Switchgrass and Miscanthus Yields on Reclaimed Surface Mines for Bioenergy Production

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Reasons for turning to Biofuel:

1. High Energy Prices

2. Energy Independence

3. Concerns About Petroleum Supplies

4. Greater Recognition of Environmental Consequences

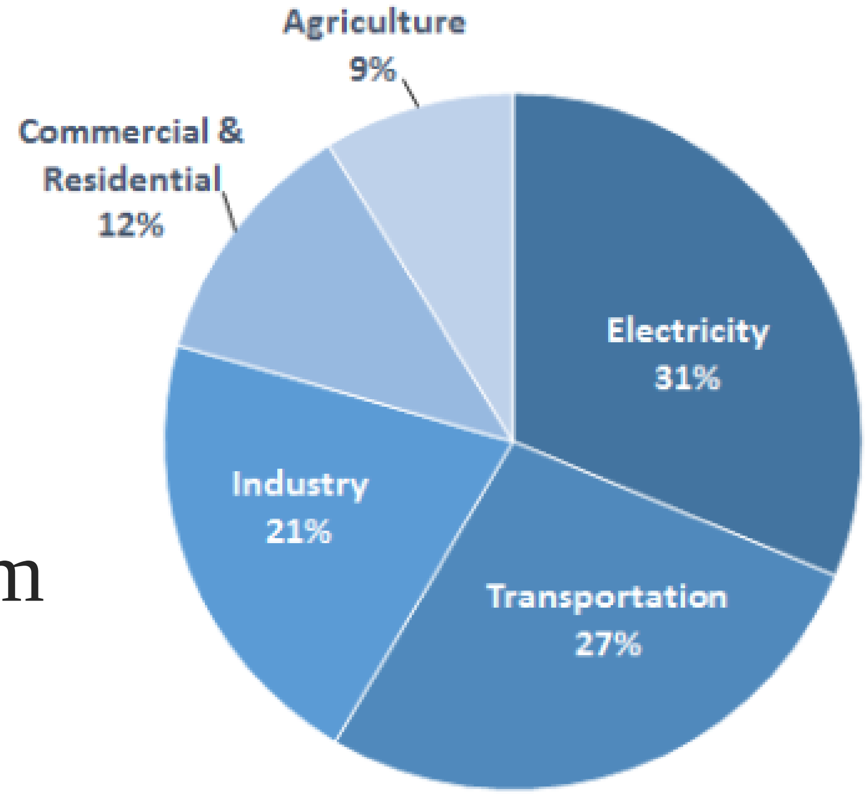
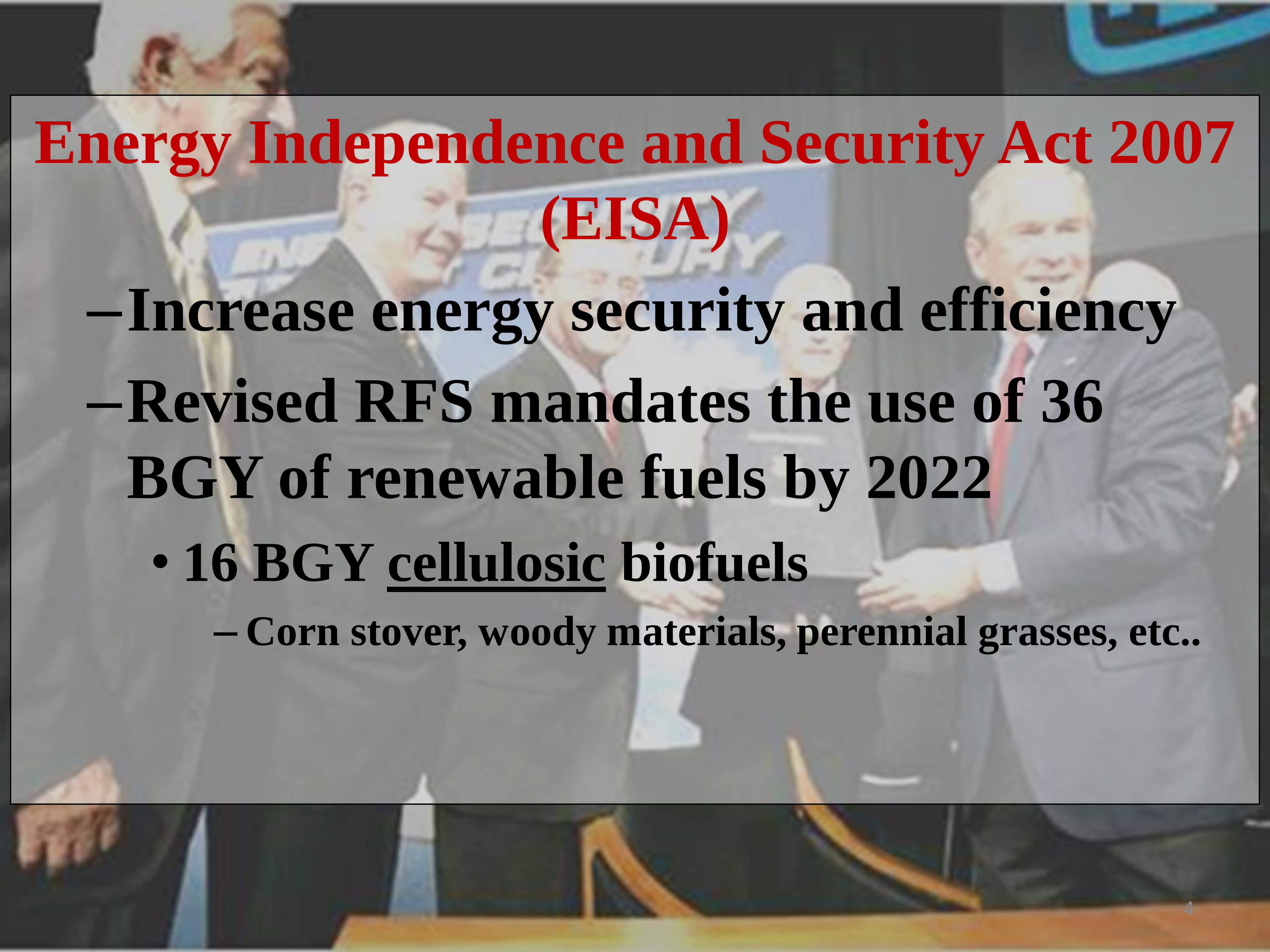


Figure 1. Total U.S. Greenhouse gas emissions by economic sector in 2013 (EPA, 2013).

Biofuels & Bioenergy

- **Carbon sources derived from photosynthesis**
- **Less GHG emissions**
- **Less dependence on foreign sources for energy**
- **Supports rural economics**
- **Currently mandated by congress**



Energy Independence and Security Act 2007 (EISA)

- **Increase energy security and efficiency**
- **Revised RFS mandates the use of 36 BGY of renewable fuels by 2022**
  - **16 BGY <u>cellulosic</u> biofuels**
    - **Corn stover, woody materials, perennial grasses, etc..**

Primary Ethanol Feedstock in U.S. is Corn

+ High carbohydrate yield & multiple uses

– Annual crop that has large nutrient requirements

– Grown on prime agricultural land

– Food vs. Fuel Conflict

- 40% of corn grain in the U.S. was used for ethanol and distiller grains
- 99% of ethanol was produced from corn
- World population is >7 billion
- Malnutrition: approximately 800 million

Solution = Cellulosic Feedstocks

Cellulosic Crops instead of Food Crops
Marginal Land instead of Farmlands

Starch/Sugar based Feedstocks:

- Corn
- Wheat
- Sugarcane

Cellulosic Feedstocks:

- Corn Stover
- Cereal Straws
- Woody Biomass
- **Perennial Grasses**

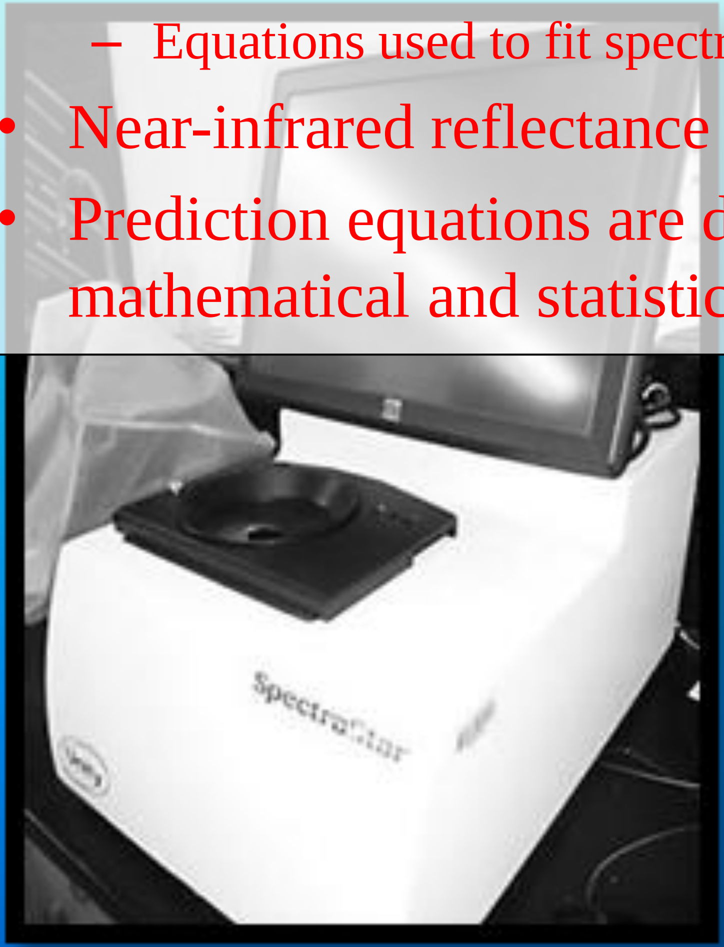
Cellulosic Ethanol Feedstocks

- **Lignocellulose is the only feedstock currently available in sufficient quantities to meet renewable energy goals.**
  - Can be produced to replace one-third of domestic gasoline usage on an energy basis.

Switchgrass & Miscanthus

- **Mostly all bioenergy crops differ in quality**
- **Techniques are needed to assess quality of biomass in a fast, inexpensive method with high accuracy**
- **Producers must know the quality of their crop before they can take it to a refinery**
- **Help in the breeding process for larger and higher quality bioenergy crop selection**
- **NIRS** is accurate, reliable, fast, non-destructive, and inexpensive

- Near-Infrared Reflectance Spectroscopy (NIRS)
  - Chemical constituents are quantified in a sample based on their spectral characteristics
  - Amount of constituent is predicted based on the samples near-infrared reflectance spectra
  - Equations used to fit spectra to a calibration set
- Near-infrared reflectance spectra profiles are determined
- Prediction equations are developed and validated using mathematical and statistical procedures

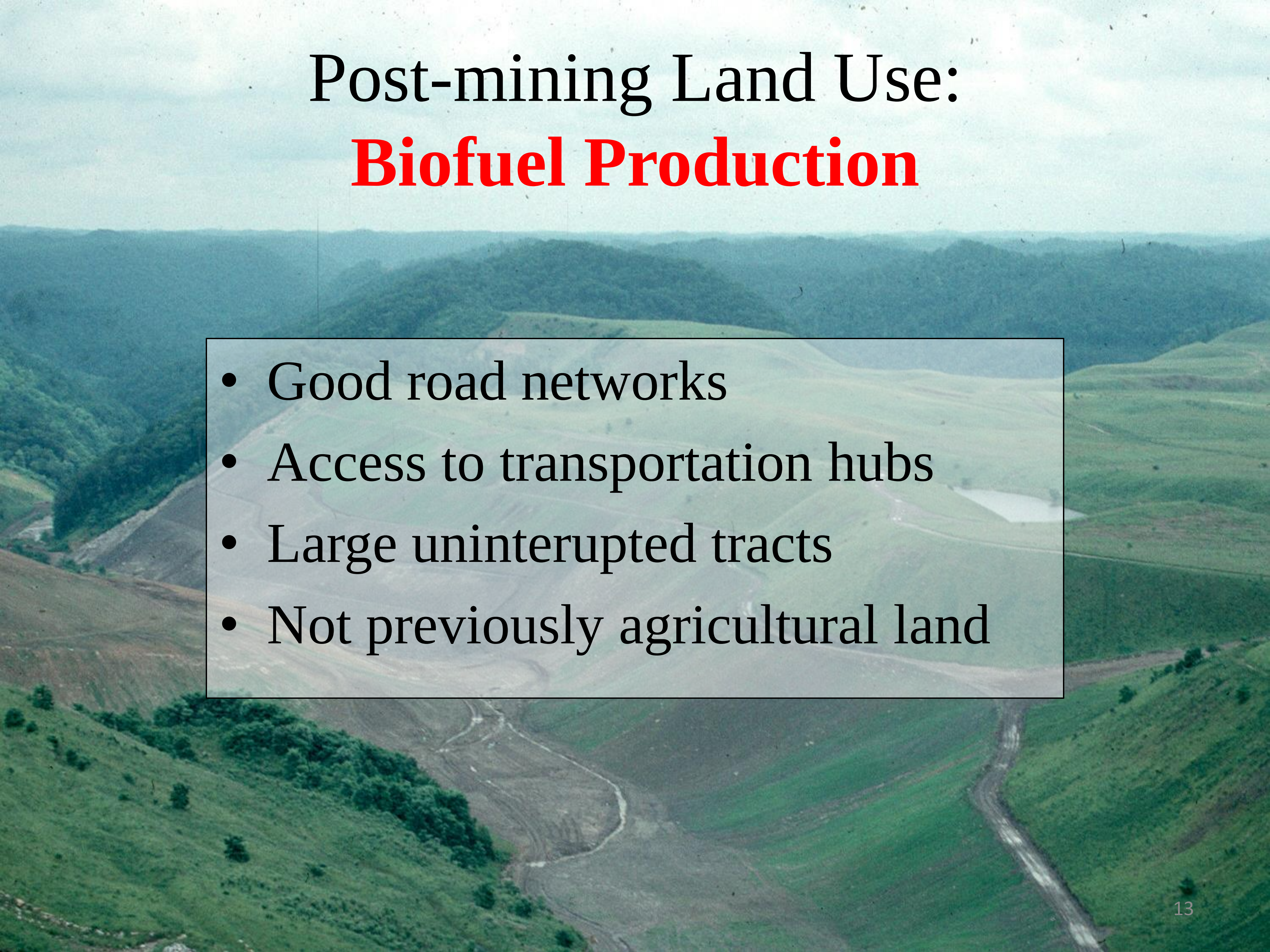


Bioenergy Crops:

- Grown on land **NOT** used for food production
- Sustainable alternative energy sources that can grow on marginal lands
- **Reclaimed mine lands!**
- 54,000 acres of land reclaimed in Appalachia in 2010 alone
- 75% of land is reclaimed to pasture/hayland

Much of this land is left unproductive or unmanaged!

Post-mining Land Use:
Biofuel Production



- Good road networks
- Access to transportation hubs
- Large uninterupted tracts
- Not previously agricultural land

Switchgrass (*Panicum virgatum*)

- Warm-season perennial
- Native to most of North America
- Two distinct ecotypes
  - Upland & Lowland
- Produce large quantities of biomass on marginal soils
- Ability to store carbohydrates and other nutrients for regrowth
- Dense rooting systems
- Ability to produce average yields of 5.2 to 11.1 Mg ha^{-1} when grown on marginal lands

- **Kanlow & BoMaster variety**
  - Lowland species
  - Tetraploid (36 chromosomes)
  - Sod former
  - Strongly rhizomatous
  - 6 to 8 ft tall when mature
  - Deep roots (10 ft or more)
  - Adapted better to flood plains and low-lying areas
  - Taller with larger and thicker stems

Summer 2014
Fall 2014


Fall 2014

Miscanthus
(*Miscanthus x giganteus*)

- **Warm-season C_4 perennial**
- **Native to Asia and Africa**
- **Sterile hybrid (*M. sacchariflorus* and *M. sinensis*)**
- **Growth comes from rhizomes**
- **Reaches heights of 3 to 3.5 m**
- **Deep rooting systems**
- **Stores nutrients in crowns and roots for regrowth in spring**
- **Stands have life spans up to 15 to 20 yrs with minimal cultural inputs**
- **High yields have been shown to range from 10 to 40 Mg ha^{-1} throughout Europe**

Miscanthus Continued

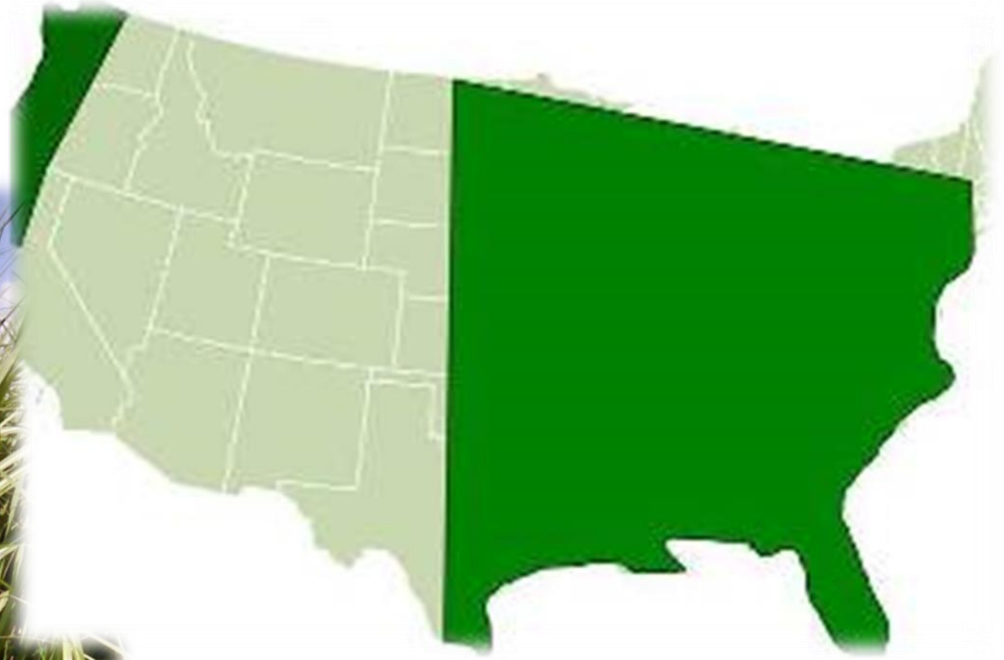
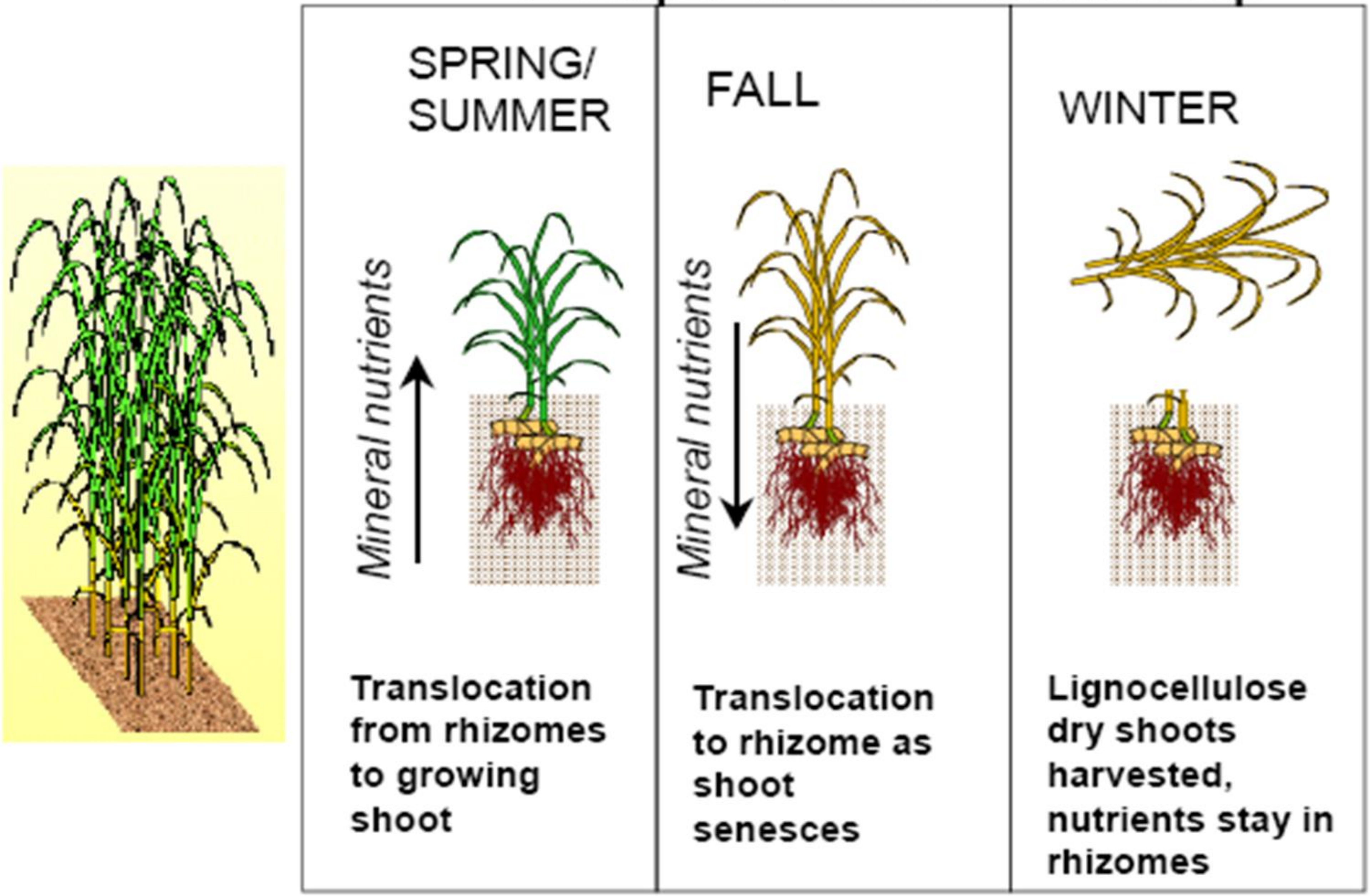


Figure 3. Approximate growing range of Giant Miscanthus in the U.S. (Heaton et al., 2014).

Example of “Ideal” biofuel crop



Source Dr. Steve Long, UIUC 2005

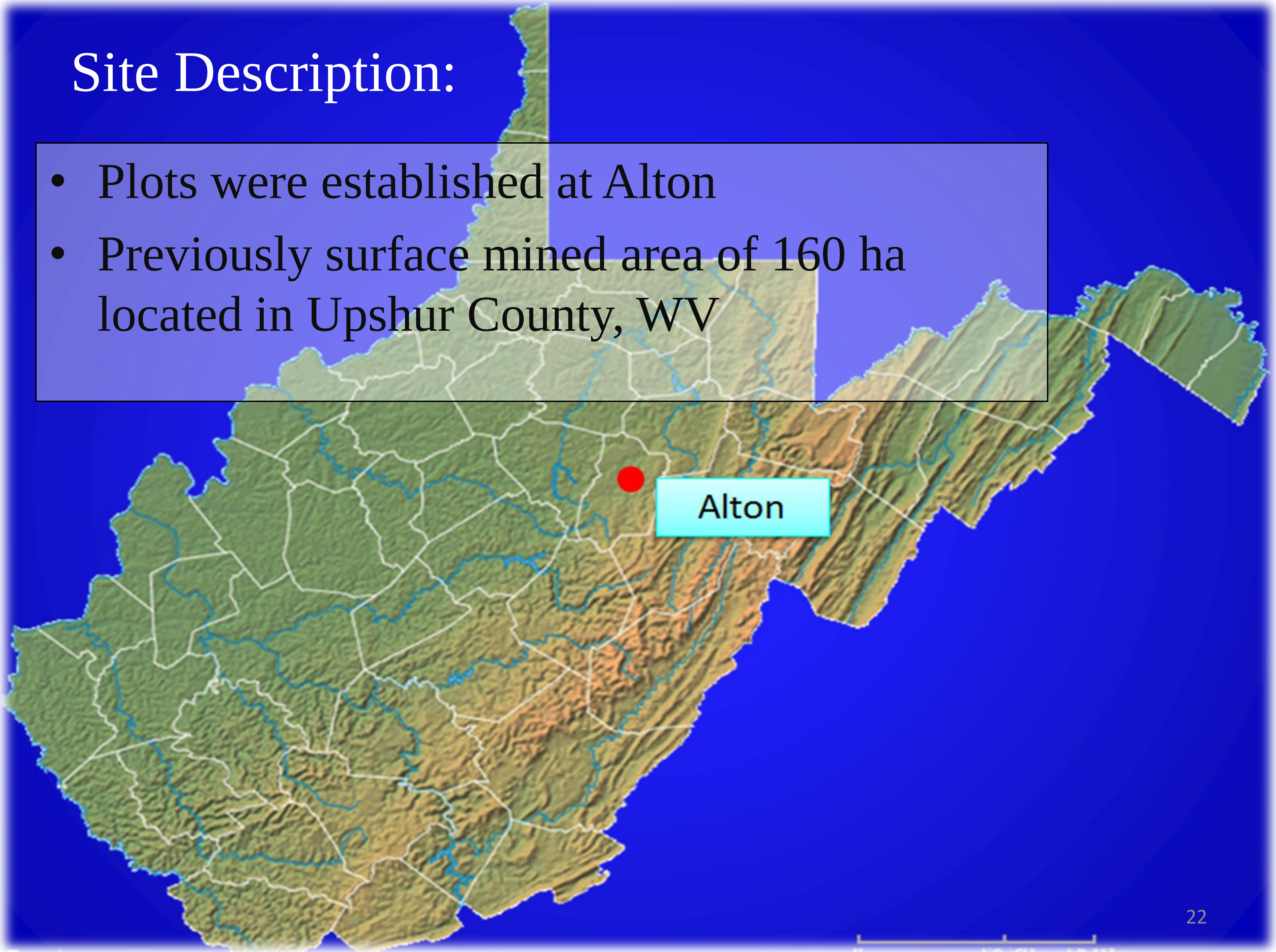
Objectives:

- **Determine yields of:**
  - **Miscanthus: Public and Private**
  - **Switchgrass: BoMaster and Kanlow**

- **Determine theoretical ethanol production (TEP) of Miscanthus and switchgrass varieties**

Site Description:

- Plots were established at Alton
- Previously surface mined area of 160 ha located in Upshur County, WV



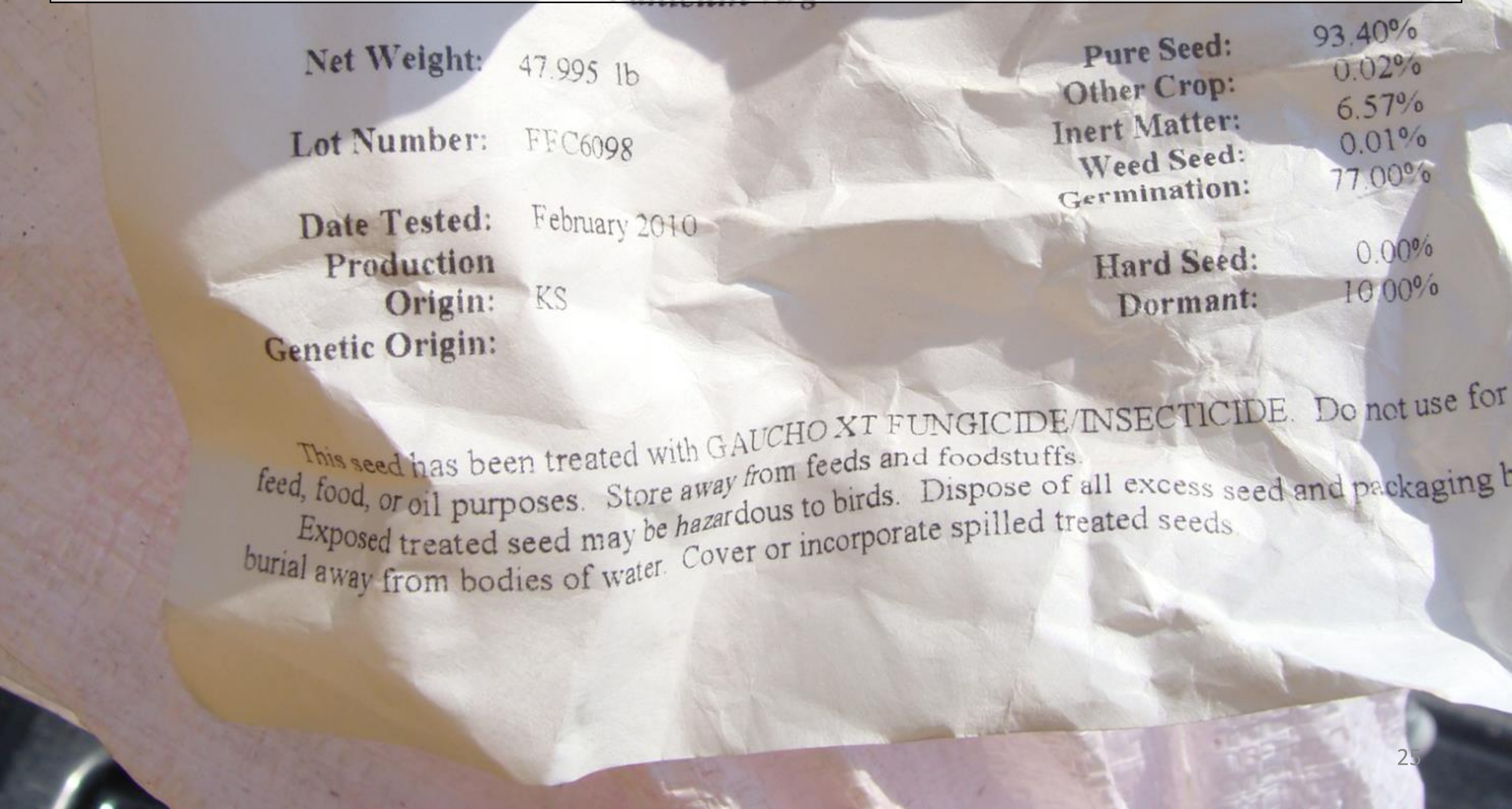
- **Reclaimed in 1985**
  - **15 cm soil placed over mixed overburden**
  - **Grass and legume species planted**
  - **Soils fertilized and limed**
- **Roughly 10 ha chosen for study site**
- **Planting began in spring of 2010**

Experimental Design

- Completely randomized design
- Cultivars were randomly assigned and established in 0.4-ha plots
- Replicated 5 times for a total of 20 plots

Figure 4. Alton site location of 0.4-ha plots of switchgrass (Kanlow and BoMaster) and Miscanthus (Public and Private).

- Kanlow and BoMaster switchgrass cultivars were no-till drilled in at rate of 11 kg ha^{-1} PLS (Ernst Conservation Seeds)



Experimental Design Continued

- Public and Private sterile Miscanthus varieties were planted as sprigs at a rate of 12,300 plugs ha^{-1} (Mendel Biotechnology)

- Clipping began in October of 2011, two years after establishment and each year thereafter

- Clipped by hand to a 10-cm stubble height

- All biomass was dried at 60°C for 48 hours to a constant weight

- DM yield was determined and converted to Mg ha^{-1}

- NIRS
  - Biomass samples were ground to a 2-mm particle size using a Wiley Mill
  - Packed into borosilicate 2 dram glass vials
  - Shipped to NREL in Colorado for chemical constituent analysis
    - Glucan, Xylan, Lignin, & Ash

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

*Results were converted to TEY (L Mg^{-1}) and then multiplied by biomass to get TEP (L ha^{-1}) for each cultivar

- Ex. Conversion calculation:
  - Hexose Sugar
    - (377 mg g^{-1} Glu x 0.57) x 1.267 L kg^{-1} = 272 L Mg^{-1} Glu
  - Pentose Sugar
    - (249 mg g^{-1} Xyl x 0.58) x 1.267 L kg^{-1} = 183 L Mg^{-1} Xyl
  - 272 L Mg^{-1} + 183 L Mg^{-1} = **455 L Mg^{-1} TEY**
  - **455 L Mg^{-1} TEY x 7.91 Mg ha^{-1} (Kanlow biomass) = <u>3,599 L ha^{-1} TEP for Kanlow</u>**

Results & Discussion

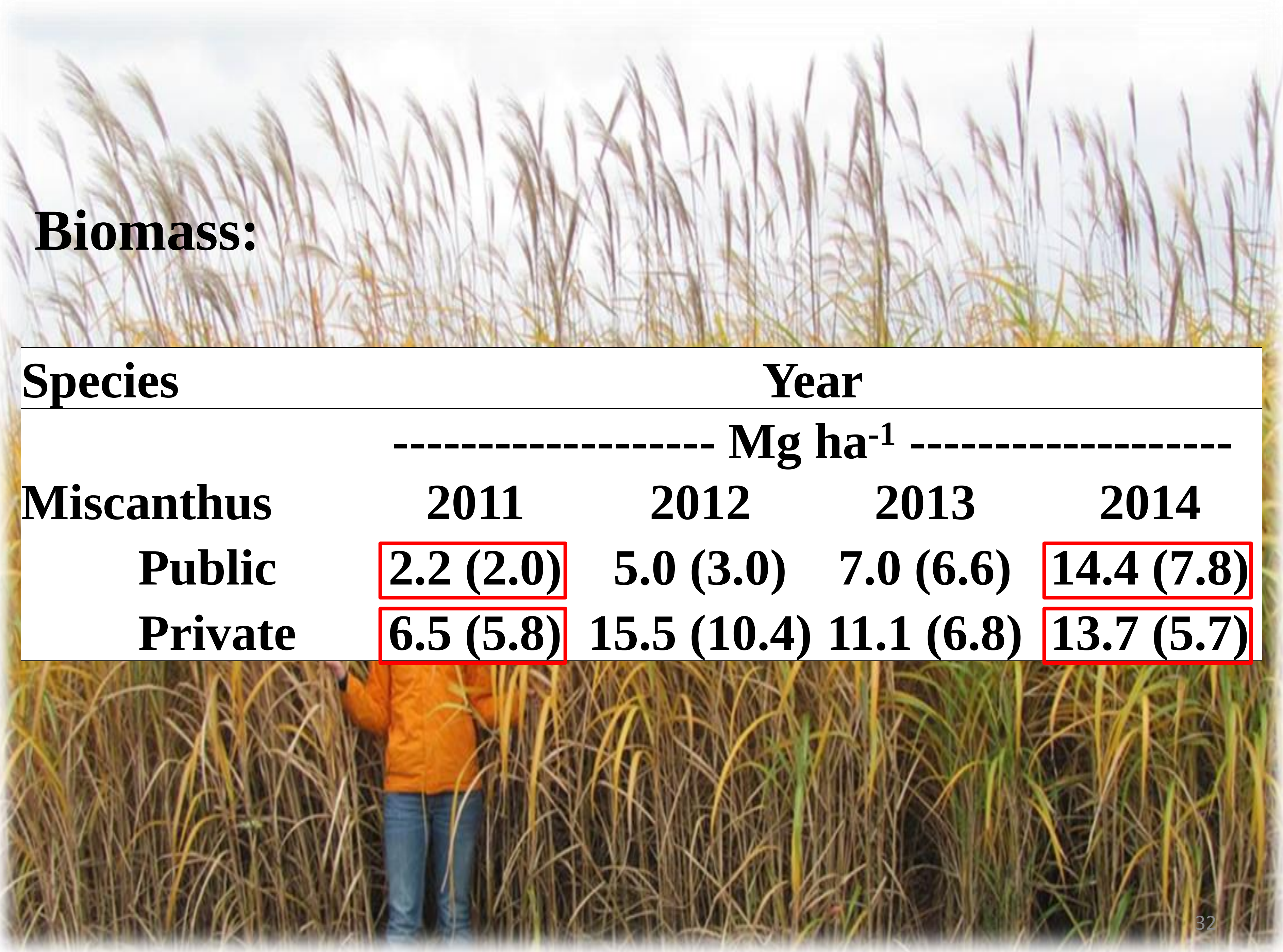
Soil analysis:

Plant Species	pH	CEC	Mg	Ca	K	P
		$\mu S\ cm^{-1}$	-----	$cmol^{+}\ kg^{-1}$	-----	$mg\ kg^{-1}$
<u>Switchgrass</u>						
Kanlow	6.5	23.7	0.55	2.6	0.18	37
BoMaster	6.8	19.9	0.21	3.9	0.13	23
<u>Miscanthus</u>						
Private	6.7	15.9	0.18	3.9	0.16	23
Public	7.2	16.7	0.43	3.4	0.13	19

Results and Discussion Continued

Biomass

Species	Year			
	-------------------- Mg ha^{-1} --------------------			
Switchgrass	2011	2012	2013	2014
Kanlow	4.0 (2.6)	4.9 (1.1)	4.9 (3.5)	7.9 (2.6)
BoMaster	2.7 (1.4)	4.0 (3.1)	5.4 (9.8)	7.3 (3.5)



Biomass:

Species	Year			
	------------------- Mg ha^{-1} -------------------			
Miscanthus	2011	2012	2013	2014
Public	2.2 (2.0)	5.0 (3.0)	7.0 (6.6)	14.4 (7.8)
Private	6.5 (5.8)	15.5 (10.4)	11.1 (6.8)	13.7 (5.7)

Results & Discussion:

Plant Species	Biomass		TEY		TEP
Switchgrass	---Mg ha^{-1}---		---L Mg^{-1}---		---L ha^{-1}---
Kanlow	7.9 (2.6)	×	473 (10.9)	=	3,700 (1,200)
BoMaster	7.3 (3.5)		457 (6.25)		3,300 (1,700)
Miscanthus					
Public	14.4 (7.8)		455 (8.21)		6,500 (3,800)
Private	13.7 (5.7)		461 (9.68)		6,300 (2,700)

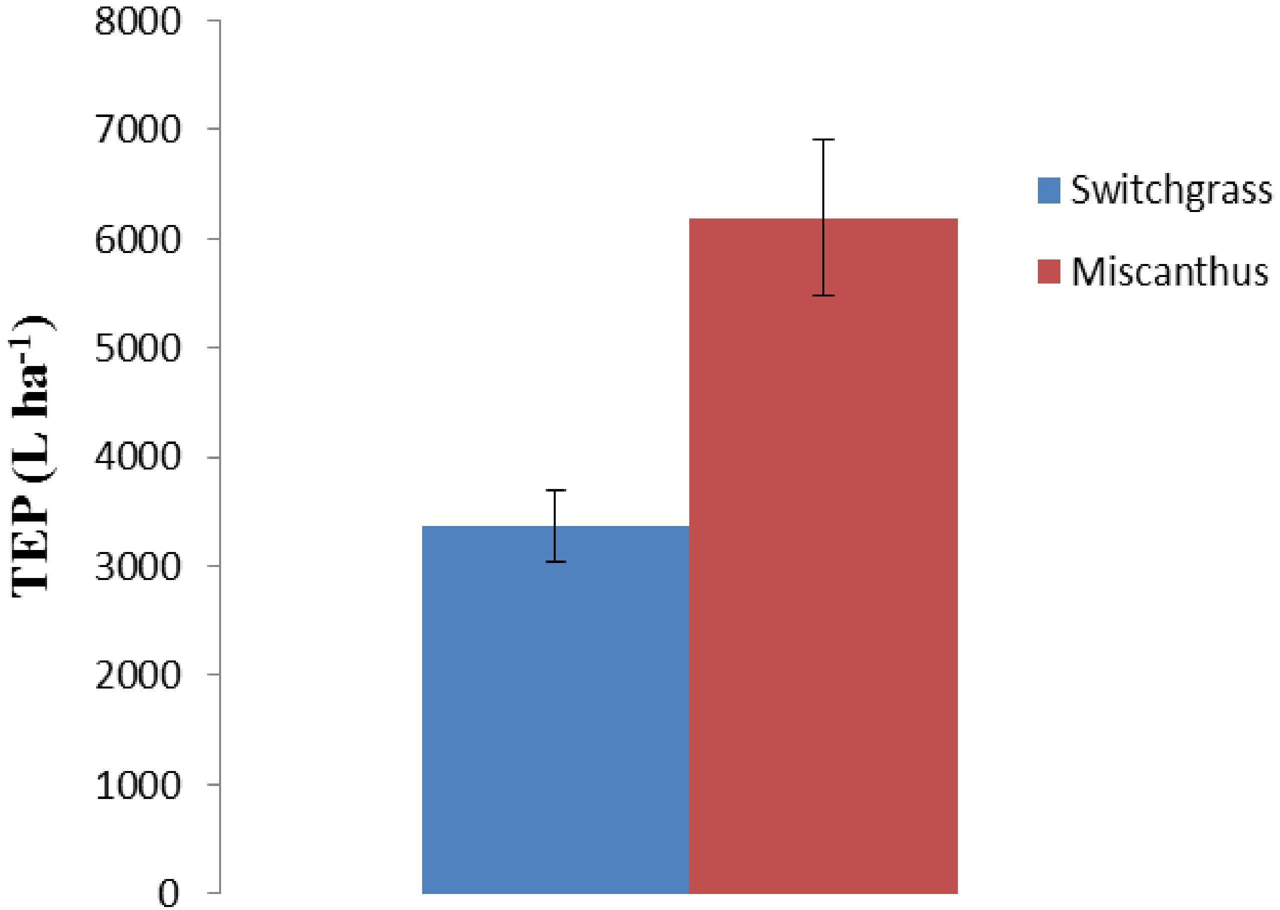


Figure 7. Theoretical ethanol production of switchgrass and Miscanthus at Alton, WV.

How do they measure up?

Feedstock	Harvestable Biomass Mg ha^{-1}	TEY L Mg^{-1}	TEP L ha^{-1}	Million Hectares Needed for RFS
Corn grain	10.2	418	4,266	31
Corn stover	7.4	379	2,805	47.2
Corn total	17.6	402	7,071	18.7
Switchgrass	10.4	379	3,937	33.7
Miscanthus	29.6	378	11,205	11.8

(Heaton et al., 2008)

Agricultural Land:

Feedstock	Harvestable Biomass Mg ha^{-1}	TEY L Mg^{-1}	TEP L ha^{-1}	Million Hectares Needed for 35 billion gallon of Ethanol
Corn grain	10.2	418	4,266	31
Corn stover	7.4	379	2,805	47.2
Corn total	17.6	402	7,071	18.7
Switchgrass	10.4	379	3,937	33.7
Miscanthus	29.6	378	11,205	11.8

Reclaimed Mine Land:

Feedstock	Harvestable Biomass Mg ha^{-1}	TEY L Mg^{-1}	TEP L ha^{-1}	Million Hectares Needed for 35 billion gallon of Ethanol
Switchgrass	7.6	465	3,500	37.9
Miscanthus	14.1	458	6,400	20.7

Conclusions

- Both species and varieties successfully established on a reclaimed surface mine
- Switchgrass and Miscanthus demonstrated high yields of biomass production (>5,000 Mg ha^{-1})
- Successful post-mining land use!

Conclusions Continued

- Miscanthus produces greater TEY and TEP than corn grain and corn stalk on reclaimed mine land!

- Sustainable option for future energy demands that will not displace food production!

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Questions?

Soil Testing

- Soil samples were taken in 2009 to a depth of 10 cm
- Samples were dried and rocks were removed
- Fine material (< 2mm) was dried and used for analyses
- pH determined on a 1:1 mixture with deionized distilled water with a pH meter
- Soil extraction done using Mehlich 1 solution

  *(0.05 mol L^{-1}HCL and 0.025 mol L^{-1} H_2SO_4)
- Solution analyzed with an emission spectrophotometer for:
  – P, K, Ca, Mg, Al, Ba, Fe, and Mn
- Mean values were determined for each plot and averaged for species

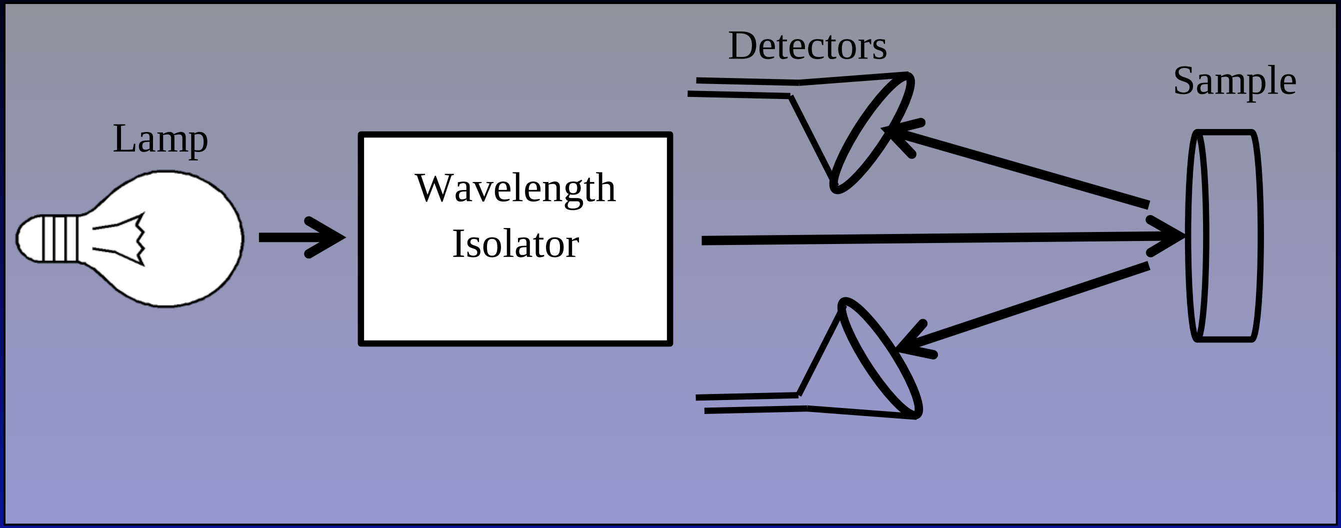

Figure 2. Simplified NIRS example.

- NIRS is able to detect hemicellulose, cellulose, and lignin because they contain hydrogen-bearing functional groups (-CH, -OH, -NH).

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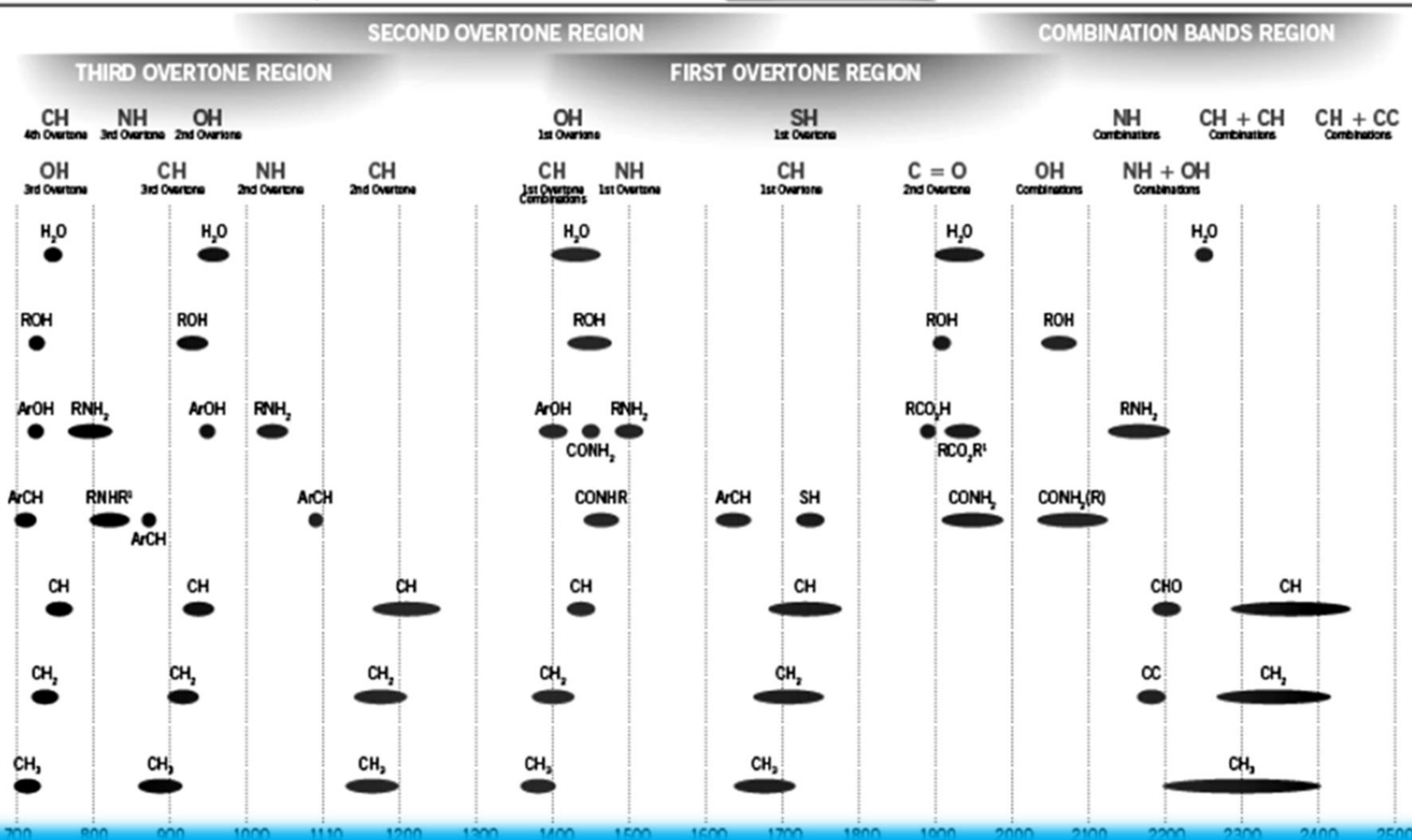
Near-IR Absorption Bands



Steps for Biochemical Conversion:

- **Pretreatment**
  - Opens up plant cell wall structure
  - Allows enzymes to access structural carbohydrates
- **Enzymatic Saccharification**
  - Hydrolytic enzymes digest pretreated biomass
  - Extract fermentable sugars
- **Fermentation**
  - Released sugars are fermented to ethanol by distillation
- **Product Recovery**
  - Recovery of ethanol by distillation

- **1.267 comes from the specific volume of ethanol which is 0.789 g mL-1
- so 1/0.789 g mL-1 = 1.267 mLg-1 ethanol.

- **0.57 and 0.58 are ethanol conversion factors for cellulose (glucose) and xylan respectively. These values arise from the weight gain associated with hydrolysis (polysaccharide to monosaccharide for fermentation).