Biomass Inventory Technology and Economics Assessment

Report 1. Characteristics of Biomass

By
Wei Liao, Craig Frear and Shulin Chen

Washington State University
Center for Bioproducts and Bioenergy

Ecology Publication No. 07-07-025

June 27, 2007

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This work was completed under an Interagency Agreement No. C07600136 between the Department of Ecology and Washington State University. This agreement was established as a partnership to complete work on Waste to Fuel Technology, directed by the Washington State Legislature in Engrossed Senate Substitute Bill 6386 of the 59th legislature, 2006 regular session.

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Executive Summary

The purpose of this project is to study potential energy production technologies for biomass feedstocks available in Washington State. The project includes four parts: 1). characterizing 42 feedstocks according to their chemical properties such as carbon content, protein content, fiber content, etc.; 2). identifying and grouping the feedstocks; 3). simulating the potential conversion processes such as thermal-chemical conversion, anaerobic digestion, and ethanol production on individual feedstock or their combinations; and 4). economic analysis of the processes from feedstock collection and distribution to energy production.

It is important both for the ensuing research and end-users of the research to know the characteristics of the feedstocks in order to select the proper conversion process to produce bioenergy products. Thus, the characterization of these 42 feedstocks has been conducted as the first effort to fulfill this project. A wide literature search for the available characterization data as well as fill-in gaps with laboratory analysis generated a detailed feedstock database that is configured by five categories (fiber/starch/sugar, ultimate analysis, elemental analysis, other parameters), and includes 33 parameters such as moisture, carbon, starch, cellulose, minerals, etc. The database could be used not only by the researchers to conduct the next steps of the project to identify and group the feedstocks and further simulate the conversion processes, but also by farmers and producers to know more about the agricultural and municipal residues they are producing or plan to utilize.

1. Introduction

Multiple national and state projects have been completed over the years in an attempt to inventory available biomass. These reports were reviewed as background for the Washington State Biomass Inventory. On the national front, Oak Ridge National Laboratory, the Energy Information Administration, the Office of Energy Efficiency and Renewable Energy, as well as the University of North Dakota Energy and Environmental Research Center and the Energy Foundation have individually or collaboratively developed several biomass reports aimed at determining the raw tonnage and potential energy available within the country down to a regional and even state level. Several states also have taken the initiative to develop their own inventories including Wyoming, Ohio, Vermont, Connecticut, California, Minnesota, Oklahoma, New Mexico and in part Oregon and Colorado with the list continuing to grow yearly.

Whereas other inventories sometimes included energy crops such as poplar stands and switchgrass or cash crop biomass such as harvested timber and/or grain, the Washington State inventory (http://www.ecy.wa.gov/biblio/0507047.htm) completed in December 2005 focused on under-utilized biomass or 'organic wastes'. This project geographically identified, categorized, and mapped 45 potential sources in Washington at a county level. The categories included field residues, animal manures, forestry residues, food packing/processing waste, and municipal wastes.

Interagency Agreement # C-0700136, establishing a partnership between the Washington State Department of Ecology and Washington State University implements the 2006 supplemental budget funding of the Waste to Fuels Technology (XQ) project. The Agri-Environmental and Bioproducts Engineering (AEBE) research group of the Center of Bioproducts and Bioenergy and the Department of Biological Systems Engineering at Washington State University (WSU) is conducting the study.

The biomass was classified into two categories: woody lignocellulosic materials and non-woody wet materials. The purposes of the follow-up phase II study are to: 1) review and report on potential energy recovery technologies for biomass feedstocks; 2) develop a list of chemical characteristics for each of the feedstocks; 3) create a best fit determination matrix of current energy technologies for applicability to feedstock types; 4) assess energy production outcomes for given technologies and feedstocks; 5) evaluate feedstock collection and transportation costs through GIS supply curves and assess waste generation and recovery options against the earlier described energy production assessment for given technologies and feedstocks, and 6) complete a final report summarizing economic factors and findings to consider in facility development.

The first task of the phase II study was the characterization of the feedstocks. The objective of this task is to conduct a broad literature search and additional laboratory analysis where necessary to provide the best available characterization data for the feedstocks.

2. Methods

The characteristics of 42 feedstocks have been tabulated in this report. Thirty two parameters were chosen to describe the feedstocks to meet the requirements of the technology assessment (Table 1). These 32 parameters were classified into six categories: carbohydrates, proteins/ammonia, fats/lipids, ultimate analysis, elemental analysis, and other.

Table 1. Parameters used to characterize the biomass

Category	Parameter	Description	Reference
Carbohydrates	NDF	NDF represents Neutral Detergent Fiber. It is the most common measure of fiber used for cellulosic material analysis, but it does not represent a unique class of chemical compounds. NDF measures most of the structural components in plant cells (lignin, hemicellulose, and cellulose), but not pectin.	[7]
	ADF	ADF represents Acid detergent fiber. An acidified quaternary detergent solution is used to dissolve cell solubles, hemicellulose and soluble minerals leaving a residue of cellulose, lignin, and minerals (ash). ADF is determined gravimetrically as the residue remaining after extraction.	[7]
	ADL	ADL represents acid detergent lignin. An acidified solution is used to dissolve lignin from fiber.	[7]
	Cellulose	Cellulose is a polysaccharide derived from beta-glucose, which is the primary structural component of plants. Cellulose contains only anhydrous glucose. Cellulose content can be estimated by ADF minus ADL.	[7]
	Hemicellulose	Hemicellulose is a heteropolymer (matrix polysaccharide) present in cell walls along with cellulose. Hemicellulose contains many different sugar monomers such as glucose, xylose, mannose, galactose, rhamnose, and arabinose. Hemicellulose content can be calculated by substracting ADF from NDF.	[7]
	Lignin	Lignin is a chemical compound (cross-linked aromatic polymer) that fills the space in the cell wall between cellulose and hemicellulose. It confers mechanical strength to the cell wall and therefore the entire plant. It is relatively hydrophobic and aromatic in nature. Lignin content can be approximately expressed by ADL.	[7]
	Starch	Starch is a complex carbohydrate that is used by plants to store excess glucose. Different from cellulose, starch polymer is derived from alpha-	[2]

		glucose, which makes it relatively easy to be deconstructed into mono-sugars by enzymes and acids.	
	Sugar	Sugar generally refers to monosaccharide (i.e. glucose) and disaccharide (i.e. maltose)	[2]
Lipid	Ether extraction	Ether extraction is a standard measurement that is used to quantify the amount of lipid/fat in the biomass. It applies ether to extract Lipid/fat from biomasses, then recovers the ether from the lipid/fat, further obtaining the lipid/fat content.	[2]
	Fatty acid distribution	All fatty acids in lipid/fat such as C14:0, C16:1, and C18:3 are measured by gas chromatography. The fatty acid distribution can be tabulated based on the content of each individual fatty acid.	[31]
Ultimate analysis	C, H, O, N, S, Ash	Ultimate analysis gives the composition of the biomass in weight-based percentage of carbon, hydrogen and oxygen as well as sulfur and nitrogen.	[30]
Elementa l analysis	Ca, P, K, Cl, Zn	Elemental analysis is used to quantify the trace elements in the biomasses.	[4]
Others	Dry matter	Dry matter is the mass of an item minus its moisture content.	[4]
	Crude protein	The crude protein concentration in biomass is determined using the Kjeldahl procedure that measures the nitrogen content in the sample. Since most biomass contains about 16% nitrogen, crude protein is estimated by multiplying the nitrogen concentration by 6.25 (the inverse of 16%). However, some portion of the nitrogen in biomass is found as non-protein nitrogen, therefore, the value calculated by multiplying N x 6.25 is referred to as crude rather than true protein.	[4]
	TS	TS represents total solid. It is another way to refer to dry matter.	[4]
	VS	VS represent volatile solids. Volatile solids are the solids being removed by firing a biomass sample in a 550^{o}C muffle furnace.	[4]
	TSS	TSS represents total suspended solid. TSS is determined by pouring a carefully measured volume of liquid sample through a pre-weighed filter of a specified pore size, then weighing the filter again after drying. The gain in weight is a dry weight measure of the particulates present in the liquid sample expressed in units calculated from the	[4]

		volume of liquid sample filtered (typically milligrams per liter or mg/l).	
	VSS	VSS represents volatile suspended solid. After measuring the total suspended solids (TSS), fire the crucible in a 550^{o}C muffle furnace for 1 hour. Weigh the crucible plus the remaining solids. This is the fixed suspended solids. The difference between the total and fixed suspended solids is the volatile suspended solids.	[4]
	COD	COD represents chemial oxygen demand. The COD test is commonly used to indirectly measure the amount of organic compounds in liquid samples. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution.	[4]
	BOD5	BOD represents biological oxygen demand in 5 days of culture time. BOD measures the rate of uptake of oxygen by micro-organisms in liquid samples at a fixed temperature (20°C) and over a given period of time (usually 5 days) in the dark.	[4]
	TKN	TKN represents total kjeldahl nitrogen. TKN is an analysis to determine both the organic nitrogen and the ammonia nitrogen. The analysis involves a preliminary digestion to convert the organic nitrogen to ammonia, then distillation of the total ammonia into an acid absorbing solution and determination of the ammonia by an appropriate method.	[2]
	NH_3N	NH_3N is called ammonia nitrogen. NH_3N is the summed weight of nitrogen in both the ionized (ammonium, NH_4^+) and molecular (NH_3) forms of dissolved ammonia.	[4]
	NO_3N	NO_3N is called nitrate nitrogen. It represents the amount of nitrogen in biomass samples found in the form of nitrates.	[4]
	pH	pH is a measure of the acidity or alkalinity of a solution.	[4]

The category of carbohydrates includes parameters such as cellulose, hemicellulose, lignin, starch, sugar, etc. that are essential for the assessment of bioethanol fuel and other bioproducts based on a sugar platform. It is well-known that mono-sugars such as glucose, xylose, arabinose etc. are the intermediate substances to biologically and chemically produce renewable energy and chemical products. Cellulose, hemicellulose, and starch from plants and crops are the main resources of the sugars. Lignin as an integral part of the cell walls of plants, fills the spaces in the cell wall between cellulose and hemicellulose, and confers mechanical strength to the cell wall and the entire plant. During the process of releasing sugars from crops and plants, lignin plays a role to protect cellulose, hemicellulose from biological and chemical attacks. Thus, cellulose, hemicellulose, lignin, sugar, and starch are very important parameters for each individual biomass in terms of selecting proper processes to treat each individual biomass according to their carbohydrate characteristics, and further evaluating biomass and assessing bioenergy conversion technology.

Fat/lipid is another category that is often used to characterize food and municipal wastes. Biomass with high fat/lipid content could be very good resources to produce biodiesel. Fat content and fatty acid distribution are the most important parameters in order to evaluate the biodiesel production potentials on various lipid-enriched biomass. Fat content is measured using ether extraction method, and fatty acid distribution is investigated using gas chromatography.

Ultimate analysis is widely used to characterize biomass fuel. It measures the composition of biomass in dry weight percentage of carbon, hydrogen, oxygen, nitrogen, and sulfur, which are widely used to calculate the heat capability of combustion (High Heating Value, HHV). The analysis is very important for assessment of thermal processes such as gasification and pyrolysis that directly convert biomasses to gas fuel and liquid fuel.

Elemental analysis gives the information of some trace elements in the biomass. Some of them are critical to certain biological conversion processes. An example is the function of zinc during yeast ethanol production, where zinc is one of the essential elements to maintain yeast activity during the entire ethanol production process. The content of minerals has to be known in terms of applying proper processes to convert biomass into bioenergy/bioproducts.

The other tested parameters include dry matter, total solids, COD, BOD etc. The information in this category is often used to design and assess anaerobic digestion of biomass.

The extent or degree of characterization of each of the feedstocks was strongly related to the available information, ability to effectively test for particular parameters within certain materials, and to the anticipated general type of conversion technology to be utilized for the feedstock. For example, wheat straw will most likely be converted to ethanol via a thermal process or perhaps a fermentation process but will not be converted to biomethane via anaerobic digestion. As a result, parameters such as COD which would be important to anaerobic digestion but not for the other conversion technologies were not deemed important and as such were not characterized. Because of this practice as well as the inability to find in literature or produce certain parameters in the laboratory there are numerous tabular inserts of NA which refers to a non-available of non-applicable parameter.

3. Characterization of Biomass

The following pages represent the characterization data for each of the representative feedstocks being studied in this interim report. Please refer to the earlier Biomass Inventory and Bioenergy Assessment for Washington State for required references as to how the feedstocks were chosen and inventoried. In some cases, characterization of particular feedstock was made particularly difficult and the feedstock category (i.e. other field residue) was of a mixed nature. In these cases, assumptions were made in regard to what represented an average or representative sample and then characterization research was conducted.

Wheat Straw

Washington State can yield 1,121,419 dry tons of wheat straw annually assuming a generic sustainability factor of 25% removal from the fields. As one of the woody materials, wheat straw is rich in cellulose and hemicellulose, which is a potential raw material for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of wheat straw utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	81	[3]
ADF (%, dry basis)	58	[3]
ADL (%, dry basis)	10	[3]
Cellulose (%, dry basis)	39	[3]
Hemicellulose (%, dry basis)	23	[3]
Lignin (%, dry basis)	10	[3]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	3	[12]
TKN (%, dry basis)	0.61	[12]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	43.2	[11]
Hydrogen (%, dry basis)	5	[11]
Oxygen (%, dry basis)	39.4	[11]

Nitrogen (%, dry basis)	0.61	[11]
Sulfur (%, dry basis)	0.11	[11]
Ash (%, dry basis)	8.9	[11]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.16	[17]
Phosphorus (%, dry basis)	0.05	
Potassium (%, dry basis)	1.3	[17]
Chlorine (%, dry basis)	0.32	[17]
Zinc (ppm, dry basis)	6	[17]

Others		
	Data	Reference
Dry matter (%)	91	[12]

Grass Seed Straw

Washington State can yield around 134,640 dry tons of grass seed straw annually. The grass seed crops include bluegrass, orchard grass, perennial ryegrass, and alfalfa etc. As a type of woody materials, grass seed straw is rich in cellulose and hemicellulose, which is a potential raw material for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of grass seed straw utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data (represented by alfalfa straw)

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	45	[18]
ADF (%, dry basis)	34	[18]
ADL (%, dry basis)	14.4	[18]
Cellulose (%, dry basis)	29.6	[18]
Hemicellulose (%, dry basis)	11	[18]
Lignin (%, dry basis)	14.4	[18]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	6.25	[18]
TKN (lb/ton)	1	[18]

TKN: Total kjeldahl nitrogen

Ultimate analysis		
	Data	Reference
Carbon (%, dry basis)	46.8	[19]
Hydrogen (%, dry basis)	5.4	[19]
Oxygen (%, dry basis)	40.7	[19]
Nitrogen (%, dry basis)	1	[19]
Sulfur (%, dry basis)	0.02	[19]
Ash (%, dry basis)	7.3	[19]

Elemental analysis		
	Data	Reference
Calcium (%, dry basis)	1.3	[18]
Phosphorus (%, dry basis)	0.23	[18]
Potassium (%, dry basis)	1.9	[18]
Chlorine (%, dry basis)	0.03	[18]
Zinc (ppm, dry basis)	18	[18]

Others		
	Data	Reference
Dry matter (%)	91	[18]

Barley Straw

Washington State can yield around 318,522 dry tons of barley straw annually. As one of the woody materials, barley straw is rich in cellulose and hemicellulose, which is a potential raw material for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of barley straw utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	78	[20]
ADF (%, dry basis)	52	[20]
ADL (%, dry basis)	7	[20]
Cellulose (%, dry basis)	44	[20]
Hemicellulose (%, dry basis)	26	[20]
Lignin (%, dry basis)	7	[20]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	3.13	[12]
TKN (lb/ton)	0.5	[12]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	45.6	[32]
Hydrogen (%, dry basis)	5.6	[32]
Oxygen (%, dry basis)	42.5	[32]
Nitrogen (%, dry basis)	0.5	[32]
Sulfur (%, dry basis)	0.09	[32]
Ash (%, dry basis)	5.7	[32]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.33	[20]
Phosphorus (%, dry basis)	0.08	[20]
Potassium (%, dry basis)	2.1	[20]
Chlorine (%, dry basis)	0.67	[20]
Zinc (ppm, dry basis)	7	[20]

Others		
	Data	Reference
Dry matter (%)	90	[20]

Corn Stover

Washington State can yield around 73,502 dry tons of corn stover annually. As one of the woody materials, corn stover is rich in cellulose and hemicellulose, which is a potential raw material for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of corn stover utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	70	[17]
ADF (%, dry basis)	44	[17]
ADL (%, dry basis)	18	[17]
Cellulose (%, dry basis)	35	[17]
Hemicellulose (%, dry basis)	28	[17]

Lignin (%, dry basis)	18	[17]
Starch (%, dry basis)	NA	[17]
Sugar (%, dry basis)	NA	[17]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	3.81	[12]
TKN (%, dry basis)	0.61	[12]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	43.65	[11]
Hydrogen (%, dry basis)	5.56	[11]
Oxygen (%, dry basis)	43.31	[11]
Nitrogen (%, dry basis)	0.61	[11]
Sulfur (%, dry basis)	0.01	[11]
Ash (%, dry basis)	5.58	[11]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.35	[17]
Phosphorus (%, dry basis)	0.19	[17]
Potassium (%, dry basis)	1.1	[17]
Chlorine (%, dry basis)	0.3	[17]
Zinc (ppm, dry basis)	22	[17]

Others		
	Data	Reference
Dry matter (%)	80	[12]

Other Field Residue

Washington State can yield around 159,174 dry tons of field residues annually. As a type of woody material, field residues include cereal grains, clearing of grasslands, pastures, orchard tear-outs and orchard thinning. They are rich in starch, cellulose, and hemicellulose, which are potential raw materials for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of field residues utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data (represented by wheat grains)

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	1.0	[21]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	69.7	[21]
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	10.6	[21]
TKN (lb/ton)	1.7	[21]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	NA	
Hydrogen (%, dry basis)	NA	
Oxygen (%, dry basis)	NA	
Nitrogen (%, dry basis)	1.7	[21]
Sulfur (%, dry basis)	NA	
Ash (%, dry basis)	1.4	[21]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	35	[21]

Others		
	Data	Reference
Dry matter (%)	87	[21]

Mint Slug

Washington State can yield around 96,878 dry tons of mint slug annually. As a type of woody material, mint slug is rich in cellulose, and hemicellulose, which is a potential raw material for commercial bioethanol production and gasification. In terms of needs of technology and economical assessment of mint slug utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, and elemental analysis.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	66.9	[4]
ADF (%, dry basis)	65.3	[4]
ADL (%, dry basis)	25.7	[4]
Cellulose (%, dry basis)	39.5	[4]
Hemicellulose (%, dry basis)	1.61	[4]
Lignin (%, dry basis)	25.7	[4]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	14	[12]
TKN (lb/ton)	2.24	[12]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	45.2	[22]
Hydrogen (%, dry basis)	5.5	[22]
Oxygen (%, dry basis)	35.8	[22]
Nitrogen (%, dry basis)	2.5	[22]
Sulfur (%, dry basis)	0.25	[22]
Ash (%, dry basis)	10.8	[22]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	1.1	[22]
Phosphorus (%, dry basis)	0.57	[22]
Potassium (%, dry basis)	2.14	[22]
Chlorine (%, dry basis)	0.43	[22]
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	27	[12]

Hops Residue

Washington State can yield around 5,400 dry tons of hops residue annually. Hops residue is rich in cellulose, and hemicellulose, which is a potential raw material for commercial bioethanol production. In terms of needs of technology and economical assessment of hops residue utilization, the categories of parameters required are carbohydrate, proteins/ammonia, and elemental analysis.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	NA	
ADF (%, dry basis)	68	[12]
ADL (%, dry basis)	26	[12]
Cellulose (%, dry basis)	42	[12]
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	26	[12]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	15	[12]
TKN (%, dry basis)	2.4	[12]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	3.3	[23]
Phosphorus (%, dry basis)	0.4	[23]
Potassium (%, dry basis)	1.8	[23]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	44	[23]

Others		
	Data	Reference
Dry matter (%)	30	[12]

Dairy Manure

Washington State can yield around 457,032 dry tons of dairy manure annually. Dairy manure is rich in cellulose, hemicellulose, and proteins which is a potential raw material for commercial bioethanol production, gasification, and anaerobic digestion. In terms of needs of technology and economical assessment of dairy manure utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	48	[4]
ADF (%, dry basis)	36	[4]
ADL (%, dry basis)	14	[4]
Cellulose (%, dry basis)	22	[4]
Hemicellulose (%, dry basis)	12	[4]
Lignin (%, dry basis)	14	[4]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	14	[4]
TKN (%, dry basis)	2.24	[4]
NH3N (%, TKN)	19	[4]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	44.7	[35]
Hydrogen (%, dry basis)	5.9	[35]
Oxygen (%, dry basis)	38.2	[35]
Nitrogen (%, dry basis)	2.24	[35]
Sulfur (%, dry basis)	0.3	[35]
Ash (%, dry basis)	8.9	[35]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	2.22	[14]
Phosphorus (%, dry basis)	0.48	[14]
Potassium (%, dry basis)	2.86	[14]

Others		
	Data	Reference
Dry matter (%)	14	[14]
TSS (%, dry basis)	66	[14]
VS (%, dry basis)	83	[14]
VSS (%, dry basis)	58	[14]
BOD5 (mg/kg)	20872	[14]
COD (mg/kg)	127946	[14]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Cattle Manure

Washington State can yield around 242,404 dry tons of cattle manure annually. Cattle manure is rich in cellulose, hemicellulose, and proteins which is a potential raw material for commercial bioethanol production, gasification, and anaerobic digestion. In terms of needs of technology and economical assessment of cattle manure utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	48	[4]
ADF (%, dry basis)	36	[4]
ADL (%, dry basis)	14	[4]
Cellulose (%, dry basis)	22	[4]
Hemicellulose (%, dry basis)	12	[4]
Lignin (%, dry basis)	14	[4]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	16	[4]
TKN (%, dry basis)	2.56	[4]
NH3N (%, TKN)	33	[4]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	45.4	[15]
Hydrogen (%, dry basis)	5.4	[15]
Oxygen (%, dry basis)	31	[15]

Nitrogen (%, dry basis)	2.56	[15]
Sulfur (%, dry basis)	0.29	[15]
Ash (%, dry basis)	15.9	[15]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	1.06	[13]
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	0.42	[13]

Others		
	Data	Reference
Dry matter (%)	15	[13]
TSS (%, dry basis)	76	[13]
VS (%, dry basis)	82	[13]
VSS (%, dry basis)	58	[13]
BOD5 (mg/kg)	28082	[13]
COD (mg/kg)	130232	[13]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Horse Manure

Washington State can yield around 407,160 dry tons of horse manure annually. Horse manure is rich in cellulose, hemicellulose, and proteins which is a potential raw material for commercial bioethanol production, gasification, and anaerobic digestion. In terms of needs of technology and economical assessment of horse manure utilization, the categories of parameters required are carbohydrate, proteins/ammonia, ultimate analysis, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	89.8	[33]
ADF (%, dry basis)	57.4	[33]
ADL (%, dry basis)	19.6	[33]
Cellulose (%, dry basis)	37.8	[33]
Hemicellulose (%, dry basis)	32.4	[33]
Lignin (%, dry basis)	19.6	[33]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	7.5	[19]
TKN (%, dry basis)	1.2	[19]
NH3N (%, TKN)	9.7	[19]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	46.9	[8]
Hydrogen (%, dry basis)	4.2	[8]
Oxygen (%, dry basis)	26.3	[8]
Nitrogen (%, dry basis)	1.2	[8]
Sulfur (%, dry basis)	1.5	[8]
Ash (%, dry basis)	18	[8]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)		
Phosphorus (%, dry basis)	0.22	[14]
Potassium (%, dry basis)	0.86	[14]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	30	[14]
TSS (%, dry basis)	83	[14]
VS (%, dry basis)	77	[14]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	27856	[14]
COD (mg/kg)	187722	[14]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Swine Manure

Washington State can yield around 13,632 dry tons of swine manure annually. Swine manure is rich in carbohydrates and proteins which are a potential raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of swine manure utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	39.1	[3]
ADF (%, dry basis)	18.7	[3]
ADL (%, dry basis)	4.1	[3]
Cellulose (%, dry basis)	14.6	[3]
Hemicellulose (%, dry basis)	10.4	[3]
Lignin (%, dry basis)	4.1	[3]
Starch (%, dry basis)	NA	[3]
Sugar (%, dry basis)	NA	[3]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	25	[19]
TKN (%, dry basis)	4	[19]
NH3N (%, TKN)	62	[3]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	4.2	[3]
Phosphorus (%, dry basis)	2.45	[3]
Potassium (%, dry basis)	1.6	[3]
Zinc (ppm, dry basis)	2167	[3]

Others		
	Data	Reference
Dry matter (%)	10	[14]
TSS (%, dry basis)	72	[14]
VS (%, dry basis)	80	[14]
VSS (%, dry basis)	67	[14]
BOD5 (mg/kg)	37134	[14]
COD (mg/kg)	102710	[14]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Poultry Manure

Washington State can yield around 784,577 dry tons of poultry manure annually. Poultry manure is rich in carbohydrates and proteins which are a potential raw material for commercial anaerobic digestion and gasification. In terms of needs of technology and economical assessment of poultry manure utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	34.5	[3]
ADF (%, dry basis)	14.3	[3]
ADL (%, dry basis)	3.2	[3]
Cellulose (%, dry basis)	11.1	[3]
Hemicellulose (%, dry basis)	20.2	[3]
Lignin (%, dry basis)	3.2	[3]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	18.3	[3]
TKN (lb/ton)	2.93	[3]
NH3N (%, TKN)	26	[3]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	39.57	[10]
Hydrogen (%, dry basis)	5.11	[10]
Oxygen (%, dry basis)	48.27	[10]
Nitrogen (%, dry basis)	2.93	[10]
Sulfur (%, dry basis)	0.77	[10]
Ash (%, dry basis)	16.42	[10]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	9.6	[14]
Phosphorus (%, dry basis)	3.4	[14]
Potassium (%, dry basis)	3.9	[14]
Chlorine (%, dry basis)	0.88	[14]
Zinc (ppm, dry basis)	500	[14]

Others		
	Data	Reference
Dry matter (%)	26	[14]
TSS (%, dry basis)	42	[14]

VS (%, dry basis)	76	[14]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	48088	[14]
COD (mg/kg)	196839	[14]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Logging Residue

Washington State can yield around 1,901,072 dry tons of logging residue annually. As a type of woody material, logging residue is rich in fiber, which is a potential raw material for commercial gasification. In terms of needs of technology and economical assessment of logging residue utilization, the categories of parameters required are ultimate analysis, and others.

Data (represented by wood)

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	50.3	[19]
Hydrogen (%, dry basis)	4.59	[19]
Oxygen (%, dry basis)	40	[19]
Nitrogen (%, dry basis)	1.03	[19]
Sulfur (%, dry basis)	0.11	[19]
Ash (%, dry basis)	4	[19]

Others		
	Data	Reference
Dry matter (%)	48.9	[19]

Forest Thinning

Washington State can yield around 505,666 dry tons of forest thinning annually. As a type of woody material, forest thinning is rich in fiber, which is a potential raw material for commercial gasification. In terms of needs of technology and economical assessment of forest thinning utilization, the categories of parameters required are ultimate analysis, and others.

Data (represented by forest residue)

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	48.2	[19]
Hydrogen (%, dry basis)	6	[19]
Oxygen (%, dry basis)	44.6	[19]
Nitrogen (%, dry basis)	0.7	[19]

Sulfur (%, dry basis)	0.1	[19]
Ash (%, dry basis)	1.2	[19]

Others		
	Data	Reference
Dry matter (%)	29	[19]

Mill Residue

Washington State yields around 5,278,353 dry tons of mill residues annually. As a type of woody material, mill residue is rich in fiber, which is a potential raw material for commercial gasification. In terms of needs of technology and economical assessment of mill residue utilization, the categories of parameters required are ultimate analysis, and others.

Data (represented by saw dust, pine)

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	51	[19]
Hydrogen (%, dry basis)	5.99	[19]
Oxygen (%, dry basis)	42.8	[19]
Nitrogen (%, dry basis)	0.08	[19]
Sulfur (%, dry basis)	NA	[19]
Ash (%, dry basis)	0.1	[19]

Others		
	Data	Reference
Dry matter (%)	29	[19]

Land Clearing Debris

Washington State can yield around 418,595 dry tons of land clearing debris annually. As a type of woody material, land clearing debris is rich in fiber, which is a potential raw material for commercial gasification. In terms of needs of technology and economical assessment of land clearing debris utilization, the categories of parameters required are ultimate analysis, and others.

Data (represented by park waste wood)

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	48.1	[19]
Hydrogen (%, dry basis)	5.8	[19]
Oxygen (%, dry basis)	37	[19]

Nitrogen (%, dry basis)	0.64	[19]
Sulfur (%, dry basis)	0.1	[19]
Ash (%, dry basis)	8.3	[19]

Others		
	Data	Reference
Dry matter (%)	39	[19]

Cull Onions

Washington State can yield around 2,322 dry tons of cull onions annually. Cull onion has relatively high contents of sugar and calcium, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of cull onion utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	6.9	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	46.2	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	11.5	[13]
TKN (lb/ton)	1.84	[13]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.3	[13]
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	13	[13]

Cull Potatoes

Washington State yields around 91,412 dry tons of cull potatoes annually. Cull potato has relatively high contents of starch, which could be potentially used as a raw material for commercial ethanol production and anaerobic digestion. In terms of needs of technology and economical assessment of cull potato utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	2	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	70.6	[13]
Sugar (%, dry basis)	2	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	10.6	[13]
TKN (%, dry basis)	1.70	[13]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.026	[13]
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	15	[13]

Cull Apples

Washington State can yield around 41,039 dry tons of cull apples annually. Cull apple has relatively high contents of sugar, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of cull apple utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	5.3	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	2.7	[13]
Sugar (%, dry basis)	51.8	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	0.9	[13]
TKN (%, dry basis)	0.14	[13]

TKN: Total kjeldahl nitrogen

Others		
	Data	Reference
Dry matter (%)	11	[13]

Other Cull Fruit

Washington State can yield around 8,934 dry tons of cull fruit annually. Cull fruits have relatively high contents of sugar, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of cull fruit utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data (represented as apricot)

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	9.6	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	0	[13]
Sugar (%, dry basis)	65.4	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	6.9	[13]
TKN (lb/ton)	1.1	[13]

TKN: Total kjeldahl nitrogen

Others		
	Data	Reference
Dry matter (%)	13	[13]

Asparagus Butts

Washington State produces around 667 dry tons of asparagus butts annually. Asparagus butt has relatively high contents of sugar, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of asparagus butt utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	10	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	5.7	[13]
Sugar (%, dry basis)	33	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	7	[13]
TKN (lb/ton)	1.12	[13]

TKN: Total kjeldahl nitrogen

Others		
	Data	Reference
Dry matter (%)	31.4	[13]

Apple Pomace

Washington State produces around 27,794 dry tons of apple pomace annually. Apple pomace has relatively high contents of fiber, which could be potentially used as a raw material for ethanol production, and commercial anaerobic digestion. In terms of needs of technology and economical assessment of apple pomace utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	63.2	[28]
ADF (%, dry basis)	54.1	[28]
ADL (%, dry basis)	1.3	[28]
Cellulose (%, dry basis)	52.8	[28]
Hemicellulose (%, dry basis)	9.1	[28]
Lignin (%, dry basis)	1.3	[28]
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	8.5	[27]
TKN (lb/ton)	1.36	[27]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.7	[27]
Phosphorus (%, dry basis)	0.7	[27]
Potassium (%, dry basis)	3	[27]

Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	55	[27]

Others		
	Data	Reference
Dry matter (%)	75	[27]

Grape Pomace

Washington State yields around 19,254 dry tons of grape pomace annually. Grape pomace has relatively high contents of fiber, which could be potentially used as a raw material for ethanol production, and commercial anaerobic digestion. In terms of needs of technology and economical assessment of grape pomace utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	58	[28]
ADF (%, dry basis)	52	[28]
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	6	[28]
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	13.2	[28]
TKN (lb/ton)	2.1	[28]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.55	[28]
Phosphorus (%, dry basis)	0.088	[28]
Potassium (%, dry basis)	0.5	[28]
Chlorine (%, dry basis)	0.011	[28]
Zinc (ppm, dry basis)	26.4	[28]

Others		
	Data	Reference
Dry matter (%)	91	[28]

Other Fruit Pomace

Washington State produces around 11,865 dry tons of fruit pomace annually. Fruit pomace has relatively high contents of fiber, which could be potentially used as a raw material for ethanol production, and commercial anaerobic digestion. In terms of needs of technology and economical assessment of fruit pomace utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data (presented by apple pomace)

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	63.2	[28]
ADF (%, dry basis)	54.1	[28]
ADL (%, dry basis)	1.3	[28]
Cellulose (%, dry basis)	52.8	[28]
Hemicellulose (%, dry basis)	9.1	[28]
Lignin (%, dry basis)	1.3	[28]
Starch (%, dry basis)	NA	[28]
Sugar (%, dry basis)	NA	[28]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	8.5	[27]
TKN (lb/ton)	1.36	[27]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.7	[27]
Phosphorus (%, dry basis)	0.7	[27]
Potassium (%, dry basis)	3	[27]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	55	[27]

Others		
	Data	Reference
Dry matter (%)	75	[27]

Cheese Whey

Washington State yields around 44,255 dry tons of cheese whey annually. Cheese whey has relatively high contents of sugar and protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of cheese whey utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
Starch (%, dry basis)	NA	
Sugar (%, dry basis)	65	[25]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	11.5	[15]
TKN (%, dry basis)	1.8	[15]

TKN: Total kjeldahl nitrogen

Others		
	Data	Reference
Dry matter (%)	6.5	[25]

Potato Solids

Washington State produces around 19,177 dry tons of potato solids annually. Potato solid has relatively high contents of starch, which could be potentially used as a raw material for commercial ethanol production, and anaerobic digestion. In terms of needs of technology and economical assessment of potato solids utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	2	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	

Lignin (%, dry basis)	NA	
Starch (%, dry basis)	70.6	[13]
Sugar (%, dry basis)	2	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	10.6	[13]
TKN (%, dry basis)	1.7	[13]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.026	[13]
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	15	[13]

Asparagus Trimmings

Washington State produces around 120 dry tons of asparagus trimmings annually. Asparagus trimming has relatively high contents of sugar, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of asparagus trimming utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	10	[13]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	
Starch (%, dry basis)	5.7	[13]
Sugar (%, dry basis)	26	[13]

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	42.8	[13]
TKN (%, dry basis)	6.84	[13]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	2.8	[13]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.28	[13]
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	7	[13]

Mixed Vegetables

Washington State produces around 14,744 dry tons of mixed vegetable processing residues annually. Mixed vegetable processing residue contains some fiber, protein, and minerals, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of mixed vegetables utilization, the categories of parameters required are carbohydrate, proteins/ammonia, elemental analysis, and others.

Data

Carbohydrates		
	Data	Reference
NDF (%, dry basis)	13.4	7]
ADF (%, dry basis)	NA	
ADL (%, dry basis)	NA	
Cellulose (%, dry basis)	NA	
Hemicellulose (%, dry basis)	NA	
Lignin (%, dry basis)	NA	

NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	11.6	[7]
TKN (%, dry basis)	1.86	[7]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Ether Extract (%, dry basis)	1.5	[7]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	0.19	[7]
Phosphorus (%, dry basis)	0.17	[7]
Potassium (%, dry basis)	2.24	[7]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	11	[7]

Others		
	Data	Reference
Dry matter (%)	11.9	[7]

Poultry Feathers

Washington State produces around 7,932 dry tons of poultry feathers annually. Poultry feather has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of poultry feather utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	88.2	[5]
TKN (%, dry basis)	14.1	[5]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	3.3	[5]
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	

Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	93	[5]

Poultry Meat Processing

Washington State yields around 5,479 dry tons of poultry meat processing waste annually. Poultry meat processing waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of poultry meat processing utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	44.4	[33]
TKN (%, dry basis)	7.1	[33]
NH3N (%, TKN)	17	[33]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	17.2	[33]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	2.06	[33]
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	5.8	[33]
TSS (%, dry basis)	NA	
VS (%, dry basis)	82	[33]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	NA	
COD (mg/kg)	78000	[33]

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Beef Meat Processing

Washington State yields around 35,842 dry tons of beef meat processing waste annually. Beef meat processing waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of meat processing utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data (represented by beef meat processing sludge)

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	45	[33]
TKN (%, dry basis)	7.2	[33]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	20	[33]

Others		
	Data	Reference
Dry matter (%)	5.5	[33]
TSS (%, dry basis)	NA	
VS (%, dry basis)	80	[33]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	NA	
COD (mg/kg)	NA	

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Swine Meat Processing

Washington State yields around 280 dry tons of swine meat processing waste annually. Swine meat processing waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of swine processing utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data (represented by swine meat processing sludge)

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	44.4	[33]

TKN (%, dry basis)	7.1	[33]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	21.3	[33]

Others		
	Data	Reference
Dry matter (%)	7.5	[33]
TSS (%, dry basis)	NA	
VS (%, dry basis)	78.7	[33]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	NA	
COD (mg/kg)	NA	

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

All Animal Mortalities

Washington State produces around 5,857 dry tons of animal mortalities annually. Animal mortality waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of animal mortality utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	24	[7]
TKN (%, dry basis)	3.84	[7]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	69.9	[7]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	1.64	[7]
Phosphorus (%, dry basis)	0.82	[7]
Potassium (%, dry basis)	0.3	[7]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	32	[7]

Others		
	Data	Reference
Dry matter (%)	59	[7]

Fish Waste

Washington State produces around 7,995 dry tons of fish waste annually. Fish waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of fish waste utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	57	[7]
TKN (%, dry basis)	9.12	[7]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Fat (%, dry basis)	19.1	[7]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	5.8	[7]
Phosphorus (%, dry basis)	2.04	[7]
Potassium (%, dry basis)	0.68	[7]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	62	[7]

Others		
	Data	Reference
Dry matter (%)	26.1	[7]

Shellfish Waste

Washington State yields around 3,674 dry tons of shellfish waste annually. Shellfish waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of shellfish waste utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	57	[7]
TKN (lb/ton)	9.12	[7]

TKN: Total kjeldahl nitrogen

Lipid		
	Data	Reference
Ether Extract (%, dry basis)	19.1	[7]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	5.8	[7]
Phosphorus (%, dry basis)	2.04	[7]
Potassium (%, dry basis)	0.68	[7]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	62	[7]

Others		
	Data	Reference
Dry matter (%)	26.1	[7]

Food Waste

Washington State produces around 246,011 dry tons of food waste annually. Food waste has relatively high contents of protein, which could be potentially used as a raw material for commercial anaerobic digestion. In terms of needs of technology and economical assessment of food waste utilization, the categories of parameters required are proteins/ammonia, elemental analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	15	[1]
TKN (%, dry basis)	2.4	[1]
NH3N (%, dry basis)	0.08	[1]
NO3N (%, dry basis)	0.03	[1]

TKN: Total kjeldahl nitrogen

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	4	[1]
Phosphorus (%, dry basis)	0.33	[1]
Potassium (%, dry basis)	0.83	[1]
Chlorine (%, dry basis)	0.4	[1]
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	28	[1]
TSS (%, dry basis)	NA	
VS (%, dry basis)	82	[1]
VSS (%, dry basis)	NA	
BOD5 (mg/kg)	NA	
COD (mg/kg)	NA	

TSS: Total suspended solid; VS: Volatile solid; VSS: Volatile suspended solid

Yard Non-wood

Washington State yields around 421,489 dry tons of yard non-wood waste annually. Yard non-wood waste has relatively high contents of fiber, which could be potentially used as a raw material for commercial gasification. In terms of needs of technology and economical assessment of yard non-wood waste utilization, the categories of parameters required are proteins/ammonia, ultimate analysis, elemental analysis, and others.

Data (presented as garden waste)

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	10	[34]
TKN (lb/ton)	1.6	[34]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	42.4	[34]
Hydrogen (%, dry basis)	5.3	[34]
Oxygen (%, dry basis)	31.8	[34]
Nitrogen (%, dry basis)	1.6	[34]
Sulfur (%, dry basis)	0.4	[34]
Ash (%, dry basis)	18.4	[34]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	0.18	[34]
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	56	[34]

Other Organics

Washington State produces around 42,152 dry tons of other organic waste annually. Organic waste has relatively high contents of carbon, hydrogen, and oxygen, which could be potentially used as a raw material for commercial gasification. In terms of needs of technology and economical assessment of organic waste utilization, the categories of parameters required are ultimate analysis, elemental analysis, and others.

Data

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	42.1	[6]
Hydrogen (%, dry basis)	5.43	[6]
Oxygen (%, dry basis)	31.1	[6]
Nitrogen (%, dry basis)	1.78	[6]
Sulfur (%, dry basis)	0.41	[6]
Ash (%, dry basis)	18.9	[6]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	NA	
Potassium (%, dry basis)	NA	
Chlorine (%, dry basis)	0.24	[6]
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	37	[6]

Paper

Washington State produces around 2,428,084 dry tons of paper waste annually. Paper waste has relatively high contents of carbon, hydrogen, and oxygen, which could be potentially used as a raw material for commercial gasification. In terms of needs of technology and economical assessment of paper waste utilization, the categories of parameters required are ultimate analysis, elemental analysis, and others.

Data

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	49.3	[19]
Hydrogen (%, dry basis)	7.07	[19]
Oxygen (%, dry basis)	34.9	[19]
Nitrogen (%, dry basis)	0.7	[19]
Sulfur (%, dry basis)	0.15	[19]
Ash (%, dry basis)	7.9	[19]

Others		
	Data	Reference
Dry matter (%)	90	[19]

Wood Residue - MSW

Washington State produces around 834,057 dry tons of wood residues (MSW) annually. Wood residue has relatively high contents of carbon, hydrogen, and oxygen, which could be potentially used as a raw material for commercial gasification. In terms of needs of technology and economical assessment of wood residue utilization, the categories of parameters required are ultimate analysis, proteins/ammonia analysis, and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	7.5	[24]
TKN (lb/ton)	1.2	[24]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	47.6	[24]
Hydrogen (%, dry basis)	6	[24]

Oxygen (%, dry basis)	32.9	[24]
Nitrogen (%, dry basis)	1.2	[24]
Sulfur (%, dry basis)	0.3	[24]
Ash (%, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	80	[24]

Yellow Grease

Washington State produces around 18,486 dry tons of yellow grease annually. Yellow grease is rich in fat, which could be potentially used as a raw material for commercial biodiesel production. In terms of needs of technology and economical assessment of yellow grease utilization, the categories of parameters required are ultimate analysis, proteins/ammonia analysis, and others.

Data

Fat/lipid		
	Value	Reference
Total fatty acid (%, dry basis)	91	[36]
Free fatty acid (%, dry basis)	15	[36]
Fatty acid distribution (%, total fatty acids)		
C12:0	0.17	[36]
C14:0	0.84	[36]
C14:1	0.16	[36]
C16:0	15.88	[36]
C16:1	2.18	[36]
C18:0	8.43	[36]
C18:1	48.43	[36]
C18:2	20.11	[36]
C18:3	1.89	[36]
C20:0	0.38	[36]
C20:1	0.79	[36]

Others		
	Value	Reference
Moisture (%)	0.12	[36]

Brown Grease

Washington State produces around 20,528 dry tons of brown grease annually. Brown grease is rich in fat, which could be potentially used as a raw material for commercial biodiesel production. In terms of needs of technology and economical assessment of brown grease utilization, the categories of parameters required are ultimate analysis, proteins/ammonia analysis, and others.

Data

Fat/lipid		
	Value	Reference
Total fatty acid (%, dry basis)	84	[36]
Free fatty acid (%, dry basis)	42	[36]
Fatty acid distribution (%, total fatty acids)		
C12:0	2.41	[36]
C14:0	1.98	[36]
C14:1	0.21	[36]
C16:0	16.56	[36]
C16:1	2.03	[36]
C18:0	9.61	[36]
C18:1	49.33	[36]
C18:2	14.28	[36]
C18:3	1.06	[36]
C20:0	0.29	[36]
C20:1	0.73	[36]

Others		
	Value	Reference
Moisture (%)	0.63	[36]

Biosolids

Washington State yields around 94,820 dry tons of biosolids annually. Biosolid has relatively high content of carbon, hydrogen, and oxygen, which could be potentially used as a raw material for commercial gasification production. In terms of needs of technology and economical assessment of biosolids utilization, the categories of parameters required are ultimate analysis, proteins/ammonia analysis, elemental analysis and others.

Data

Proteins/Ammonia		
	Data	Reference
Crude protein (%, dry basis)	5	[29]

TKN (%, dry basis)	0.8	[29]

TKN: Total kjeldahl nitrogen

Ultimate Analysis		
	Data	Reference
Carbon (%, dry basis)	40.4	[29]
Hydrogen (%, dry basis)	6.2	[29]
Oxygen (%, dry basis)	20.4	[29]
Nitrogen (%, dry basis)	0.8	[29]
Sulfur (%, dry basis)	0.8	[29]
Ash (%, dry basis)	30.4	[29]

Elemental Analysis		
	Data	Reference
Calcium (%, dry basis)	NA	
Phosphorus (%, dry basis)	2.3	[29]
Potassium (%, dry basis)	0.3	[29]
Chlorine (%, dry basis)	NA	
Zinc (ppm, dry basis)	NA	

Others		
	Data	Reference
Dry matter (%)	26	[29]

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