

Cellulosic Biomass: Harvesting, Transportation, and Storage

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Northern Plains Biomass Economy: What Makes Sense?

Fargo

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Collaborators

Plant & Soil Sciences

Charles Taliaferro (Retired) – grass breeding

Yanqi Wu – feedstock development

Biosystems & Agricultural Engineering

Ray Huhnke – biomass harvest and storage

Dani Bellmer - gasification

Tim Bowser - gasification

Mark Wilkins - bioconversion

Chemical Engineering

A.J. Johannes – process engineering

Randy Lewis (BYU) – bioreactor, bioconversion

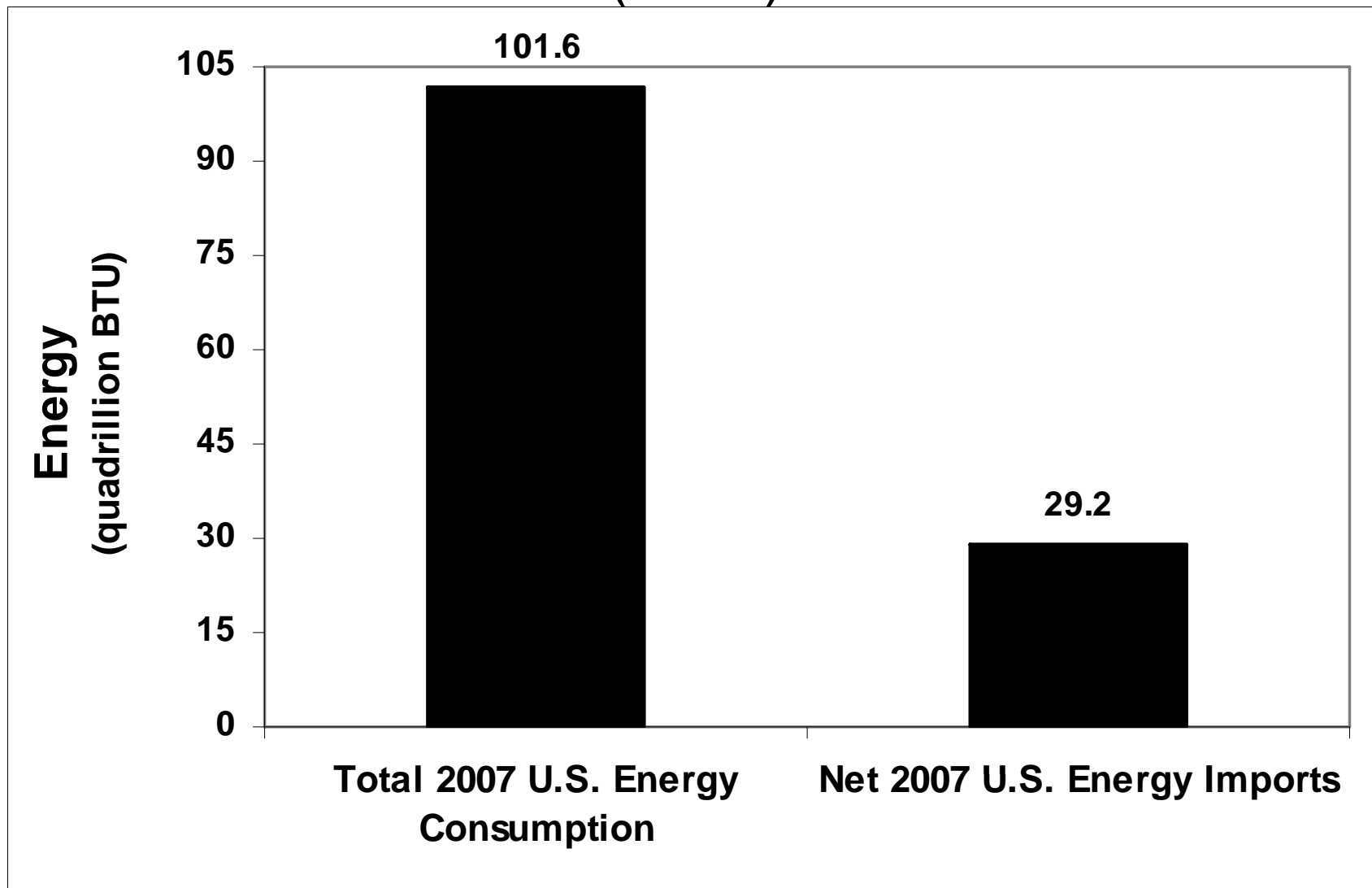
Microbiology

Ralph Tanner (OU) – microbial catalyst development

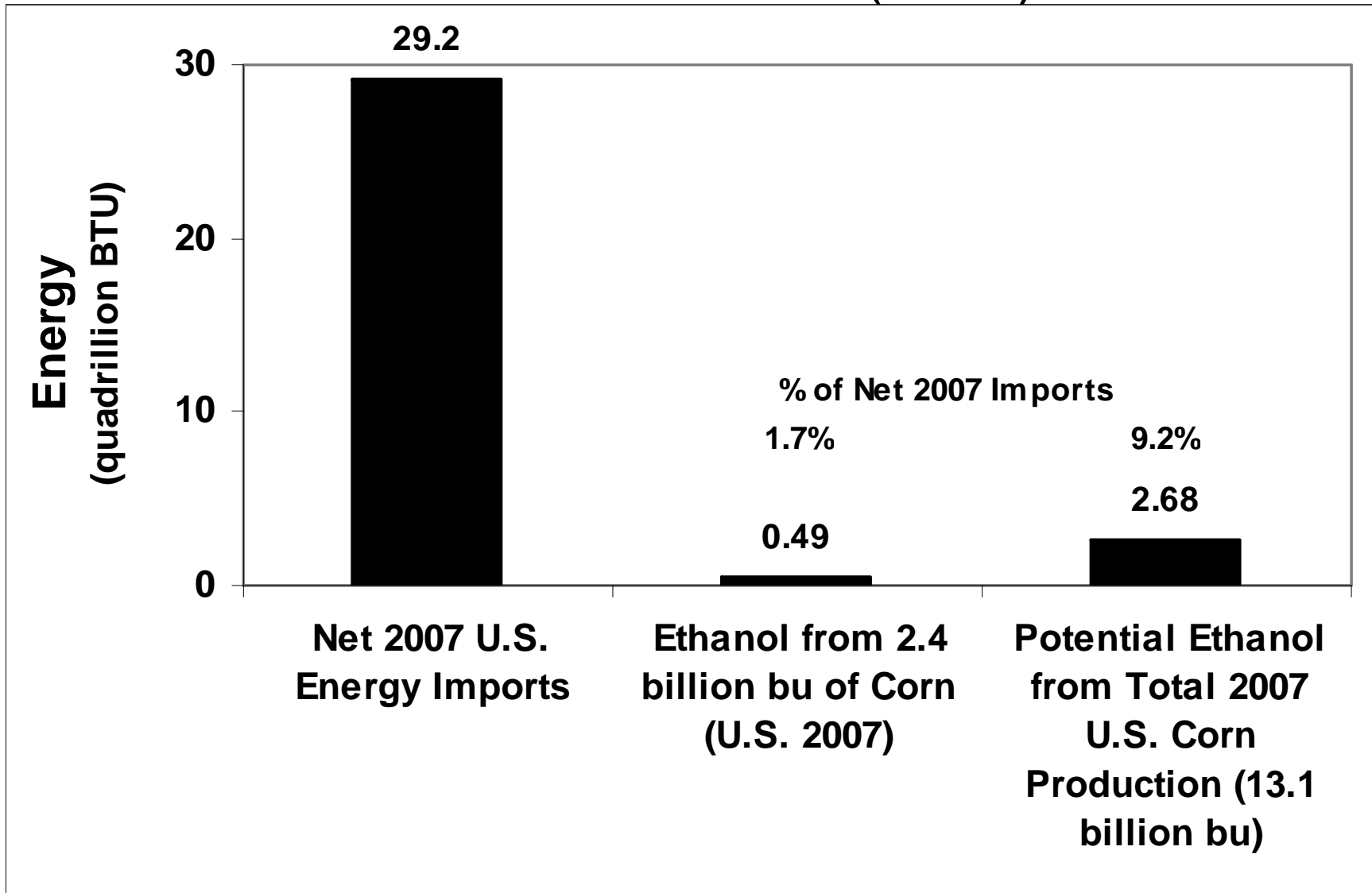
Outline

- Perspective
 - Size of the Energy Business
 - Land Requirements
 - Acres
 - Yield
- Harvest System
 - One Alternative
 - Importance of Harvest Costs
- Challenges

U.S. Energy Use and Imports (2007)



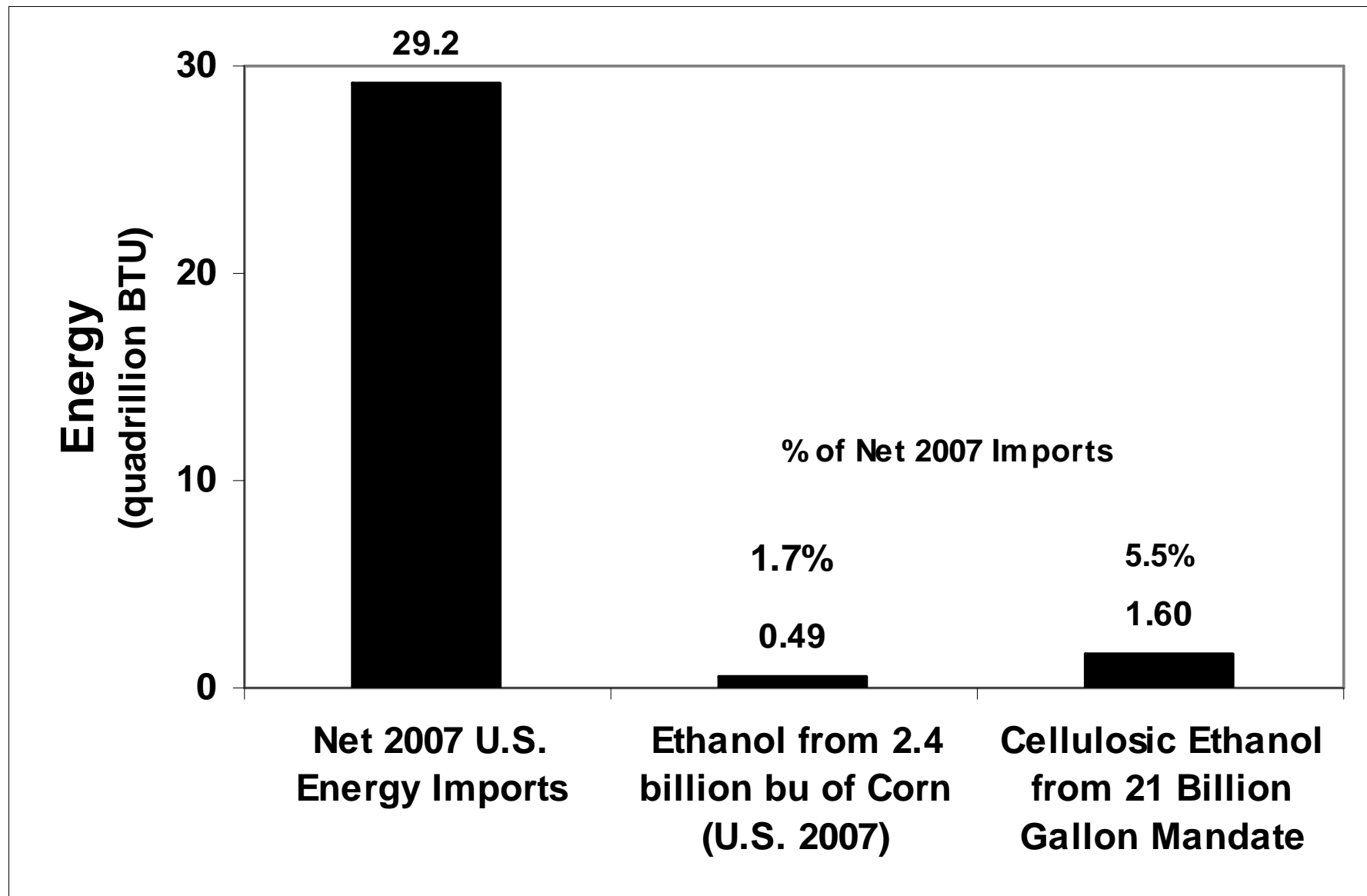
U.S. Energy Imports and Energy from Corn Ethanol (2007)



Cellulosic Ethanol

- Energy Independence and Security Act of 2007
 - By 2022, 21 billion gallons of ethanol to be derived from non-cornstarch products (e.g. sugar or cellulose)

U.S. Energy Imports and Potential Energy from 21 Billion Gallons of Cellulosic Ethanol (EISA Mandate for 2022)



Feedstock Acres

- 21 billion gallons (2007 Energy Act)
- 90 gallons per ton (DOE NREL goal)
- **233 million tons**
- 3 - 7 dry tons per acre
- **33 - 78 million acres**
- In 2007 US farmers planted
 - 94 million acres of corn
 - 64 million acres of soybeans
 - 60 million acres of wheat
 - 11 million acres of cotton

Quantity of Feedstock Required for a 2,000 tons per day Biorefinery

- 700,000 tons / y / biorefinery
- 218,750 (3.2 t/a) acres
- 63 million gal / y / biorefinery (90 gal/t)
- 333 biorefineries to produce 21 billion gal / y
(73 million acres)

Quantity of Feedstock Required for a 2,000 tons per day Biorefinery

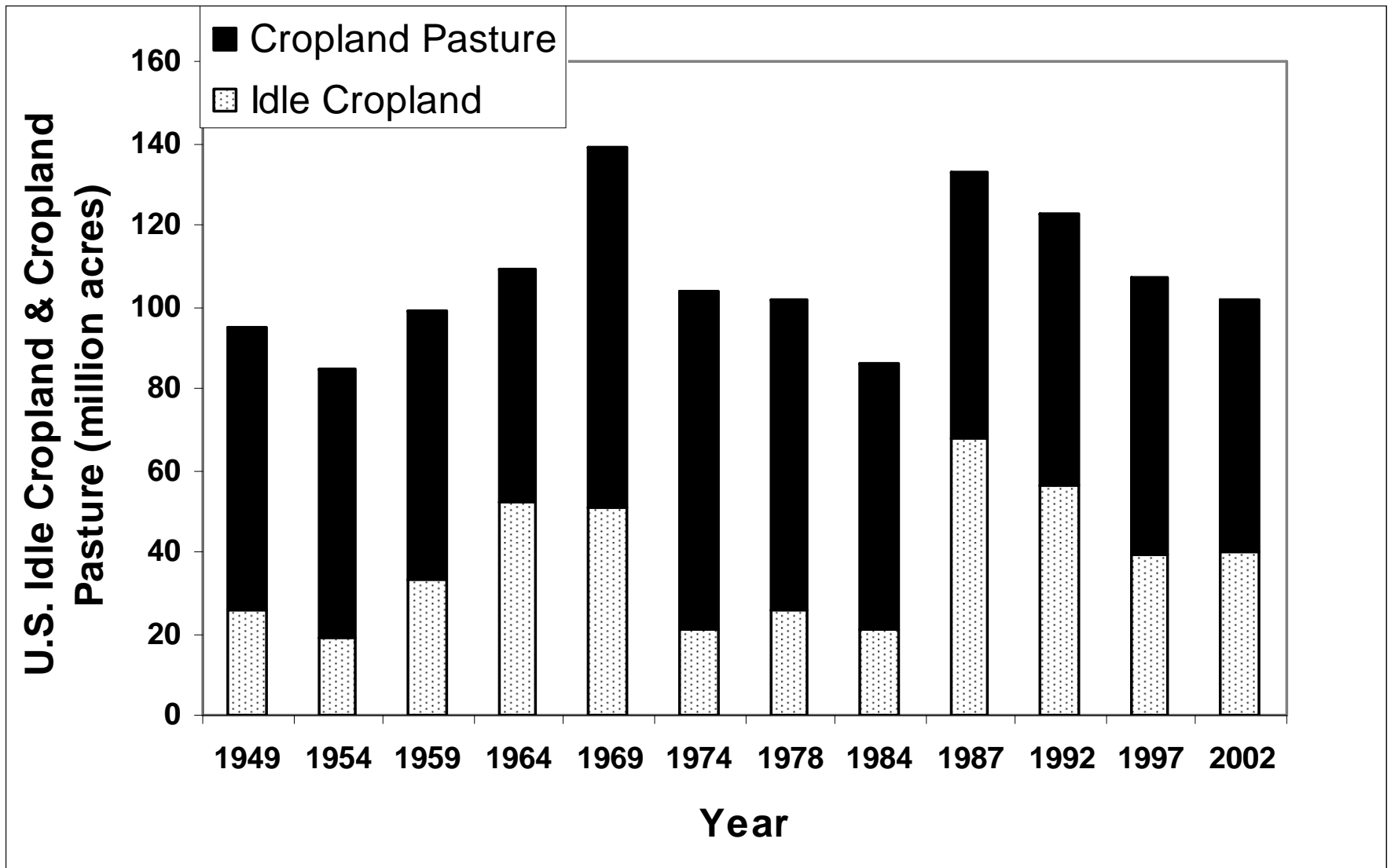
- 700,000 tons of biomass per year
- 350 days of operation per year
- 17 dry tons per truck
- 118 trucks per day
- 24 hours per day
- 4.9 trucks per hour



Land ?

“...The rationale for developing lignocellulosic crops for energy is that ...poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land....” (McLaughlin et al. 1999, p. 293).

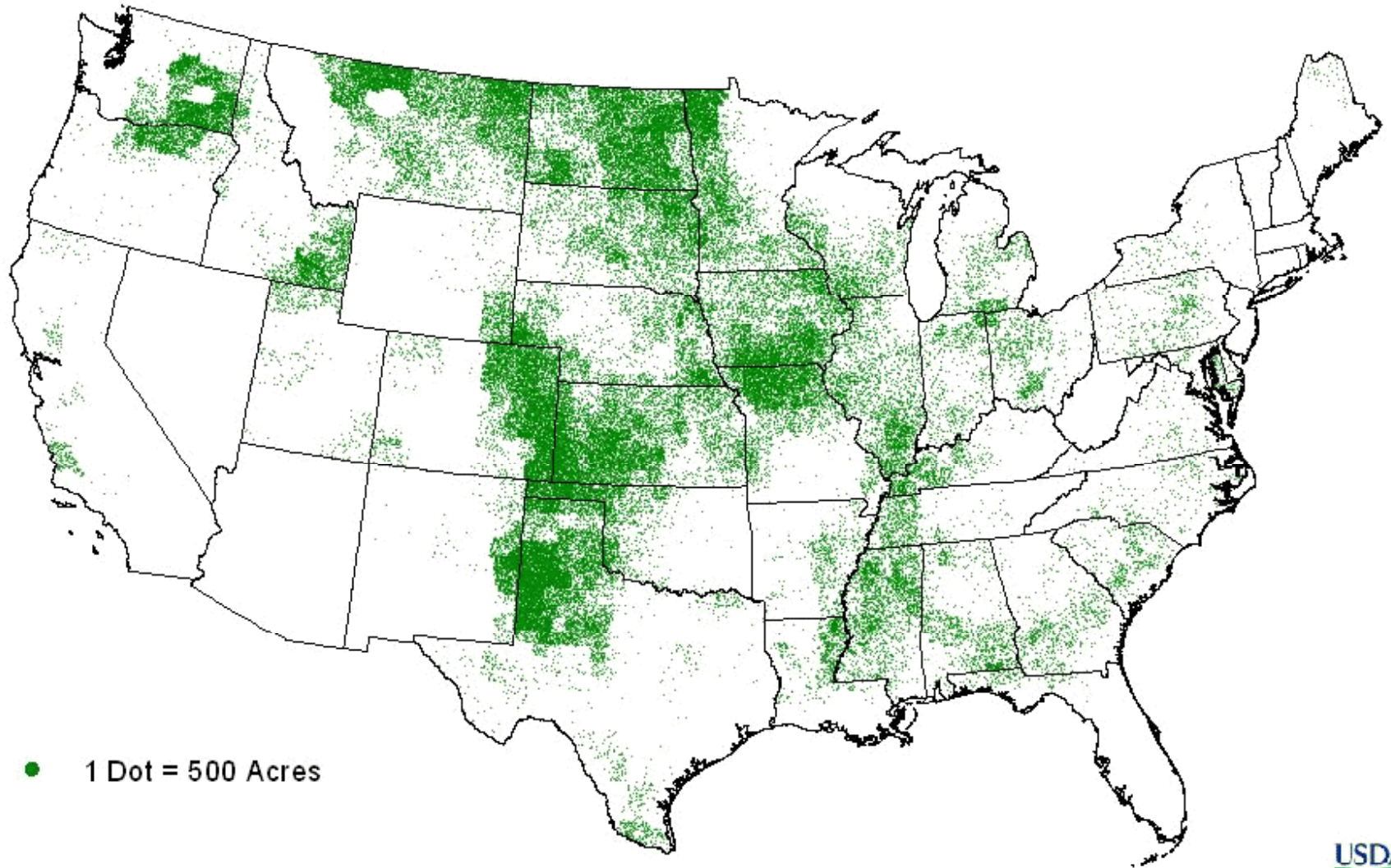
(Source: McLaughlin, S., J. Bouton, D. Bransby, B. Conger, W. Ocumpaugh, D. Parrish, C. Taliaferro, K. Vogel, and S. Wullschleger. 1999. Developing Switchgrass as a Bioenergy Crop. J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, VA.)



Source: R.N. Lubowski, M. Vesterby, S. Bucholtz, A. Baez, M.J. Roberts. Major Uses of Land in The United States, 2002. USDA ERS Electronic Report Econ. Info. Bul. 14, May 2006.

CRP Enrollment, FY 2007 (Cumulative)

CRP Acres, All Signup Types and Practices



● 1 Dot = 500 Acres

USDA

Farm Service Agency

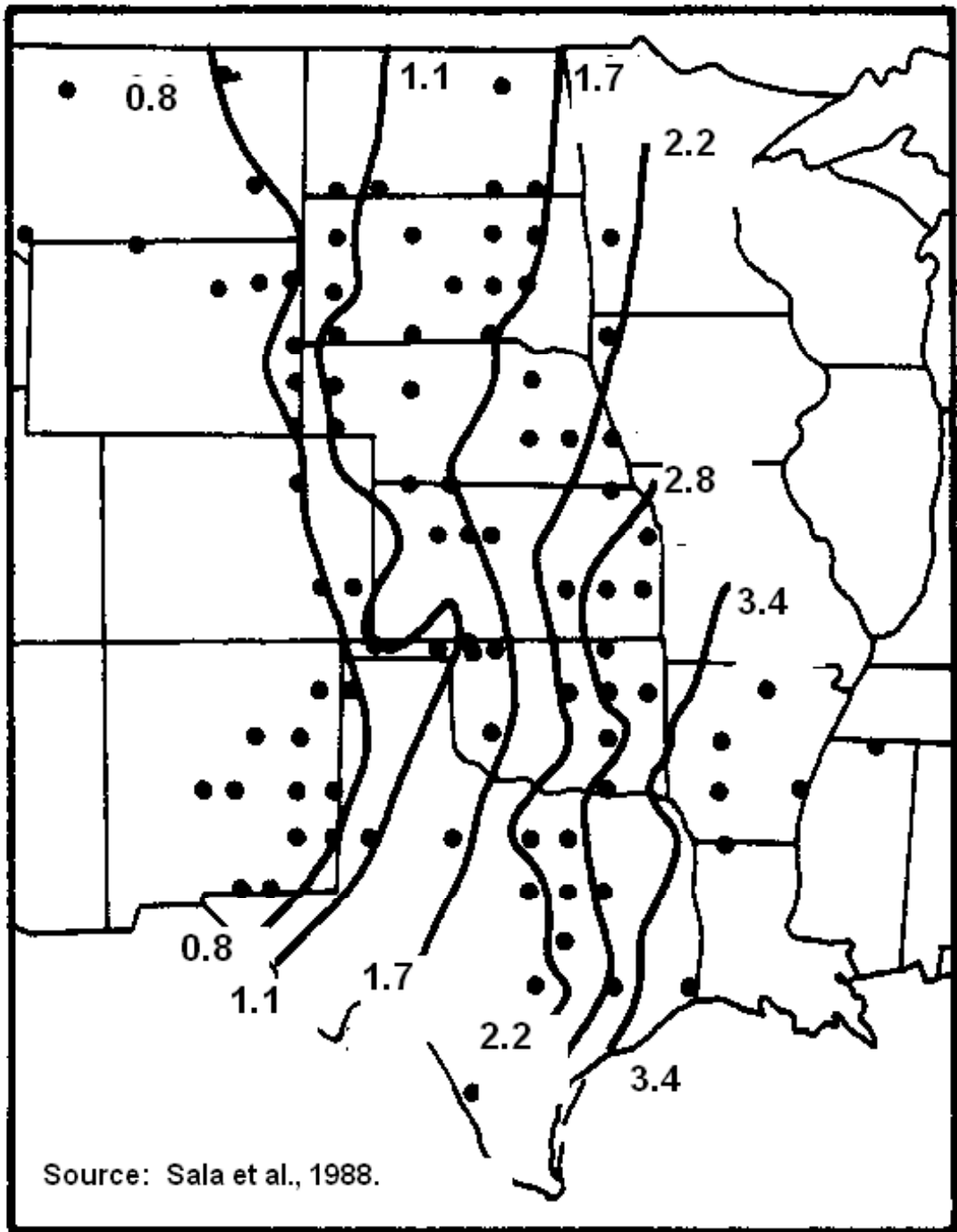
Idle Cropland and Cropland Used for Pasture

(million acres)

	Idle Cropland	Cropland Used for Pasture	Total
North Dakota	3.0	1.3	4.3
South Dakota	1.3	2.5	3.7
Nebraska	1.1	1.9	3.0
Kansas	2.5	2.5	5.0

Biomass Yield Potential ?

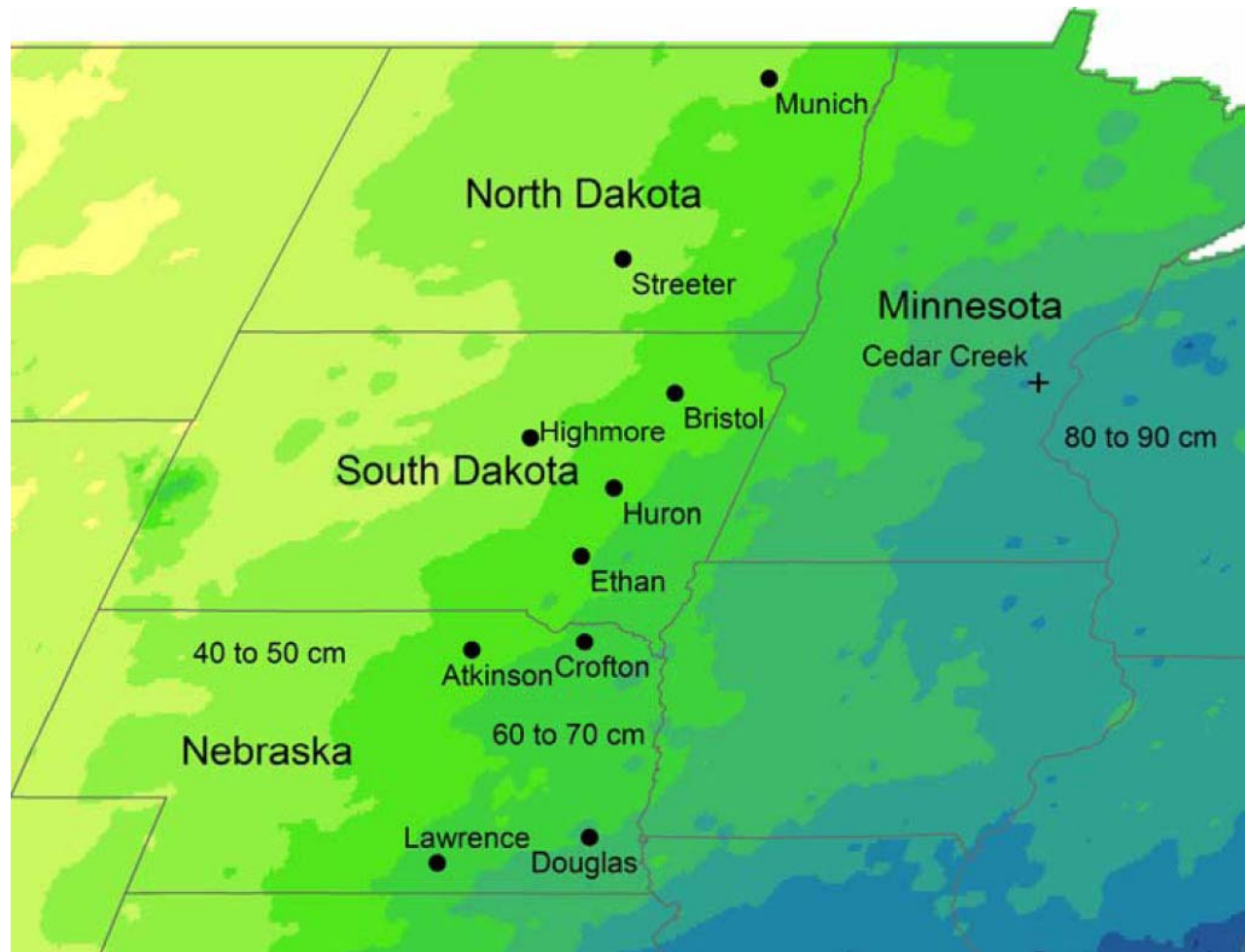
Central
Grassland
Region Biomass
Production
During Years of
Average
Precipitation
(tons/acre)



Switchgrass Yields - Northern Plains

marginal cropland – 10 farms

Source: Schmer, M.R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass Proc. National Academy of Sciences 105-2:464-469.



Switchgrass Yields Northern Plains

marginal cropland – 10 farms
Annual Yields Across Three Years

10 farms

2 farms

4 States

North Dakota

tons/acre

Mean	3.2	3.2
Minimum	1.7	2.2
Maximum	5.4	3.7

Source: Schmer, M.R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. Net energy of cellulosic ethanol from switchgrass Proc. National Academy of Sciences 105-2:464-469.

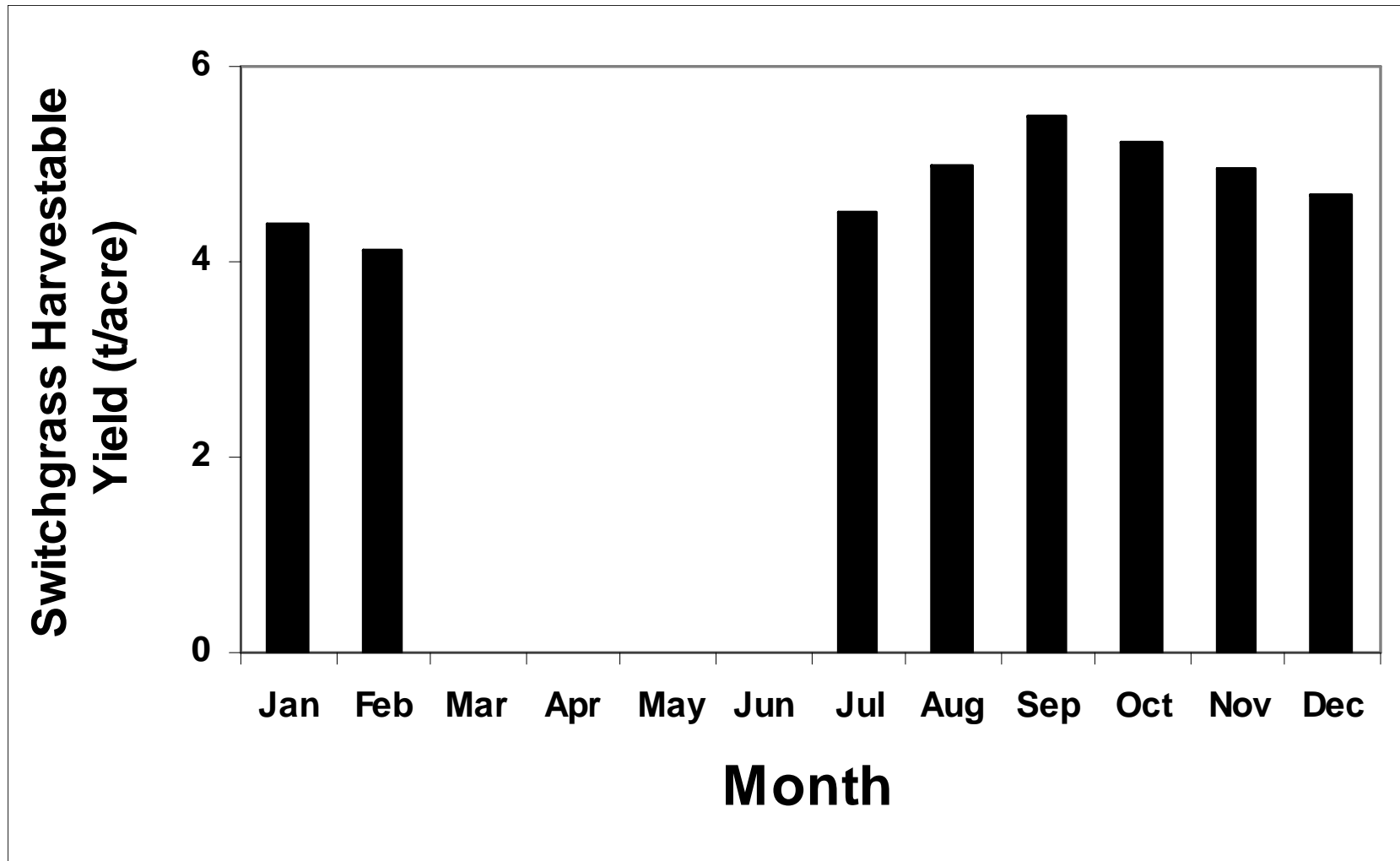
Switchgrass

Oklahoma Data

- Yields more than
 - miscanthus; bermudagrass; flaccidgrass; lovegrass; eastern gammagrass
- Harvest window extends from July through February
- Single harvest per year is more economical than multiple harvest
- Nutrient requirements depend on time of harvest
 - single harvest October 5.5 t/a 60 lb/a N
 - two harvests (July, Oct) 6.3 t/a 170 lb/a N

Switchgrass Expected Harvestable Yield Oklahoma Cropland (tons/acre)

expected yield 5.5 to 4 t/a depending on
county and month of harvest (preliminary data)



Production Challenges

- Continuous year-round flow of material from fields to biorefinery
- Unlike corn grain, harvest, storage, transportation, marketing, and risk management infrastructure does not exist
 - Spot markets work fine for corn grain
 - Spot markets don't exist for switchgrass
- Large investment required in harvest machines
- Massive quantities must be stored until processed

Harvest System

- Depends on whether the processing system prefers
 - dry versus wet
 - loose versus dense
- Depends on which cellulose processing technology “wins”
 - enzymatic hydrolysis
 - acid hydrolysis
 - gasification
 - gasification-fermentation
 - liquefaction
 - mixalco

Which Harvest Method?

- Current forage harvest systems
 - Small bales
 - Large cylindrical solid bales
 - Large rectangular solid bales
 - Loose chop
 - Cotton module systems
 - Silage systems
- Collect for field storage and transport substantial distances
- For large volume, and current forage harvest technologies, large rectangular solid bales is the most economical system for harvesting biomass from perennial grasses in the Western Plains (Source: Thorsell et al.)

Bale



Collect
Bales
and
Stack for
Field
Storage





Experience from Custom Grain Harvest Companies (Great Plains)

- A substantial quantity of the grain in the Great Plains is Harvested by Custom Harvest Companies

	Average
• Acres Harvested per Year	28,049
• Number of Combines	4.1
• Number of Trucks	6.3
• Number of Employees	10.3

(Source: Kastens and Dhuyvetter, 2006)

Coordinated Harvest System for Switchgrass

- 1 Field Stacker
- 3 Balers (large rectangular solid bales)
- 3 Mowers
- 3 Rakes
- 9 Tractors
- 10 Workers

(Source: Thorsell et al.)

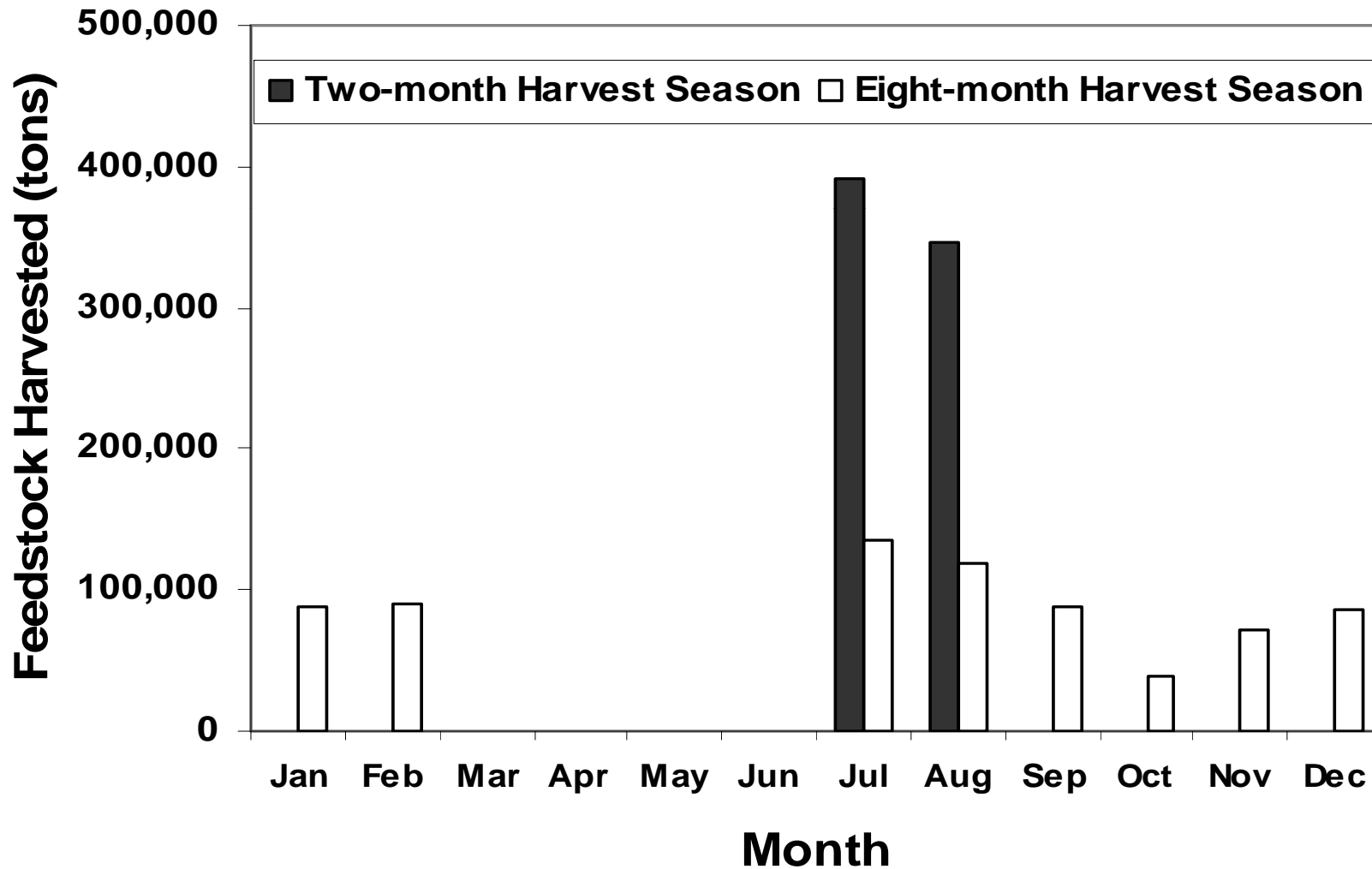
Modeling

- Multi-region, multi-period, mixed integer mathematical programming model
 - Tembo et al. 2003. *JARE* 28:611-633.
 - Mapemba et al. 2007. *RAE* 29:227-246.
 - Epplin et al. 2007. *AJAE* 89:1296-1302.
 - Mapemba et al. 2008. *Biomass and Bioenergy* 32:1016 – 1027.

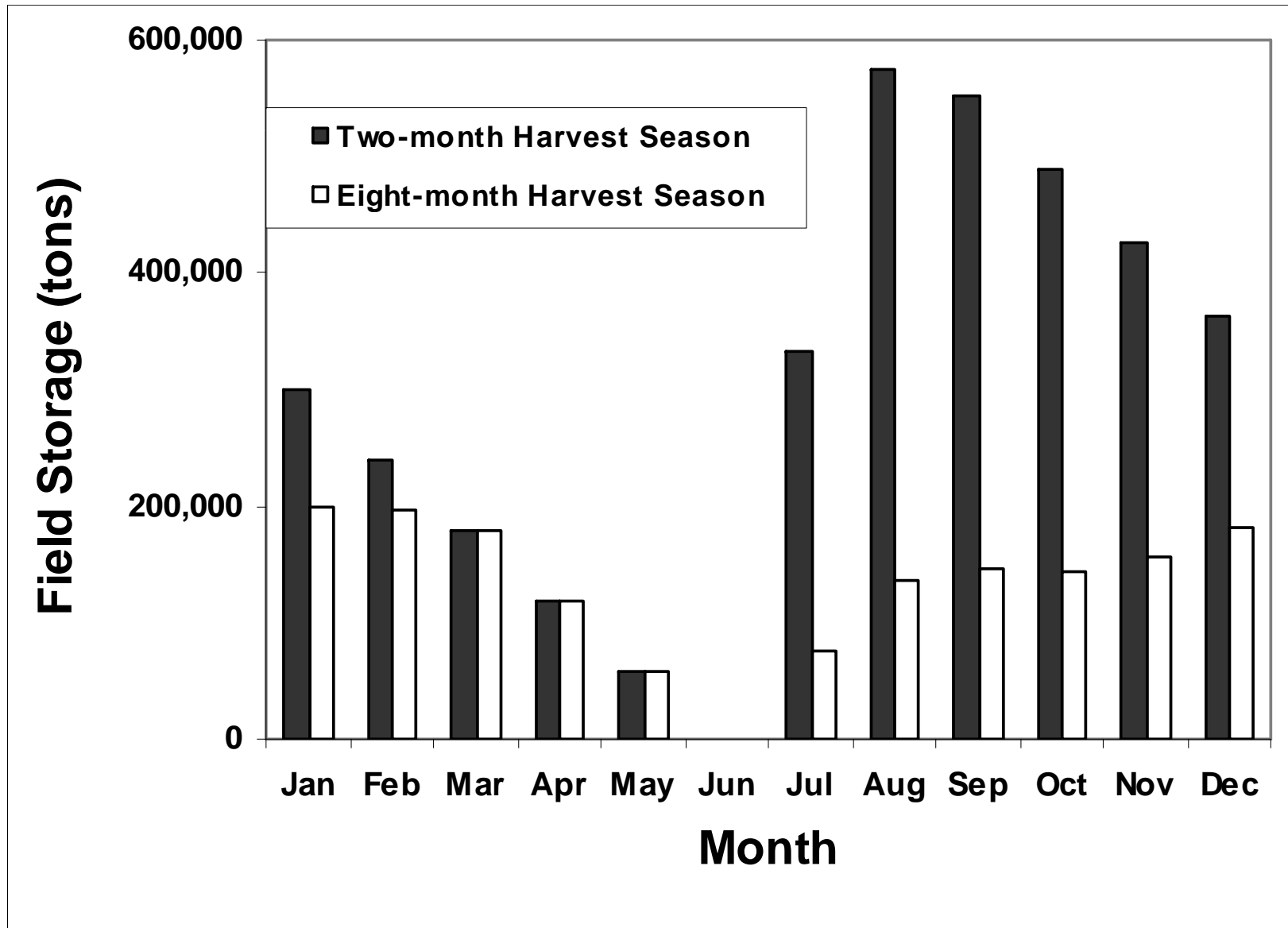
Oklahoma Model

- Field workday distributions built from historical weather data (Mesonet system)
 - Mowing days
 - Raking, baling, stacking days
- Single harvest per year
 - 8 month harvest window (Jul – Feb)
- 2,000 dry tons per day
- Use the model to determine optimal number of harvest machines and harvest, storage, and transportation by month

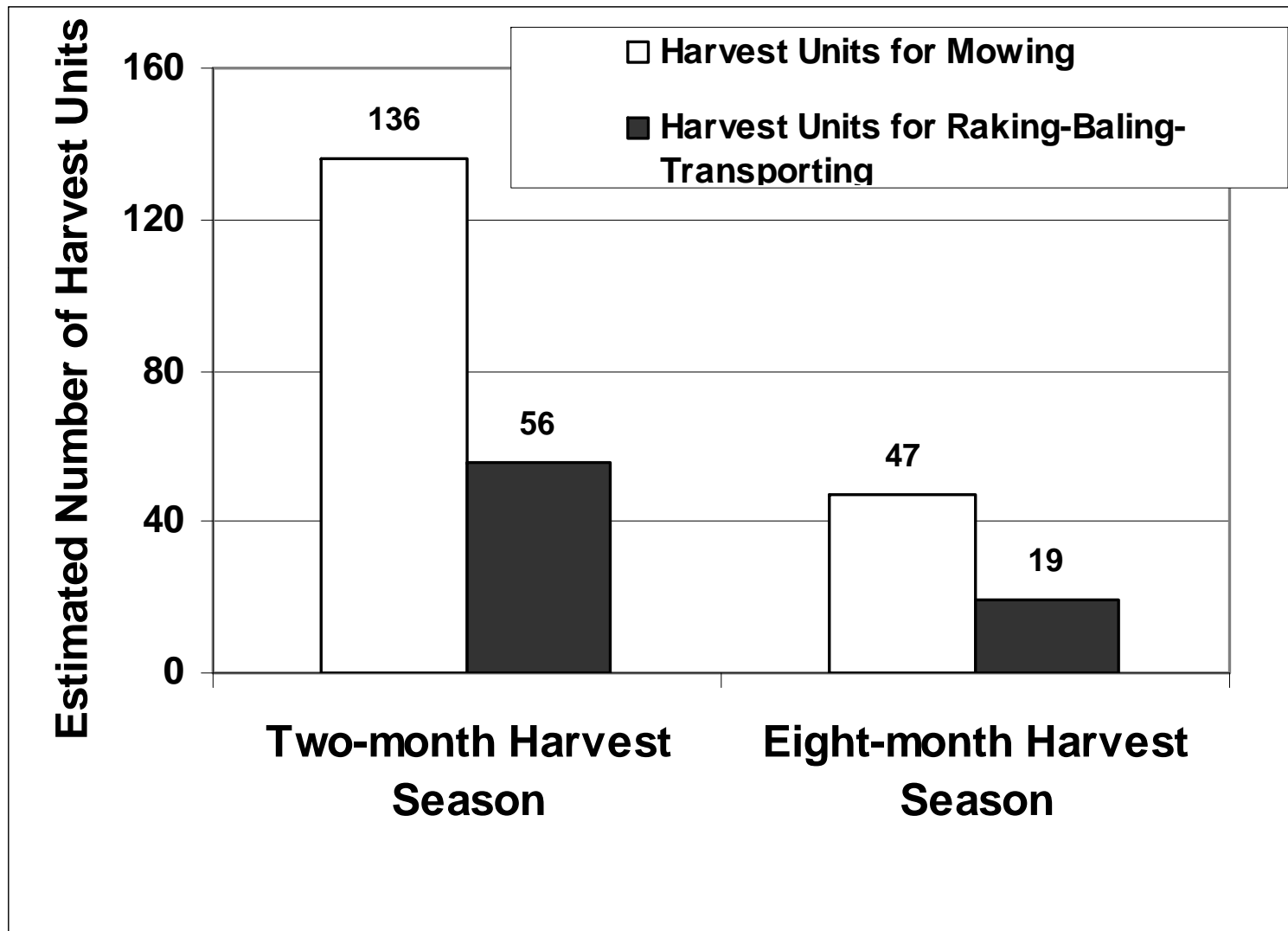
Switchgrass harvested per month for both a two- and eight-month harvest season to provide a flow of feedstock to a 2,000 dry tons per day biorefinery



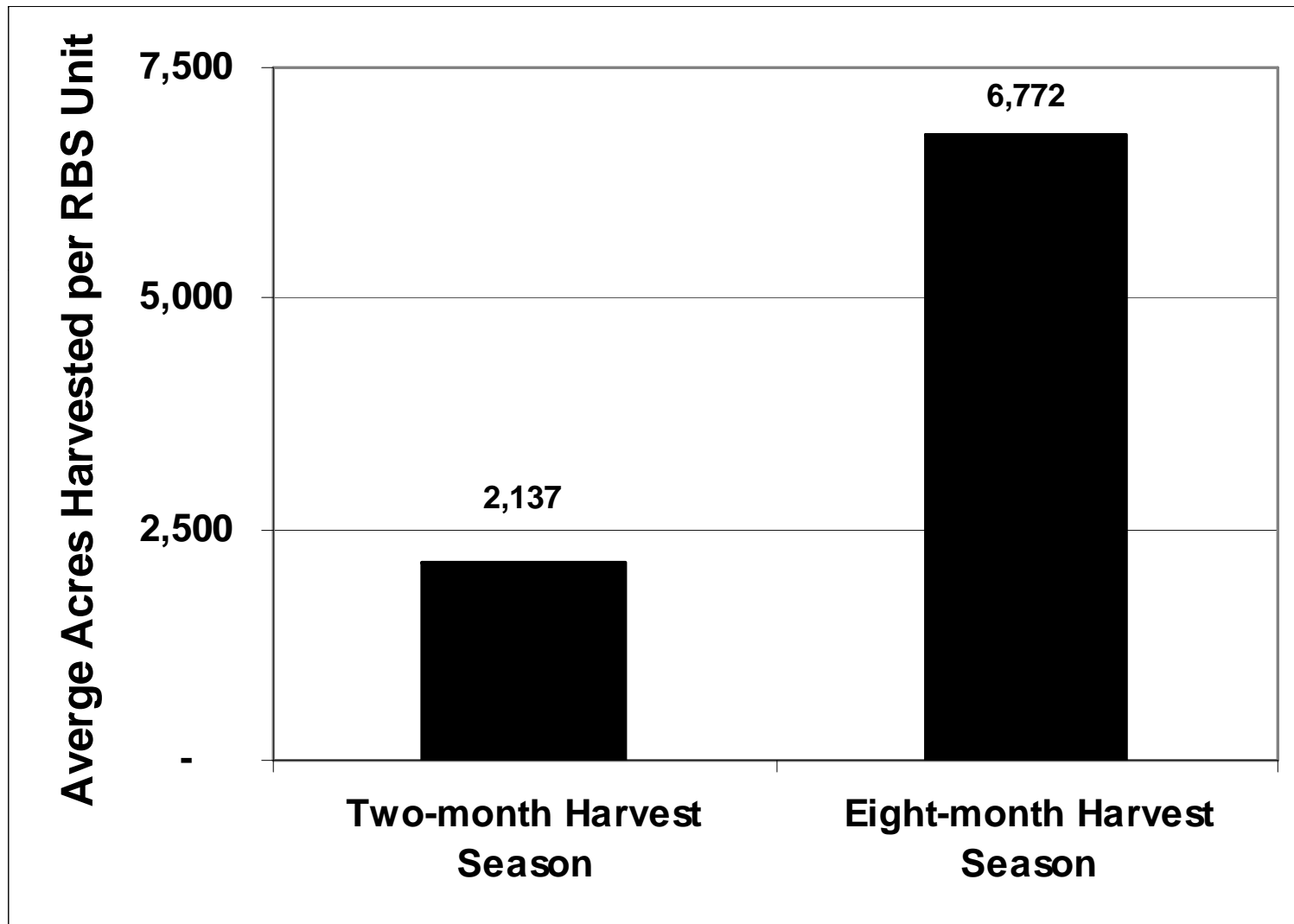
Field storage by month for both a two- and eight-month harvest season to provide a flow of feedstock to a 2,000 dry tons per day biorefinery



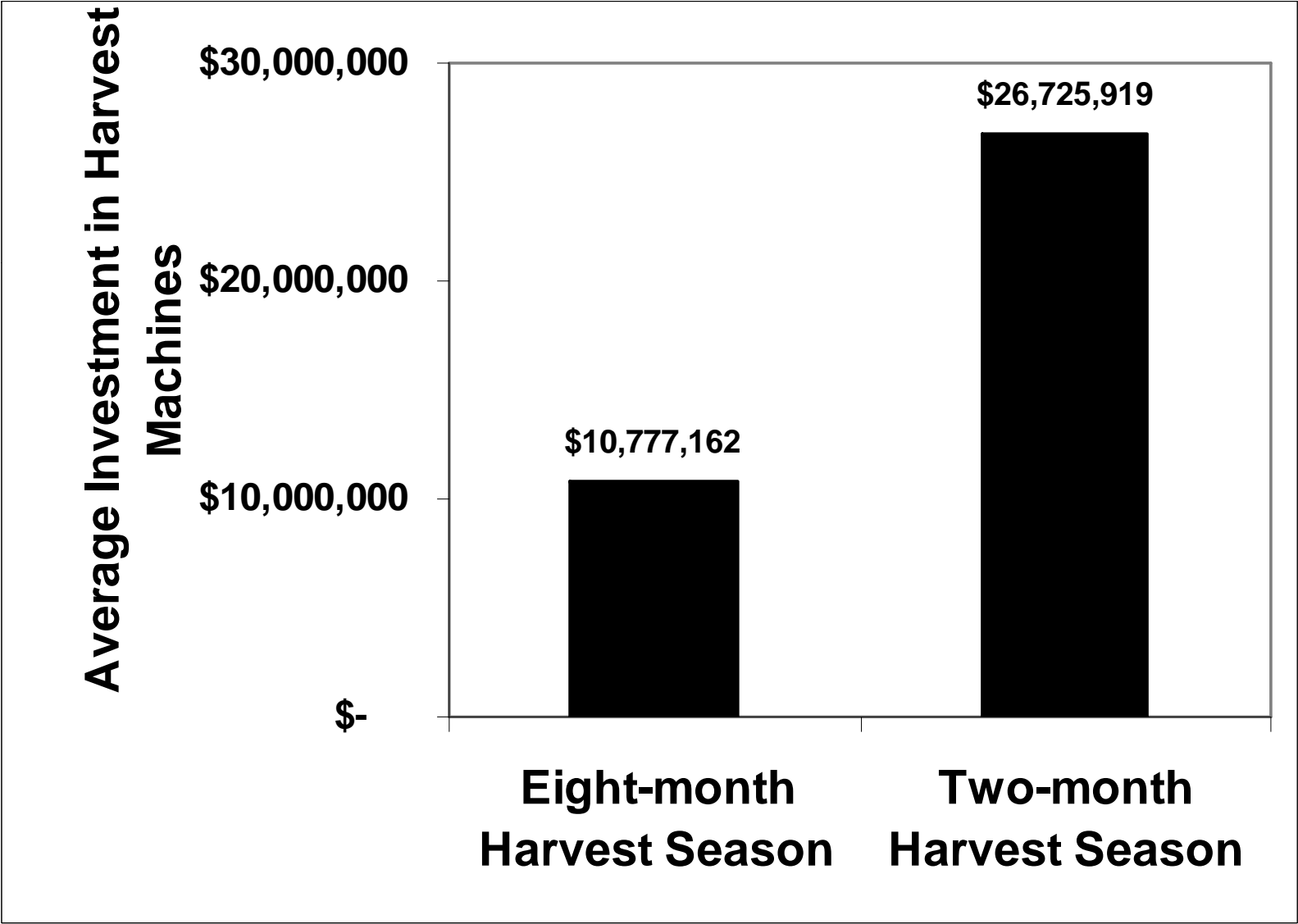
Estimated number of harvest machines for two- and eight-month harvest season to provide a flow of 2,000 t/day



Estimated number of acres harvested per year per raking, baling, stacking harvest unit for two- and eight-month harvest season to provide a flow of 2,000 t/day



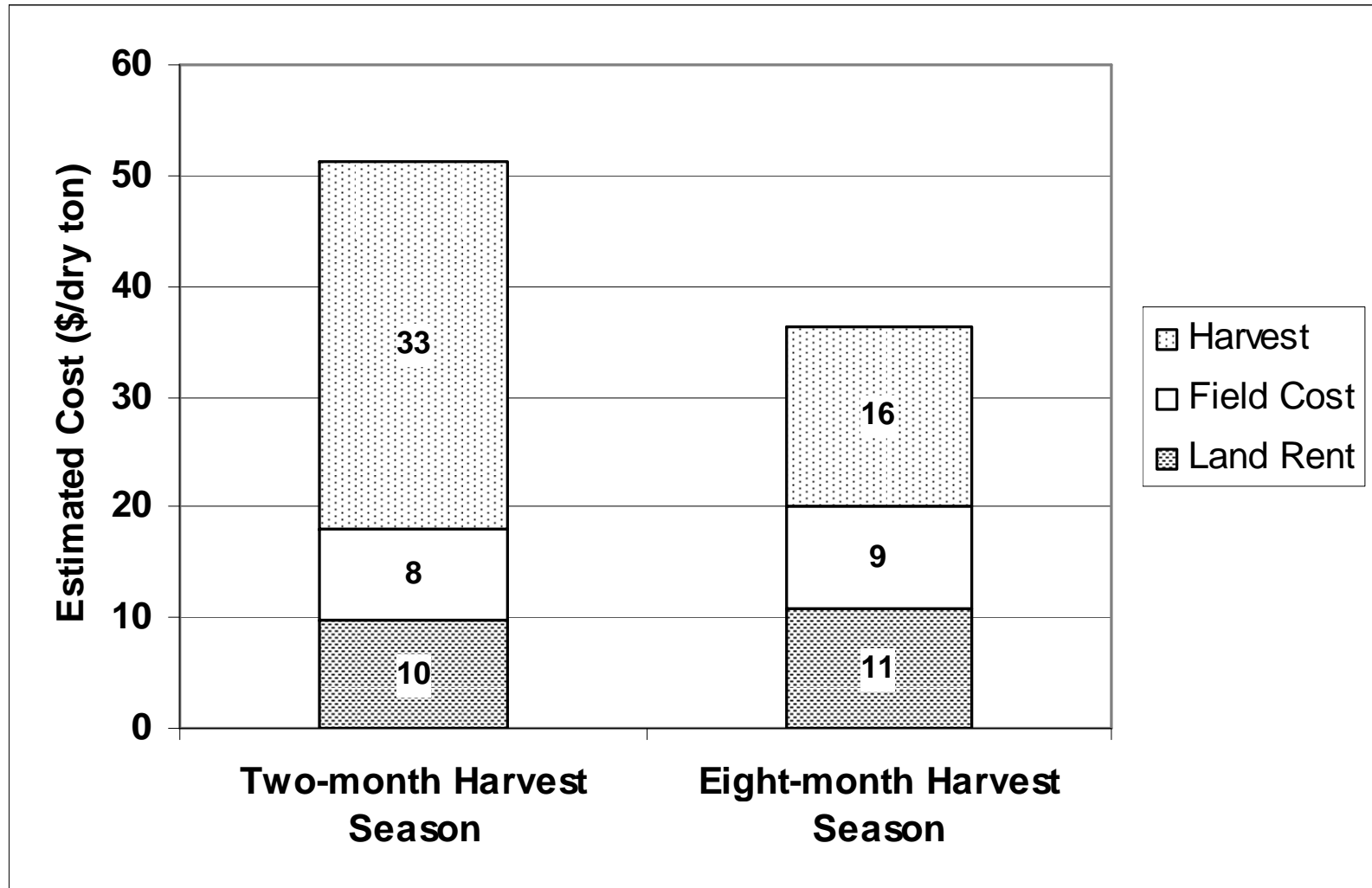
Estimated average investment in harvest machines required to provide a flow of 2,000 t/day for two- and eight-month harvest season



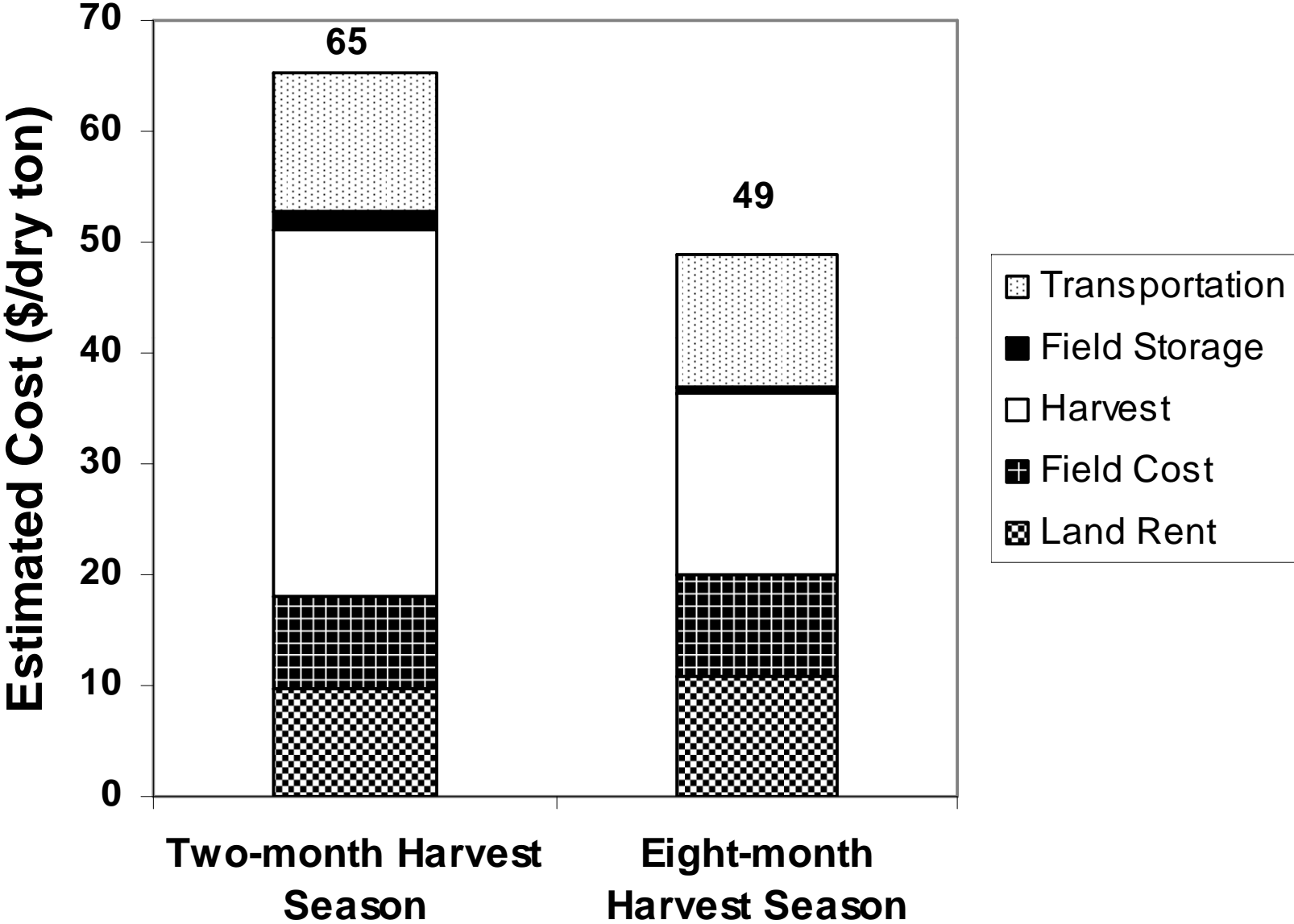
Harvest Costs

45-65 % of “Farm Gate” Production Costs

(2007 prices)



Estimated cost to deliver a flow of 2,000 t/day of switchgrass for both a two- and eight-month harvest season (2007 prices)



What do the Models Tell Us?

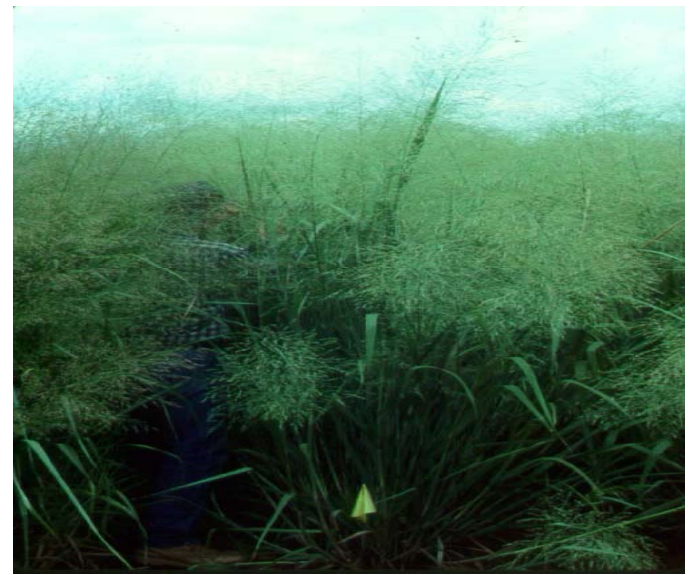
- Harvest would extend over as many months as permitted by weather, feedstock sources, and policy
- Given the quantity of biomass required, and the lack of an existing infrastructure to harvest and transport a continuous flow of massive quantities of biomass, it is likely that an **integrated and centrally controlled harvest and transportation system would develop**
 - Very risky for a biorefinery to depend on spot markets for feedstock

What do the Models Tell Us?

- The structure of a mature biomass to bioproducts industry that produces bulk commodities such as liquid fuel, from dedicated feedstocks such as switchgrass, **may evolve to resemble a vertically integrated timber production and processing business**
- Public policy that restricts business ties between feedstock production and feedstock processing is likely to hinder the development of a cellulosic biomass biorefinery industry.

Industry Structure ?

- Perennial grass
- After establishment year, very little annual maintenance required
 - One trip to broadcast fertilizer
 - Harvest



- Structure likely to be determined by the most efficient harvest, storage and transportation system

Possible Arrangements to Insure a Reliable Flow of Feedstock

- Acquire Land
- Long-term land leases similar to Conservation Reserve Program
- Contract with individual growers
- Contract with a group of growers via cooperative arrangement

Additional Challenges

- Risk management
 - Feedstock yield variability
 - Fire of standing and stored switchgrass
- 16 million acres of idle cropland and cropland pasture in the Northern Plains are widely dispersed
- The grain-ethanol program has increased the cost of inputs (land, fertilizer, machinery) required to produce switchgrass
- Discover, develop, design, and demonstrate an economically competitive biorefinery technology
- Build a **profitable business model**



