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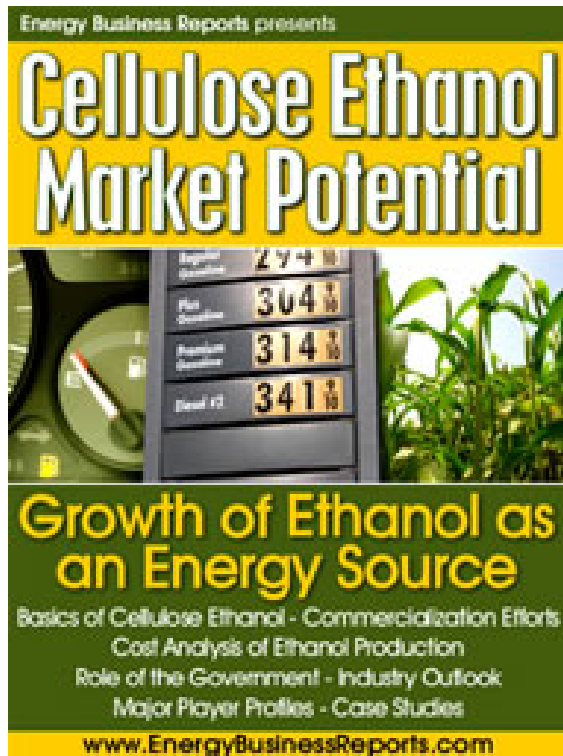
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# The Realities of a Biomass-Based Energy System



**Hans-Joachim G. Jung**

**USDA-Agricultural Research Service, St. Paul, MN**

**Hans.Jung@ars.usda.gov**



# Types of Bioenergy



- **Biopower:** Thermal energy for heating and electricity generation produced by combustion (direct or gasification)
- **Biofuel:** Liquid transportation fuel
  - Ethanol and butanol are produced by biological fermentation
  - Biodiesel is produced by chemical modification of plant and animal oils
  - Fischer-Trop syngas is produced by thermo-chemical processes



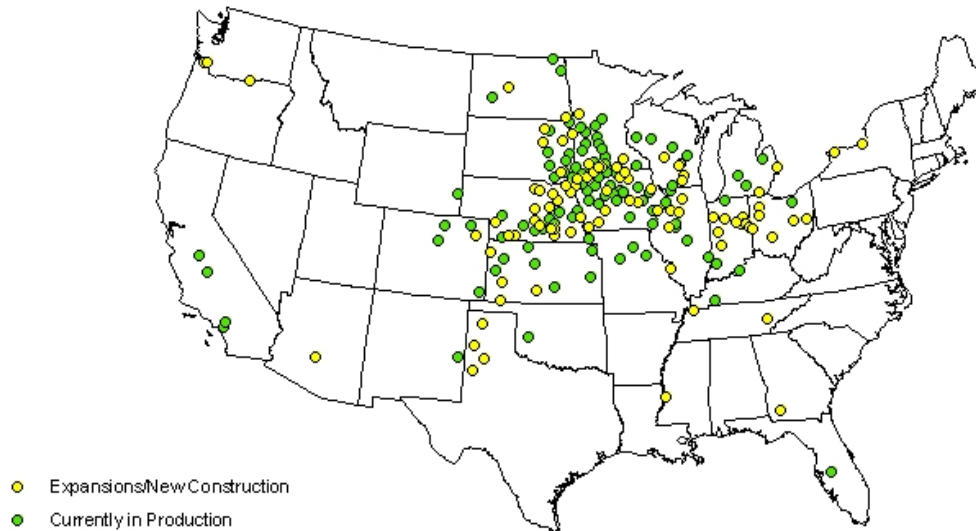
# Ethanol is Produced from the Fermentation of Sugars

- **Simple carbohydrates (sucrose)**  
*sugar cane, sweet sorghum, sugar beets*
- **Storage polysaccharides (starch)**  
*corn, cereal grains, potatoes*
- **Cell wall (dietary fiber)**  
**polysaccharides (cellulose, hemicellulose, pectin)**  
*crop residues, switchgrass, alfalfa stems, wood*



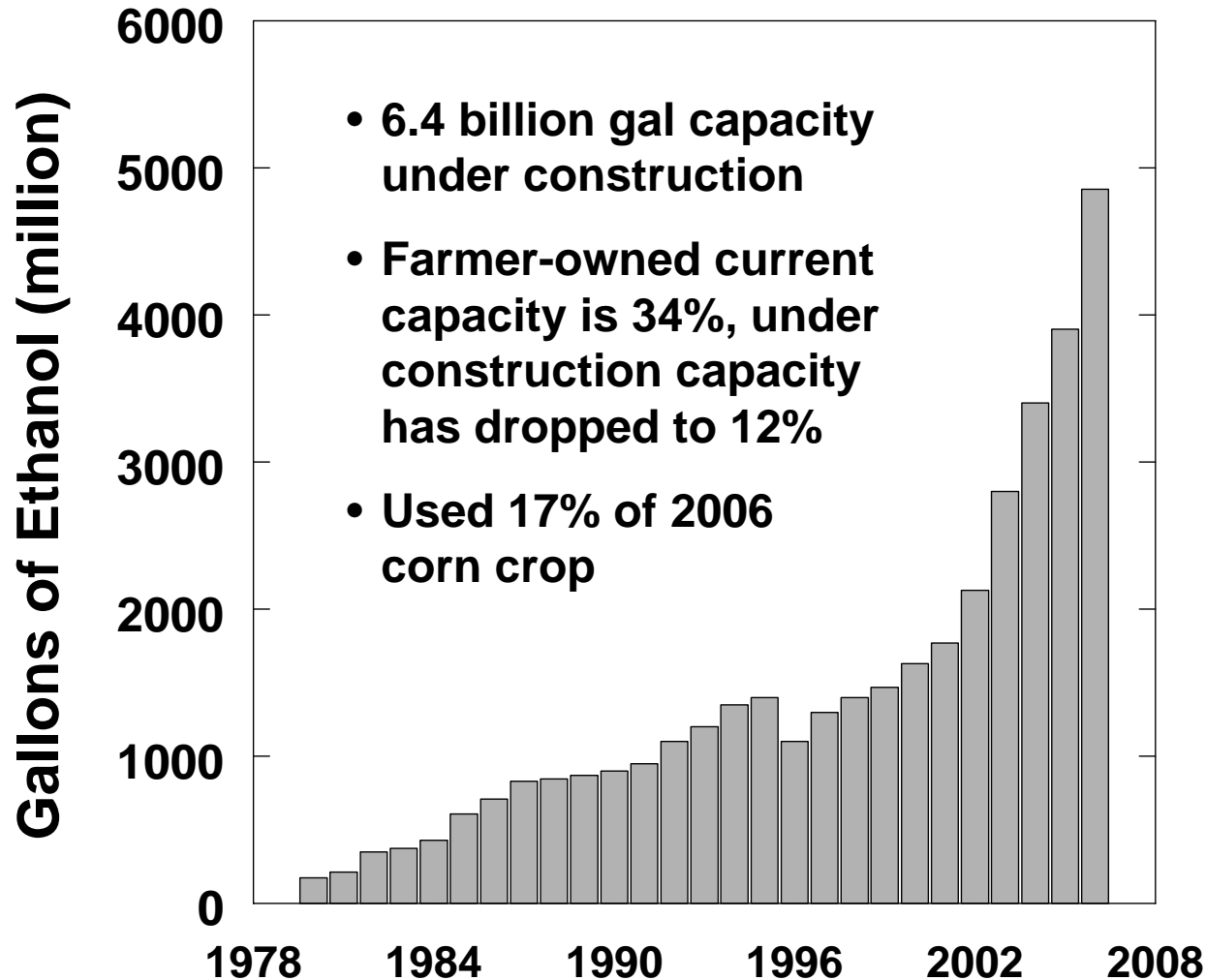
# Ethanol Biorefinery Locations

as of January 2007



- **99% of U.S. ethanol is from corn**
- **Sorghum grain is the next most utilized substrate**
- **113 ethanol biorefineries in operation**
- **78 ethanol biorefineries under construction**

# U.S. Ethanol Production





# Bioenergy Goals & Requirements

- **In response to President Bush's 2006 Advanced Energy Initiative, federal goal was set to make cellulosic ethanol cost competitive by 2012.**
- **Production goals for 2012-2015 timeframe:**
  1. **grain ethanol 7 to 8 billion gallons (~ 5 billion gallons today)**
  2. **cellulosic ethanol 3 to 4 billion gallons (zero gallons today)**

# **Even Larger Bioenergy Goals and Requirements in the Future**

- **A national goal has been set to replace 30% of 2004 petroleum demand with biomass-derived energy by 2030.**
- **Production goals for 2030 timeframe:**
  1. **grain ethanol 13-14 billion gallons**
  2. **cellulosic ethanol 40-50 billion gallons**
- **The 2030 goal would require one billion tons of biomass annually.**
- **“Billion Ton Report” projected that 77% of total biomass could come from agricultural lands (377 million tons from perennial biomass crops).**



# ETHANOL FROM CORN

## *Dry Milling Process*

Grain



Grind, Steep,  
Enzyme Digestion



Sugars



ETHANOL

Yeast, Distillation



Distillers Grains



One bushel of corn  
yields 2.8 gal (112  
gal/ton) of ethanol  
and 17 lb. of DDGS.



Wet Milling Process Yields  
More Coproducts



# ETHANOL FROM CELLULOSIC BIOMASS



Leaves (alfalfa)



Corn stover  
Switchgrass  
Wood

Stems

Grind,  
Thermo-Chemical Pre-Treatment,  
Enzyme Digestion

Residue



One ton of  
cellulosic  
biomass is  
expected to  
yield 65 to  
80 gal of  
ethanol

Sugars

Microbes,  
Distillation

ETHANOL



# **Barriers to Cellulosic Ethanol Commercialization**

- **Process is very capital expensive (~3x more than corn grain ethanol)**
- **Serious biomass supply logistic problems**
  - **a 50 million gal facility would require ~625,000 tons of cellulosic biomass every year for 20 to 30 years**
  - **cellulosic biomass is expensive to transport**
  - **storage of biomass for year-round operation**
- **Current yeast strains cannot efficiently ferment many cell wall sugars to ethanol**
- **Even with expensive oil and current ethanol subsidies, venture capitalists have been unwilling to finance a commercial facility.**

# Why the Push for Cellulosic Ethanol?

- **Corn grain ethanol competes with food/feed uses of corn and only produces ~ 25% net energy.**
- **Cellulosic ethanol does not directly compete with food because people do not eat cellulosic biomass and projected to yield 4x to 8x more energy than used for its production.**
- **Cellulosic biomass production is more sustainable on marginal and environmentally sensitive land.**
- **High yields of perennial cellulosic crops are expected with minimal inputs (\$, fertilizer, energy).**
- **Cellulosic biomass is expected to be cheap (\$30 to \$50/ton).**

# Are the Advantages of Cellulosic Ethanol Real?

- All bioenergy crops are in competition for access to land with food production (direct consumption and animal feed), urban uses (roads, homes, etc.), forestry, mining, natural areas, etc.
- High yields of any crop are only possible with good soil, adequate fertility, and sufficient water.
- Regular mechanical harvesting exposes sensitive land to erosion.
- Minimal amounts of crop residues will become available below \$35/ton and perennial crops have production costs of \$30 to \$50+/ton.

# Potential for Cellulosic Ethanol From “Marginal Land”

- **Where are these marginal acres? Is it CRP?**
- **If all Minnesota CRP land (1.8 million acres) were used for low-input switchgrass or mixed prairie, how much ethanol could this yield?**
- **All other hay yield (mostly low-input grass) was 1.7 tons/acre in Minnesota over the last five years.**
- **CRP land could at best provide 3.1 million tons of cellulosic biomass ... enough to run 5 facilities producing a total of 250 million gallons of ethanol.**
- **In 2006 Minnesota produced 500 million gallons of ethanol from corn grain and is projected to reach 1 billion gallons in 2008.**

# How Much Energy Could be Produced from Minnesota Cropland?



## Minnesota Crop Yields

- **Corn yield (5-year average) was 3.8 ton of grain/acre (stover yield approximately equal).**
- **Soybean yield was 1.1 ton/acre.**
- **Alfalfa hay yield was 3.4 ton/acre (stem fraction 40 to 60%).**



# Theoretical Ethanol Yield

## *Minnesota Example*

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<b>Species</b>	<b><u>Feedstock</u></b>		<b>Protein</b>
	<b>Primary</b>	<b>Coproducts</b>	
	<b>Gal/Acre</b>		<b>Tons/Acre</b>
<b>Alfalfa</b>	<b>137</b>	<b>65</b>	<b>0.49</b>
<b>Corn (grain)</b>	<b>473</b>	<b>62</b>	<b>0.34</b>
<b>Corn (½ stover)</b>	<b>174</b>	<b>0</b>	<b>0</b>
<b>Soybeans</b>	<b>80*</b>	<b>53</b>	<b>0.42</b>

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\* Ethanol energy equivalent of biodiesel.

# Theoretical Yields

## *Current Cropping Systems*

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<b>Species</b>	<b>Corn</b>	<b><u>Ethanol</u> Alternate Gal/Acre</b>	<b>Total</b>	<b>Protein Tons/Acre</b>
<b>Corn/Soybean (alternate years)</b>	<b>324</b>	<b>40</b>	<b>364</b>	<b>0.38</b>
<b>Continuous Corn (5% yield loss)</b>	<b>616</b>	<b>0</b>	<b>616</b>	<b>0.32</b>
<b>Corn/Alfalfa (5% yield boost)</b>	<b>340</b>	<b>69</b>	<b>409</b>	<b>0.42</b>

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# Biomass-Type Alfalfa

*Developed by USDA-ARS*



## Traits Incorporated:

- **Large, lodging resistant stems**
- **Maintenance of leaf yield**
- **Winter hardiness**
- **Disease/Pest resistance**
  - **Root rot**
  - **Leaf hopper**

# Alfalfa Biomass Production Practices

## First Production Year Stand



**Traditional**  
42 plants/ft<sup>2</sup>



**Biomass**  
17 plants/ft<sup>2</sup>

**Modify production practices to maximize both leaf and stem yield.**

**Bigger Plants: Decrease stand density to give plants more room to grow.**

**More Stem Biomass: Delay harvest from early bud stage to late flower/green pod stage to get longer stems. Lodging increases at later maturities.**

## Full Bloom Maturity Stage

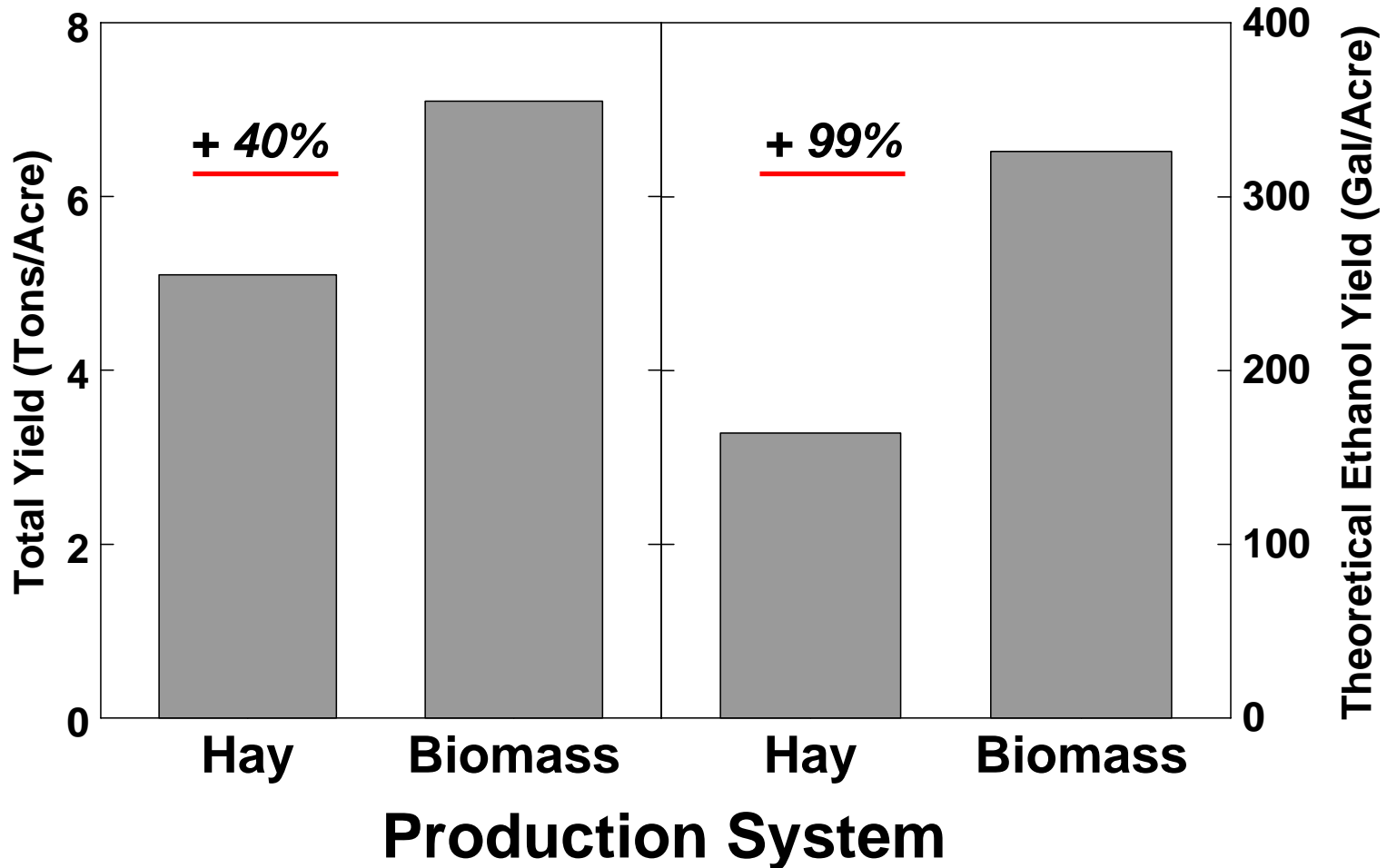


**Dairy Hay-Type**



**Biomass-Type**

# Biomass-Type Alfalfa + Biomass Management Doubles Ethanol Yield



Lamb et al. 2007. Crop Sci. 47:1407-1415.

# Theoretical Yields

## *Improved Cropping Systems*

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<b>Species</b>	<b>Corn</b>	<u><b>Ethanol</b></u>	<b>Total</b>	<b>Protein</b>
		<b>Gal/Acre</b>		
<b>Continuous Corn (5% yield loss)</b>	<b>616</b>	<b>0</b>	<b>616</b>	<b>0.32</b>
<b>Corn/Improved Alfalfa (2x stem yield) (5% yield boost)</b>	<b>340</b>	<b>138</b>	<b>478</b>	<b>0.42</b>
<b>Corn Silage (all stover)/Improved Alfalfa (5% yield boost)</b>	<b>432</b>	<b>138</b>	<b>570</b>	<b>0.42</b>

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# What are Likely Scenarios for Future Ethanol Production?

- **Corn stover will be the first cellulosic ethanol feedstock in the Midwest ... this will make corn more attractive as a bioenergy crop.**
- **Soybean acreage may continue to fall in the face of corn ethanol and South American soybean production.**
- **Perennial bioenergy crops could be relegated to low-value land.**

*Assumes Ethanol Production is Profitable!*

# **Factors that Could Impact the Ethanol Craze**

- **Ethanol demand is nearing a constraint due to saturation of the gasoline oxygenate replacement need and 10% inclusion mandates ... need more E85 vehicles and pumps, higher mandates.**
- **Limits on corn stover removal (erosion control).**
- **Rising costs of inputs (energy, fertilizer).**
- **Saturated DDGS market and high corn prices.**
- **Water availability for processing.**
- **Public policy drivers (subsidies, carbon tax, carbon sequestration credits).**

# Conclusions

- **Cellulosic ethanol is not here yet.**
- **Goals are impressive ... fantasy?**
- **Feedstock supply logistics will be difficult if facilities must be large to be profitable.**
- **Conversion technology is still too expensive.**
- **Research pendulum appears to be shifting to gasification technologies.**
- **Barring a technology breakthrough, public policy drivers may be essential to large-scale biomass energy production.**