Switchgrass and Miscanthus Biomass and Theoretical Ethanol Production from Reclaimed Mine Lands in WV

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Order of Presentation

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    - Treatment and Experimental Design
    - Vegetation Sampling
    - Soil Sampling
    - Statistical analysis
- Results and Discussion
- Conclusion

Introduction

- Prior to 1977 SMCRA
  - Minimal reclamation
- Post 1977 SMCRA
  - Must complete EIA
    - Post-mining land use designation
  - Regulations

- Post-mining land use
  - Minimize impacts
  - Compatible
  - Acceptable to land owner
  - Income opportunities
- Common post-mining land uses:
  - Pasture
  - Hay
  - Forestry
  - Urban development

From Mining to Alternative Fuels

- EISA 2007
  - Increase energy security and efficiency
  - Revised RFS mandates the use of 36 BGY of renewable fuels by 2022
    - 16 BGY cellulosic biofuels
      - Corn stover, woody materials, perennial grasses, etc..
    - 14 BGY advanced biofuels
    - 1 BGY biomass-based diesel
    - 15 BGY conventional biofuels

- Largest source of GHG emissions in U.S. comes from burning fossil fuels for electricity and transportation

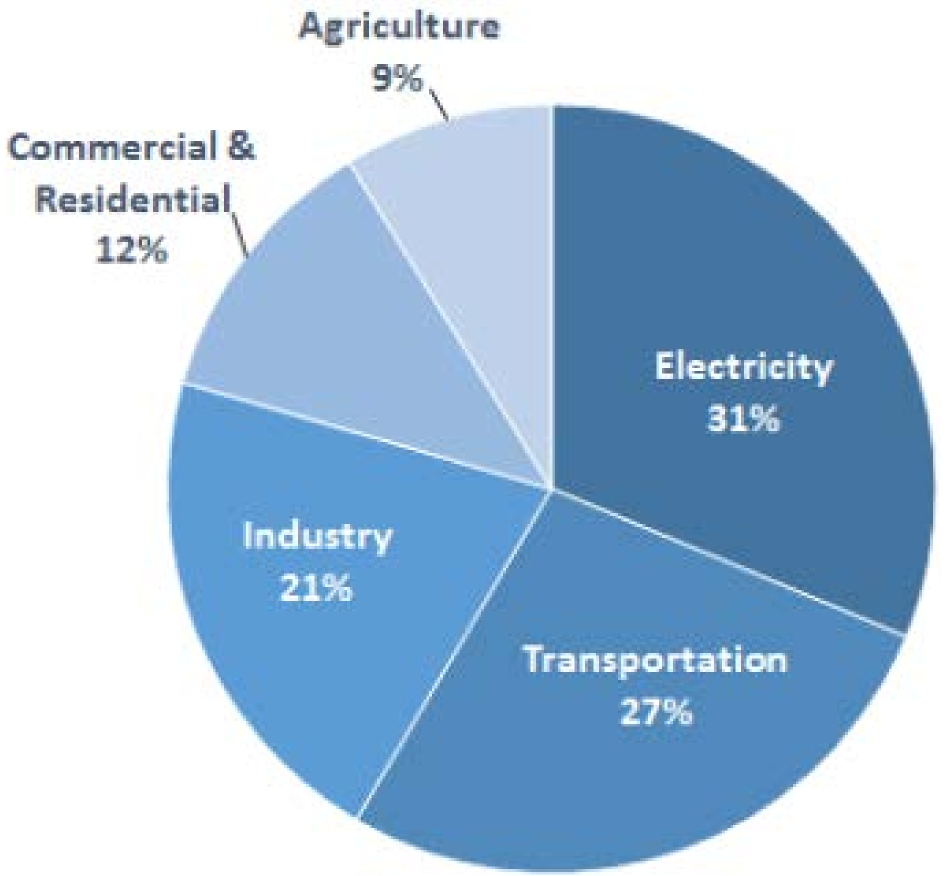


Figure 1. Total U.S. Greenhouse gas emissions by economic sector in 2013 (EPA, 2013).

Cellulose….it's everywhere!

Alternative bioenergy species

Switchgrass – *Panicum virgatum*

- Warm season
- Perennial
- Bunch grass
- Well adapted to a variety of lands:
  - pH ranging from 4.9 to 7.5
  - Sand to loams
- Extensive rooting system
- Multiple ecotypes available
- Low maintenance and management

Miscanthus – *Miscanthus x giganteus*

- Warm season
- Perennial
- Rhizomatous
- Well adapted to a wide variety of lands
- Extensive rooting system
- Low maintenance and management
- Can grow on marginal lands
- Largely studied in Europe

- Alternative post-mining land use
  - Bioenergy production
    - Good road networks established
    - Access to transportation hubs
    - Large uninterrupted tracts
    - Not previously agricultural land

Main Objectives

- Determine switchgrass and Miscanthus biomass yields on reclaimed mine lands for potential bioenergy production capabilities
- Determine TEY, L Mg^{-1} and TEP, L ha^{-1} from switchgrass and Miscanthus biomass grown from reclaimed mine lands

Materials & Methods: Site Location

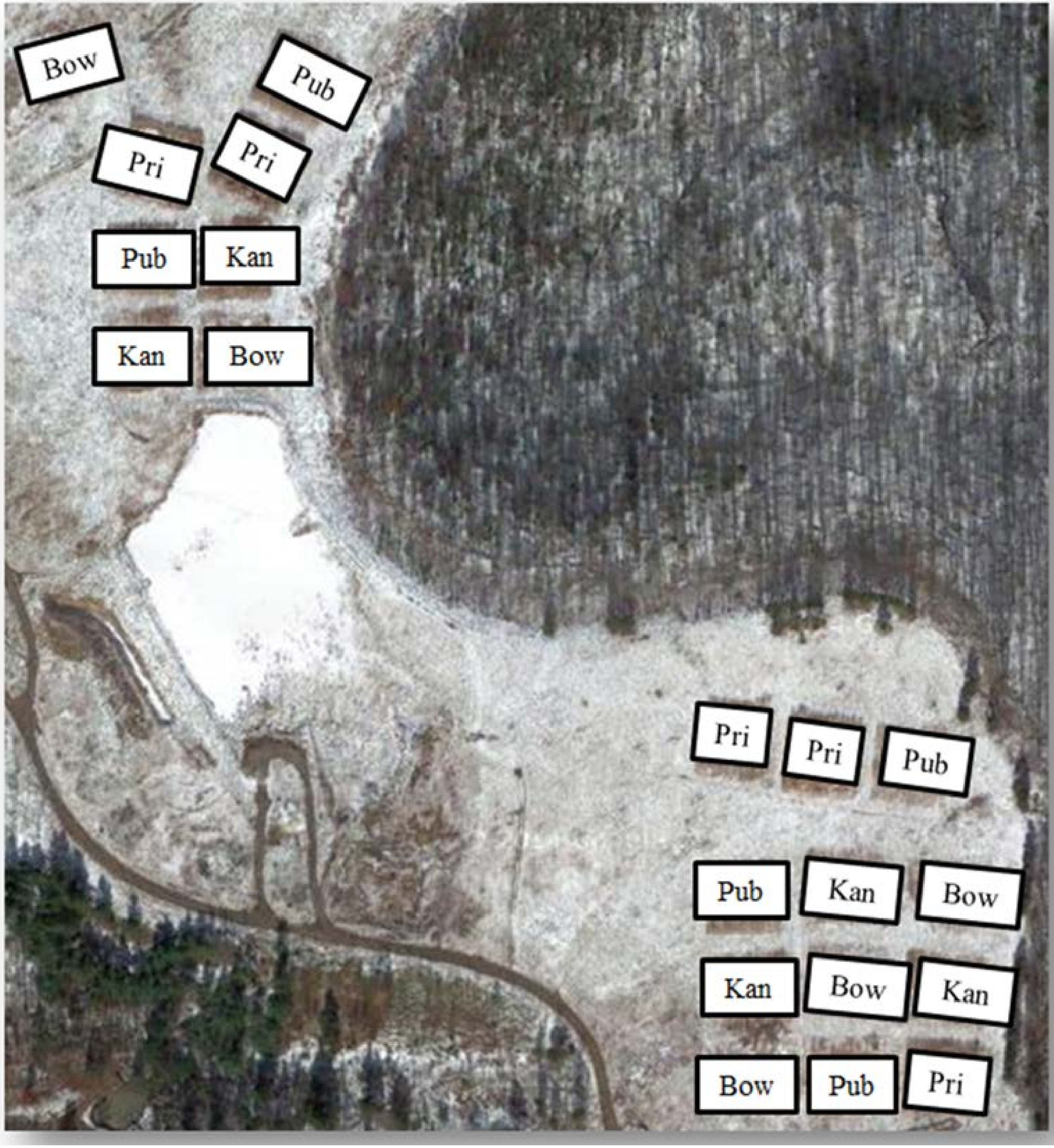
Upshur County, WV

Alton

- Reclaimed in 1985
  - 15 cm topsoil
  - Grass and legume species planted
  - 25 years for topsoil to restore
  - Ground cover killed with glyphosate, herbicide before seeding and sprigging

Experimental Setup

- Switchgrass
  - Kanlow and BoMaster
- Miscanthus
  - Private and Public
- Five reps
- Twenty 0.4-ha plots
- Switchgrass seed drilled in at 11 kg PLS ha^{-1}
- Sterile Miscanthus sprigs planted at 12,300 plugs ha^{-1}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Biomass and Soil Sampling

Soil Sampling

- Three random locations in each plot in 2014
- Approximately 15-cm depth
- Analyzed for:
  - pH,
  - electrical conductivity (EC),
  - and selected nutrients (P, K, Ca, Mg, and Fe)
- Air-dried, weighed, and passed through a 2-mm sieve
- Subsamples of the sieved fraction were taken using a riffle splitter and used for soil analysis

Vegetation Sampling

- Six biomass samples from each plot
- 0.21-m^2 quadrats
- Post-anthesis stage in October
- Clipped at a 10-cm stubble height
- Samples oven dried at 60°C

- Miscanthus biomass collected from six random locations in each plot

- Post-anthesis stage in October

- Because Miscanthus was planted on 0.9-m spacings, the entire plant was clipped at a 10-cm stubble height (0.81 m^2).

Statistical Analysis

- Nested design
- Two species (switchgrass, Miscanthus)
- Kanlow and BoMaster within switchgrass; Public and Private within Miscanthus
- Ln-transformed
- Repeated measures ANOVA
- Main fixed effects = species and cultivar within a species
- Random factors = year (5 years) and plot

Results and Discussion

Soil Results

Parameter	Alton
pH	6.9
EC (µS cm^{-1})	106
% Fines	64

Biomass Results

Effect			P>F	Yield	SE
				Mg ha^{-1}	
Species			0.01		
		Switchgrass		5.8	0.5
		Miscanthus		9.7	1.0
Cultivar (Species)			0.02		
	Switchgrass				
		Kanlow		5.8	0.5
		BoMaster		5.7	0.9
	Miscanthus				
		Public		7.3	1.2
		Private		12.2	1.4
Year			<0.01		
		2011		4.2^{b}*	0.9
		2012		7.3^{ab}	1.6
		2013		7.1^{ab}	1.2
		2014		10.8^{a}	1.4
		2015		9.5^{a}	1.0

Conclusions – Biomass

- Can Miscanthus and Switchgrass establish on reclaimed mine site?
  - YES!
  - Miscanthus (9.7 Mg ha^{-1}) and Switchgrass (5.8 Mg ha^{-1}) both established on the reclaimed mine site
  - Miscanthus yielded significantly higher biomass than switchgrass


10/30/2014

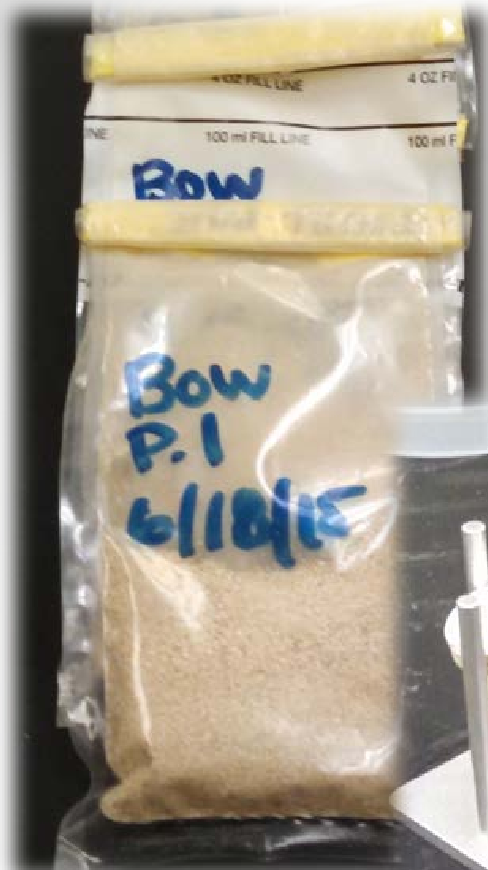

10/30/2014

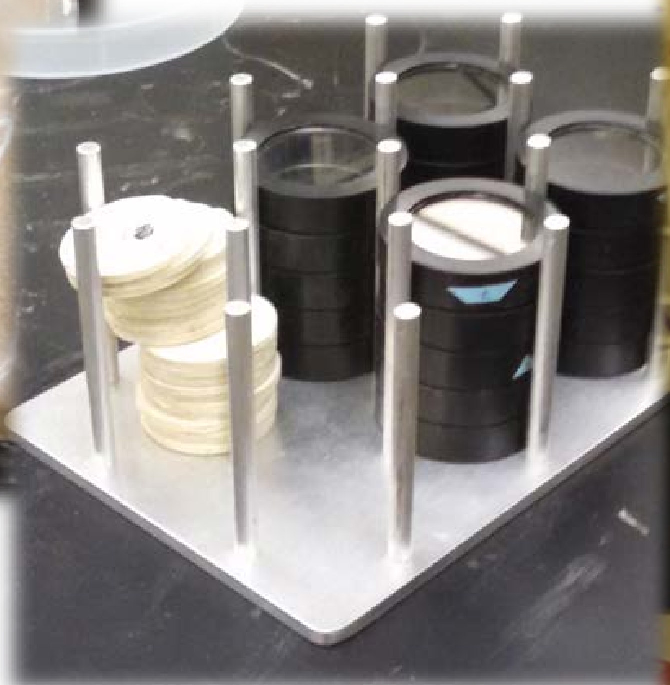

10/30/2014

Objectives – Part II

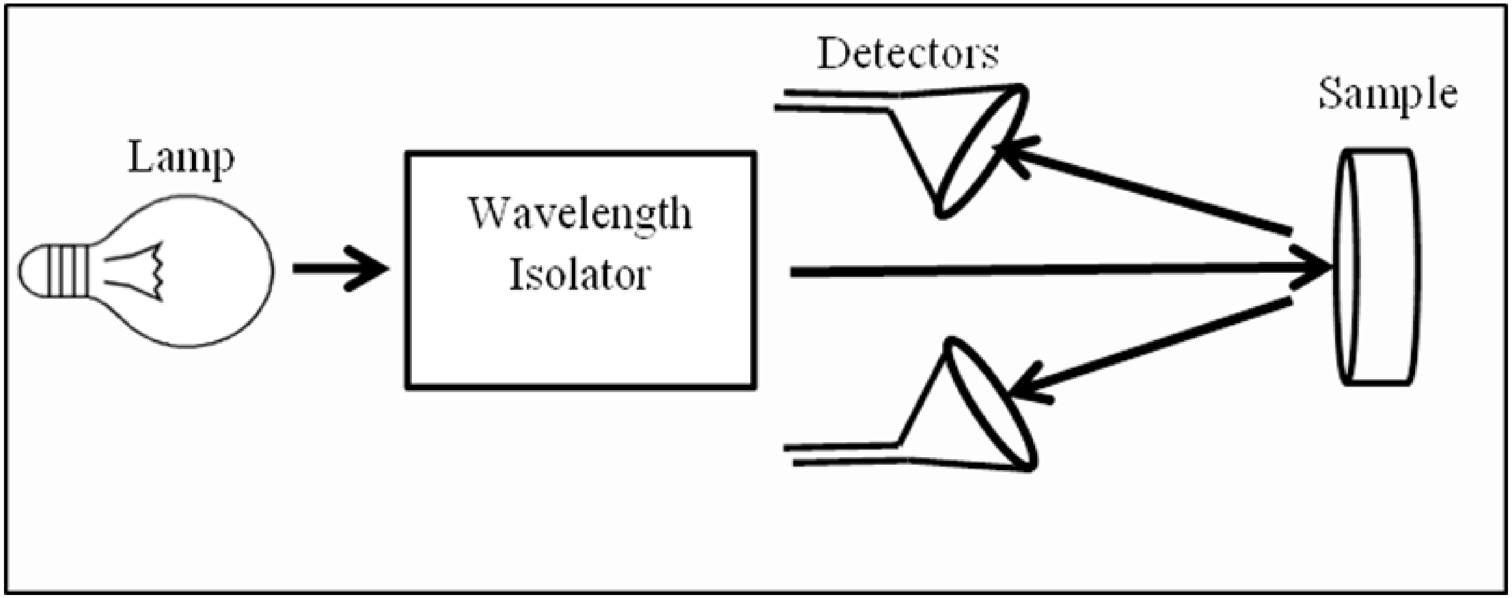
- Determine carbohydrate yields of switchgrass and Miscanthus cultivars using NIRS to predict
  - Theoretical ethanol yield (TEY; L Mg^{-1})
  - Theoretical ethanol production (TEP; L ha^{-1})

Near Infrared Reflectance Spectroscopy





- Near-Infrared Reflectance Spectroscopy (NIRS)
  - Analytes are quantified in a sample based on the spectral characteristics of that sample
  - An analyte is defined as a substance or chemical constituent
  - Amount of analyte is predicted based on the samples near-infrared reflectance spectra using equations fitted to a calibration set
- Near-infrared reflectance spectra profiles are determined
- Prediction equations are developed and validated using mathematical and statistical procedures


Detectors
Sample
Lamp
Wavelength
Isolator

Calibration of Spectra

- Spectra files standardized to master instrument (Foss model 6500)
  - NIRS Forage and Feed Testing Consortium (NIRSC)
  - Equations for comp. analyses obtained from NIRSC

- Bioenergy equation based on:
  - Samples from USDA ARS
  - Agricultural sites in Great Plains region
  - Diverse varieties, locations, harvesting tech., timing

- Spectra “fit” into calibration equations if:
  - Mean global H values (GD) < 4.5
  - Nearest distance (ND) values < 1.7 in conjunction with GD limit

Biomass compositional traits predicted with NIRS used in theoretical ethanol prediction equations.

Biomass Variable	Abbreviation
Quality from NIRSC grass-hay equation	
Ash	ASH
Lignin	LIGNIN
Neutral detergent fiber	aNDF
Cell Wall Constituents from Vogel et al. (2011)	
Pentose – C5	
Arabinan	ARA
Xylan	XYL
Hexose – C6	
Galactan	GAL
Glucan	GLC
Mannan	MAN

Ethanol Yield Prediction

Method/ parameter	Reference and constituents[a]	Unit
Method 1	Dien et al. (2010)	
HEX	(GLC+GAL+MAN) × 0.57 × 1.267	L Mg^{-1}
PEN	(XYL+ARA) × 0.579 × 1.267	L Mg^{-1}
TEY1	HEX + PEN	L Mg^{-1}
TEP1	TEY2 × biomass yield (Mg ha^{-1})	L ha^{-1}
Method 2	Payne and Wolfrum (2015)	
C6	(GLC) × 0.57 × 1.267	L Mg^{-1}
C5	(XYL) × 0.579 × 1.267	L Mg^{-1}
TEY2	C6 + C5	L Mg^{-1}
TEP2	TEY2 × biomass yield (Mg ha^{-1})	L ha^{-1}

Results and Discussions

		Biomass Quality Traits		
		Lignin	Ash	aNDF
		------	% DM	------
Species				
	Switchgrass	5.0	4.5	86.2
	Miscanthus	5.5	4.6	87.5
	SE	0.3	0.4	0.5
	p-value	0.09	0.8	0.03
Cultivar(Species)				
Switchgrass				
	Kanlow	5.0	4.4	86.4
	BoMaster	5.1	4.6	85.9
	SE	0.4	0.5	0.7
	p-value	0.8	0.7	0.4
Miscanthus				
	Public	6.0	5.0	87.3
	Private	4.9	4.1	87.7
	SE	0.4	0.5	0.8
	p-value	0.04	0.2	0.9
Year				
	2014	4.9	4.5	88.2
	2015	5.7	4.7	85.3
	SE	0.1	0.3	0.6
	p-value	≤0.01	0.4	≤0.01

		Cell Wall Constituents				
		ARA[a]	XYL	MAN	GAL	GLC
		--------------------- % DM ---------------------				
Species						
	Switchgrass	3.4	26.6	0.3	1.0	34.6
	Miscanthus	3.0	25.1	0.1	0.8	35.4
	SE	0.1	0.3	0.02	0.03	0.2
	p-value	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01
Cultivar(Species)						
Switchgrass						
	Kanlow	3.5	26.7	0.3	1.0	34.6
	BoMaster	3.3	26.4	0.3	1.0	34.6
	SE	0.1	0.4	0.03	0.04	0.3
	p-value	0.3	0.4	0.7	0.4	0.8
Miscanthus						
	Public	2.9	24.7	0.1	0.8	35.5
	Private	3.1	25.6	0.1	0.8	35.5
	SE	0.1	0.4	0.03	0.05	0.3
	p-value	0.1	0.04	0.5	0.2	0.4
Year						
	2014	3.2	26	0.2	0.9	35.6
	2015	3.2	25.7	0.2	0.9	34.4
	SE	0.04	0.3	0.02	0.02	0.3
	p-value	0.2	0.2	≤0.01	0.2	≤0.01

Theoretical Ethanol Yield and Production				
	C6[a]	C5	TEY2	TEP2
	--------	L Mg^{-1}	-------	L ha^{-1}
Species				
Switchgrass	259	220	479	4,275
Miscanthus	261	206	467	5,802
SE	1.6	2.6	2.3	581
p-value	0.3	≤0.01	≤0.01	≤0.01
Cultivar				
Kanlow	259	221	481	4,714
BoMaster	259	218	477	3,840
SE	2.1	3.5	2.1	661
p-value	0.6	0.3	0.4	0.6
Public	263	202	464	5,127
Private	267	211	472	6,514
SE	2.4	3.8	4.2	896
p-value	0.7	≤0.05	0.2	≤0.05
Year				
2014	267	214	481	5,206
2015	256	212	468	4,925
SE	1.9	2.1	3.7	157
p-value	≤0.01	0.2	≤0.01	0.7

Conclusion

- Significant differences between species for comp. values but not between cultivars
- Switchgrass produced higher comp. values than Miscanthus
- Switchgrass produced significantly higher results for TEY
- Miscanthus produced significantly higher TEP due to the higher biomass results

- Important: these ethanol yields assume 100% conversion efficiency

- These yields do not factor in large-scale commercial ethanol plants and the issues that face conversion rates and efficiency

Questions?

Table 1. Biomass production, potential ethanol production, and land area needed for different potential bioenergy systems to reach the 35 billion gallon U.S. renewable fuels goal (Heaton et al., 2008).

Feedstock	Harvestable biomass ($Mg\,ha^{-1}$)	Ethanol ($gal\,ha^{-1}$)*	Million hectares needed for 35 billion gallons of ethanol	Harvested US cropland (%) in 2006†
Corn grain†	10.2	1127	31.0	24.4
Corn stover‡	7.4	741	47.2	37.2
Corn total	17.6	1868	18.7	14.8
LIHD§	3.8	380	92.1	72.5
Switchgrass	10.4	1040	33.7	26.5
Miscanthus	29.6	2960	11.8	9.3

*DOE (2006).
†USDA-NASS.
‡Perlack *et al.* (2005).
§Tilman *et al.* (2006).
LIHD, Low-input high-diversity.

- Reflectance spectrum correlated against standard samples of known composition to derive a relationship that can be used for future predictions

- Principal components analysis
  - Groups spectral data into a few, independent components which are used as the predictors
- Multiple partial least squares
  - Similar to PCA but uses both lab data & spectral data in the prediction
  - Often most accurate

- Constants for HEX:
  - 0.57= 0.51 (lbs of EtOH/lb of sugar) x 1.11 (lbs of C6 sugar/lb of C6 polymeric sugar)
  - 0.537= 0.51 (lbs of EtOH/lb of sugar) x 1.053 (lb of sucrose/lb of polymeric sugar)
  - 1.267= 1/0.789 g/mL (Specific volume of EtOH)
- Constants for PEN:
  - 0.579= 0.51 (lbs of EtOH/lb of sugar) x 1.136 (lbs of C5 suagr/lb of C5 polymeric sugar)
  - 1.267= 1/0.789 g/mL (Specific volume of EtOH)

- Data is received in polymeric form: Glucan, Xylan, etc…
  - Monomeric form: Glucose, Xylose, etc…
  - Recorded in % DW, but convert to mg/g for equations