Water}_I\right)$$

Explanation

A	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass
B	Conversion Efficiency of Heat or Electricity	Depends on the technology being used. Variable.
C	LHV of biomass	Calculated earlier
D	Energy Requirements	For the collection of crop residues. E_1
E	Total tons biomass	n/a
F	Transportation Energy	See Appendix C

G	Miles travelled from source to technology	From GIS tool
H	Moisture percentage	Variable
I	H_{Cp}	Shown earlier

Additional Work

Temperature: determine the actual running temperature of a combustion furnace
Efficiency: determine the actual conversion efficiency of a facility to heat or electricity
Mass fractions: need more accurate information on the mass fractions of different biomass sources or the empirical formula of them

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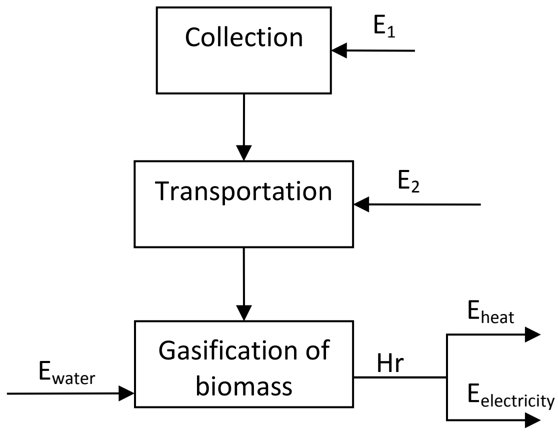
Gasification



E_1: collection

E_2: In the form of diesel fuel

E_{water}: Needed to vaporize H2O

$E_{(heat\ or\ elec)}$= conversion factor * H_r - E_1 - E_2 - E_{water}

Biomass Sources Considered

Corn Stover
Wheat Straw
Animal Manure (all varieties)
Food Waste

Energy *E_1: Collection Energy (only applies to crop residues)*

General Equation:

$$\frac{X\ MJ}{kg}_A * \frac{947.1\ Btu}{MJ}_B * \frac{1000\ kg}{1.102\ dry\ tons\ corn\ stover}_C$$

Explanation			
	A	Energy for collection of residue	This is the amount of energy needed to collect the residue from the field and prepare it for transport. Variable
	B	Conversion Factor	n/a
	C	Conversion Factor	n/a

Sources:

A Kim, S., B. E. Dale, R. Jenkins. Life cycle assessment of corn grain and corn stover in the United States. 2009. International Journal of Life Cycle Assessment. 14:160-174.
B n/a
C n/a

E_2: Transportation Energy. See Appendix C.

E_{water}: This is the energy needed to vaporize the water off of the biomass
Source: Personal Communication with Greg Mulder

H_r: This is the gross energy yield for gasification of waste water treatment plant bio solids. This number is a rough estimation for all biomass sources.
Source: Personal Communication with Greg Mulder

$E_{heat\ or\ electricity}$

General Equation:

$$\left(\frac{MBtu\ heat\ produced}{MBtu\ total}_A * \frac{Dry\ tons\ biomass}{yr}_B * \frac{15\ MBtu}{dry\ ton\ biomass}_C - \left(\frac{Dry\ tons\ biomass}{yr}_B * \frac{MBtu\ consumed}{dry\ ton\ biomass}_D\right) - \left(\frac{Tons\ Water}{Wet\ tons\ biomass}_E * \frac{Wet\ tons\ biomass}{yr}_F * \frac{MBtu\ to\ vaporize}{ton\ Water}_G\right) - \left(\frac{wet\ tons\ biomass}{yr}_F * \frac{MBtu}{wet\ tons\ biomass * mile}_H * miles_I\right)\right.$$

$$\left(\frac{TS}{year}_A * \frac{Hr\ kJ}{TS}_B - \frac{water}{year}_C * \frac{kJ\ heat}{water}_D\right) * \frac{kJ\ actual}{kJ\ theoretical}_E$$

Explanation

A	Conversion Efficiency of Heat or Electricity	Depends on the technology being used. Variable.
B	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass
C	H_r	Mentioned above
D	Energy Requirements	For the collection of crop residues. E_1
E	Total tons biomass	n/a
F	Moisture %	Variable
G	E_{water}	Mentioned above
H	Transportation Energy	See above
I	Miles travelled	From GIS map

Additional Work All: a more sophisticated analysis was done like that for combustion but it needs to be refined. Specifically, the exact reaction taking place in a gasifier needs to be known

This is heavily based on estimations.

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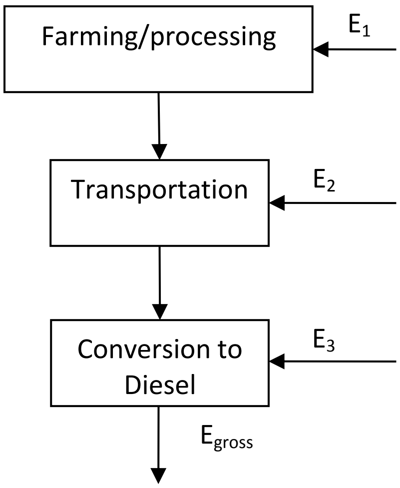
Biodiesel Production



E_1: includes collection and processing in order to convert to diesel

E_2: In the form of diesel fuel

E_3: In the form of heat

E_{gross}: Gross energy available from biomass in the form of diesel

$E_{net} = E_{gross} - (E_1 + E_2 + E_3)$

Biomass Sources Considered Corn Oil (From Corn Grain)

Energy E_1: Collection Energy (only applies to crop residues)

Source: "The Energy Balance of Corn Ethanol: An Update" Agricultural Economic Report No. 814, USDA, July 2002.

E_2: Transportation Energy. See Appendix C.

E_3: This is the energy needed to convert the biomass to biodiesel. Same source as E_1

E_{gross}:

General Equation:

$$\frac{gallon}{lbs}_A * \frac{130000\ Btus}{gallon}_B ** \frac{1\ MBtu}{1000000\ Btus_D}$$

$$\frac{amount\ biomass}{year}_A * \frac{gallon\ biodiesel}{amount\ biomass_B} * \frac{130000\ Btus}{gallon\ biodiesel_C}$$

Explanation	A	Density of feedstock	Variable
	B	Energy value of biodiesel	n/a
	C	Conversion factor	n/a
	D	Conversion factor	n/a

Sources

A Tyson, K.S., J. Bozell, R. Wallace, E. Peterson, and L. Moens. "Biomass Oil Analysis: Research Needs and Recommendations". National Renewable Energy Laboratory; NREL/TP-510-34796, June 2004.

B Hoffman, V. "Biodiesel Fuel", AE-1240. North Dakota State University Extension Service, February, 2003.

C n/a

D n/a

E_{net}: Note, for crop sources, this number is based on amount of crop oil, not crop itself.

General Equation:

$$\frac{m\ tons\ oil}{yr}_A * \left(\frac{MBtu\ produced}{ton\ oil}_B - \frac{MBtu\ consumed}{ton\ oil}_C\right) - \left(\frac{wet\ tons\ biomass}{yr}_D * \frac{MBtu}{wet\ tons\ biomass * mile}_E * miles_F\right)$$

Explanation	A	Tons crop oil	Amount of oil available from crop
	B	Gross Energy of biodiesel	Shown above
	C	Energy for processing	Shown Above (E_1 and E_3)
	D-F	Energy for Transportation	From Appendix C

Additional Work Include more sources, find where they come from.

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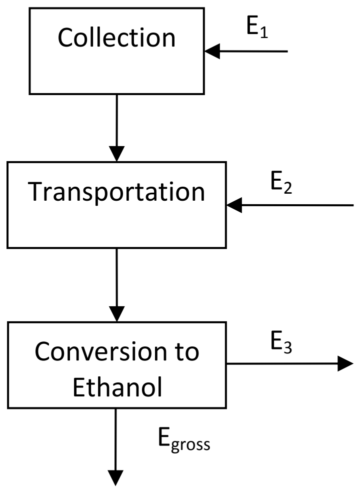
Ethanol Production



E_1: collection (for energy crops, full production) of crops

E_2: In the form of diesel fuel

E_3: Extra electrical energy produced

E_{gross}: Gross energy available from biomass in the form of Ethanol

Biomass Sources Considered

- Corn Stover
- Wheat Straw
- Corn Grain
- Switchgrass
- Food Waste

Estimated amount ethanol

General Equation:

$$\frac{TS}{year}_A * [(\frac{Cellulose}{TS} * \frac{1\ ton\ glucose}{0.9\ ton\ Ce} * \frac{0.51\ ton\ EtOH}{ton\ glucose} * \frac{0.8\ tons\ EtOH(a)}{ton\ EtOH}_B) + (\frac{HemiCellulose}{TS} * \frac{1\ ton\ Xyulose}{0.88\ ton\ HC} * \frac{0.51\ ton\ EtOH}{ton\ Xyulose} * \frac{0.8\ tons\ EtOH\ (a)}{ton\ EtOH}_C)]$$

Explanation:	A	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass
	B	Cellulose content	% of biomass in the form of cellulose. Variable
	C	Stoichiometry	Cellulose to glucose
	D	Stoichiometry	Glucose to Ethanol, maximum yield of ethanol
	E	Actual Yield	Actual yield of ethanol from Cellulose. Variable
	F	Hemicellulose content	% of biomass in the form of hemicellulose. Variable
	G	Stoichiometry	Hemicellulose to Xyulose
	H	Stoichiometry	Xyulose to Ethanol, maximum yield of ethanol
	I	Actual Yield	Actual yield of ethanol from Hemicellulose. Variable.
Sources:	A	n/a	
	B	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the	

Netherlands
Switchgrass: From Brummer, et al., 2002. In: Barnes, et al. Chapter 41, Forages, Vol. II.

C-E Personal Communication with Dr. Chriss Saffron, MSU, BAE

F Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the Netherlands
Switchgrass: From Brummer, et al., 2002. In: Barnes, et al. Chapter 41, Forages, Vol. II.

G-I Personal Communication with Dr. Chriss Saffron, MSU, BAE

Energy E_1: Collection Energy (only applies to crop residues and energy crops) Variable

Source:

Crop Residues: Life Cycle assessment of Corn Grain and Stover in the United States. International Journal of Life cycle assessment (2009). 14: 160-174

Corn Grain: Kraatz, S. , W. Berg, and D.J. Reinemann. Energy inputs for corn production in Wisconsin. Applied Engineering in Agriculture (in press).

Switchgrass: Based off of production for alfalfa, since numbers are not available for switchgrass.
From Martin, 1998. In: Barnes, R. F., C. J. Nelson, K. J. Moore and M. Collins. 2007. Biomass, Energy, and Industrial Uses of Forages. Chapter 41 in: Forages, Vol. II, 6th ed. Blackwell Publishing

E_2: Transportation Energy. See Appendix C.

E_3: Extra Electrical Energy Produced.

General Equation:

$$\frac{16\ MMkcal}{hr}_A * \frac{hr}{174\ MMkcal_B} * \frac{E_{gross}\ MBtu}{ton\ EtOH}_C$$

Explanation:

A	Facility Production	The total electrical energy produced by a facility by burning off residues
B	Ethanol Energy	Total energy produced in the form of ethanol from a facility. A/B gives the % of energy that is made in the form of electricity per ethanol energy made.
C	E_{gross}	The amount of energy made in the form of ethanol

Sources:

A-B A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover. 2002. NREL/TP-510-32438

C n/a

E_{gross}: energy produced in the form of ethanol

General Equation:

$$\frac{75700\ Btu}{gal\ EtOH}_A * \frac{gal\ EtOH}{.00329\ tons\ EtOH_B} * \frac{1\ MBtu}{1000000\ Btus_C}$$

Explanation A LHV of ethanol Assuming that the water comes off as a vapor, this is the total amount energy available if the ethanol

			is combusted
	B	Density of Ethanol	n/a
	C	Conversion	n/a

Sources: A-B LHV of ethanol. http://bioenergy.ornl.gov/papers/misc/energy_conv.html
C n/a

E_{net}

General Equation:

$$\frac{tons\ EtOH}{yr}_A * \left(\frac{MBtu\ produced}{ton\ EtOH}_B + \frac{MBtu\ electrical}{ton\ EtOH}_C\right) - \frac{Dry\ Tons\ Biomass}{yr}_D * \frac{MBtu\ used}{dry\ ton\ biomass}_E - \frac{tons\ biomass}{yr}_F * \frac{0.0007\ MBtu}{\frac{mile}{ton}\ biomass}_G * miles_H$$

Explanation	A	Amount ethanol	Calculated above
	B	E_{gross}	Calculated above
	C	E_3	Calculated above
	D	Dry tons biomass/yr	Total solid % of biomass * wet tons biomass
	E	E_1	Calculated above
	F	Total tons biomass	From GIS map
	G	Transportation Energy	See Appendix C
	H	Miles travelled from source to technology	From GIS tool

Additional Work

More about the energy balance around an ethanol facility
More accurate data on ethanol yield from each biomass

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Appendix E: Data Tables and Sources

Anaerobic Digestion

Bakery Waste

Ton COD/dry ton Biomass	COD Concentration (g/L)	TS Concentration (g/L)	COD destruction
1.6	23.5	15.1	97.3

Source: 1- Byong S. Shin, Carl W. Eklund and Kenneth V. Lensmeyer (1990) Bakery Waste Treatment by an Anaerobic Contact Process Research Journal of the Water Pollution Control Federation, Vol. 62(7), 920-925.

Fish processing and Slaughter House Waste

Feedstock	TS (g/L)	VS (g/L)	COD Destruction	COD/dry ton
all animal mortilities	59.0	55.5	94.0	2295.5
fish waste	26.1			1197.2

Source: 2- Garcia, A. J., Esteban, M.B., Marquez, M.C., Ramos, P. (2005) Biodegradable municipal solid waste: characterization and potential use as animal feedstuffs. Waste Management 25, 780-787.

3- Irini Angelidaki, Lars Ellegaard, Birgitte K. Ahring (1999) A Comprehensive Model of Anaerobic Bioconversion of Complex Substrates to Biogas Biotechnology and Bioengineering, Vol 63 (3), 363-372.

Food Processing Wastewater 1

Feedstock	TS lb/ton raw product	BOD lb/ton raw product
Potatoes	116.4	76.4
Pumpkins	60.9	29.1
Peppers	52.7	31.8
Broccoli	35.5	18.2
Onions	15.5	51.8
Carrots	15.5	27.3
Squash[1]	12.7	18.2
Peas	10.0	34.5
Corn, Sweet	9.1	24.5
Peaches	7.8	31.8
Cucumbers	7.5	38.2
Cauliflower	7.1	14.5
Blueberries	6.5	17.3
Beans, Snap	5.5	13.6

Source: 4- Liu Y, Miller S, Safferman S (2009) Screening co-digestion of food waste water with manure for biogas production, Biofuels, Bioproducts and Biorefining, 3(1), 11-19.

Food Processing Wastewater 2 and WWTP biosolids

Feedstock	BOD (g/kg)	COD (g/kg)	TS (g/kg)	VS (g/kg)	TOC (g/kg)	TKN (g/kg)	Biogas Yield (mL/g TVS)
Cheese Whey	64.9	128.3	71.4	59.8	39.6	1.2	423.6
Plain Pasta	188.7	934.3	422.6	407.7	298.3	12.3	326.1
Vegetable Oil	600	1205	991	988.8	-	-	648.5
Ice Cream	-	266.8	113.8	109.1	-	-	502.3
Fresh Dog Food	-	530.4	132.2	125.6	-	-	426.6
Cola Soda	-	121.5	93.6	88.7	46.6	0	373.1
Potatoes	53.5	261.8	177.4	163.5	-	4	334.5
WWTP Biosolids	201	600.1	267.2	229.7	-	-	407.3
Switchgrass	88.6	706.7	930.1	904.9	91.1	8	122.2

Source:

5- Labutut, Rodrigo A. and Norm Scott. Experimental and Predicted Methane Yields from the Anaerobic Co-Digestion of Animal Manure with Complex Organic Substrates. 2008. Presented at the ASABE conference. Paper number 08.

Food Waste/Animal Manure

Feedstock	Moisture %	VS % (of TS)	Biogas Yield (m^3/kg VS)	CH4 Content
Food Waste	90	80	0.25-0.50	-
Beef/Dairy Manure	91.5	80	0.20-0.30	55-75
Sheep	75	83	-	-
Swine	94.5	75	0.25-0.50	70-80
Turkey/Chicken	33	75	0.35-0.60	60-80
Straw/Corn Stover	15-30	90	0.35-0.45	-

Source:

6- Steffen, R., Szolar, O. and Braun, R. Feedstocks for Anaerobic Digestion. 1998. Institute for Agrobiotechnology, Tulln. University of Agricultural Sciences, Vienna.

7- Kim, S., A. A. Agblevor, J. Lim. Fast pyrolysis of chicken litter and turkey litter in a fluiized bed reactor. Journal of Industrial and Engineering Chemistry, 15 (2009). 247-252.

8- Manure Characteristics. MWPS-18 section 1.

Sugar Beet Pulp

Biogas Generation (m^3/kg dry beet pulp) 0.391

Source:

9- M. Hutnan, M. Drtil, J. Derco, L. Mrafkova, M. Hornak, S. Mico (2001) Two-Step Pilot-Scale Anaerobic Treatment of Sugar Beet Pulp.

Polish Journal of Environmental Studies Vol. 10 (4), 237-243.

Specific Heat Data

10- www.Engineeringtoolbox.com

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Combustion/Gasification

% Mass Composition

Feedstock	C %	H %	S%	O%	N%	Ash%
Corn Stover	44.0	5.4	0.1	38.9	0.6	4.7
Wheat Straw	46	5.5	0.1	41.4	1.65	5
Sugar Beet Pulp	44.5	5.9	0.13	42	1.84	4.8
Dairy/Beef Manure	45.4	-	0.29	31	0.96	15.9
Sheep Manure	40.6	-	0.6	30.7	2.1	20.9
Turkey/Chicken Manure	46.5	-	0.63	37.2	5.75	0
Swine Manure	35	-	0	21.3	2.79	35.4
Food Waste	51.2	-	0.16	40.1	1.74	0

Source:

11- Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis. Energy research Centre of the Netherlands

12- BIOBIB. http://www.vt.tuwien.ac.at/biobib/biobib.html
(7) for Turkey and Chicken Manure

LHV calculation

Source:

13- Channiwala, S. A. and P. P. Parikh. A unified correlation for estimating HHV of solid, liquid and gaseous fuels. 2001. Fuel 81: 1051-1063.

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Biodiesel

Gross Energy: Trap Grease, Poultry Fat, Tallow, Soybean and Corn Oil

Density: 7.4 lbs./gallon biodiesel
Energy Value: 130,000 BTUs/gal biodiesel

Source:

14- Tyson, K.S., J. Bozell, R. Wallace, E. Peterson, and L. Moens. “Biomass Oil Analysis: Research Needs and Recommendations”. National Renewable Energy Laboratory; NREL/TP-510-34796, June 2004.

Gross Energy: Yellow Grease

Density: 7.65 lbs./gallon biodiesel
Energy Value

Source:

15- Radich, A. “Biodiesel Performance, Costs and Use”. eia.doe.gov.

Energy Requirements: Soybean Oil

Source:

16- Sheehan, J., V. Camobreco, J. Duffield, M. Graboski, H. Shapouri. “Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus”, National Renewable Energy Laboratory, May 1998

Energy Requirements: Corn Oil

Source: 17- H. Shapouri, J. Duffield, and M. Wang. "The Energy Balance of Corn Ethanol: An Update" Agricultural Economic Report No. 814, USDA, July 2002

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Ethanol

Composition Information

Feedstock	Cellulose %	Hemicellulose %
Corn Grain	37	24
Switchgrass	36	32
Corn Stover	37	24
Wheat Straw	33	25
Sugar Beet Pulp	26	28
Food Waste	14	21

Source: 18- Switchgrass: From Brummer, et al., 2002. In: Barnes, et al. Chapter 41, Forages, Vol. II.
Beet Pulp: (9)
Others: (11)

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$$\frac{TS}{year}_A * [(\frac{Cellulose}{TS} * \frac{1\ ton\ glucose}{0.9\ ton\ Ce} * \frac{0.51\ ton\ EtOH}{ton\ glucose} * \frac{0.8\ tons\ EtOH(a)}{ton\ EtOH}_B) + (\frac{HemiCellulose}{TS} * \frac{1\ ton\ Xylose}{0.88\ ton\ HC} * \frac{0.51\ ton\ EtOH}{ton\ Xylose} * \frac{0.8\ tons\ EtOH\ (a)}{ton\ EtOH}_C)]$$