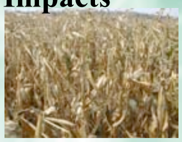
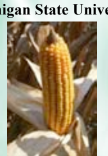
BioFuel Crop Decision Impacts

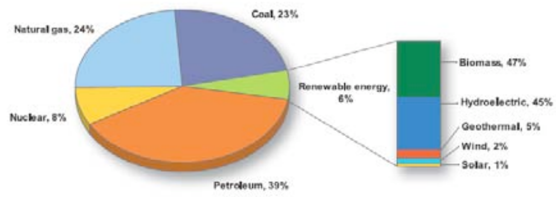
Biomass

Kurt D. Thelen
Michigan State University




NC Branch ASA
Indianapolis IN
March 13, 2007



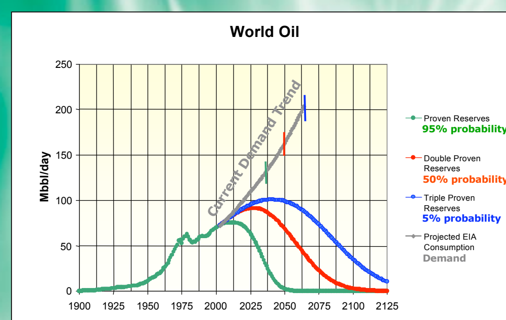
Biomass Consumption	Million dry tons/year
Forest products industry	
Wood residues	44
Pulping liquors	52
Urban wood and food & other process residues	35
Fuelwood (residential/commercial & electric utilities)	35
Biofuels	18
Bioproducts	6
Total	**190**

- Forestlands and agricultural lands contribute 190 million dry tons of biomass - 3% of America's current energy consumption.

Source: EIA, 2004a & b

Current U.S. liquid fuel consumption ~ 200 Billion gallons about ½ of our total oil use

Increasing Energy Demand



Colored bars on the projected consumption curve indicate the years when proven reserves, double and triple proven reserves are depleted at the current consumption growth rate. **Source: C. Gray, EPA**

Biomass Research & Development Act of 2000

- **Established the Biomass R&D Technical Advisory Committee: By 2030 Biomass will supply:**

- 5% of the nations power
- 20% of the nations transportation fuels
- 25% of its chemicals

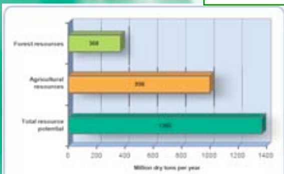
The Goal is equivalent to 30% of the current US petroleum consumption and will require 1 billion dry tons of biomass feedstock annually, a 5X increase over current consumption.

Energy Policy Act of 2005

- **Created the Renewable Fuels Standard (RFS) which established for the first time a nationwide baseline for renewable fuel use.**
- **Beginning in 2006, oil refiners are required to use at least <u>4 billion gallons</u> of renewable fuel.**
- **That level increases incrementally to <u>7.5 billion gallons</u> per year in 2012.**

Agriculture Sources:

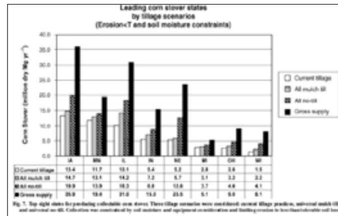
428 million dt crop residue
377 million dt perennial crops
87 million dt grain (17.6 mil A)
106 million dt manures, process residues



Requirements to reach goal of displacing 30% of U.S. petroleum

Source:USDA, USDoE

- yields of corn, wheat, and other small grains were increased by 50%;
- the residue-to-grain ratio for soybean was increased to 2:1;
- harvest technology was capable of recovering 75% of annual crop residues;
- all cropland was managed with no-till methods;
- 55 million acres of cropland, idle cropland, and cropland pasture were dedicated to the production of perennial bioenergy crops;
- all manure in excess of that which can be applied on-farm for soil improvement was used for biofuel;
- all other available residues were utilized;

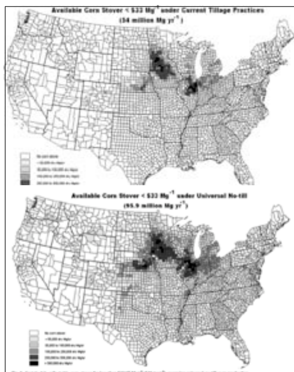


How much corn stover is available??

Corn Stover (million dry Mg yr^{-1})

System	IA	MN	IL	IN	NE	MI	OH	WI	Totals
Current	13.4	11.7	10.1	5.4	5.2	2.8	2.6	1.5	52.7
All mulch	14.7	13.1	14.2	7.2	5.7	3.1	3.2	2.2	63.4
All no-till	19.9	13.9	18.3	8.8	12.6	3.7	4.6	4.1	85.9
Gross	35.9	19.4	31	15.3	23.5	5.1	9	8.1	147.3

Graham et al. 2007. Agron J. 99:1-11



Available corn stover under current tillage systems:

54 million Mg yr^{-1}
59 million ton yr^{-1}

Available corn stover under all no-till systems:
95.9 million Mg yr^{-1}
105.6 million ton yr^{-1}

428 million ton goal
-106 million ton corn stover
322 million ton deficit

Where will the 322 million ton come from????

Graham et al. 2007. Agron J. 99:1-11

Ethanol Production Capacity

U.S. Ethanol Biorefinery Locations

January, 2007 update

Total operating plants:	109
Under construction:	57
Expansions	8
Total:	**166**

Capacity	Million gal yr
Current	5,281.4
Under Construct & Expansion	4,857.5
Total Capacity	**10,138.9**

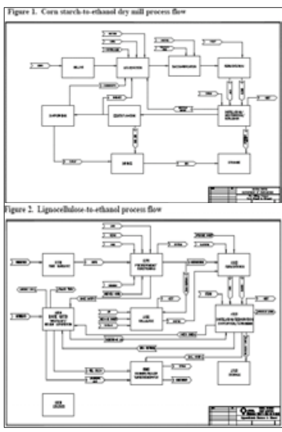
What is the best we can do with corn grain……

Acreage availability and competing demands limit the amount of ethanol that can be produced from corn to approximately 10% of U.S. motor gasoline needs.

Conclusion:

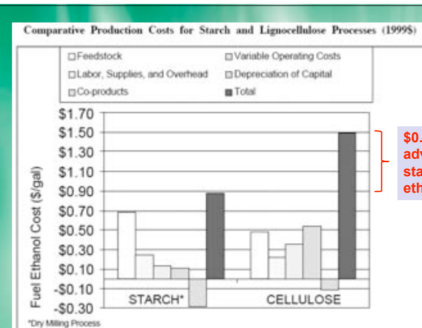
The U.S. will need cellulosic ethanol production to meet our renewable energy goals.

So ---- what's holding cellulosic ethanol production back?



A comparison of a starch-based ethanol production plant with a cellulose-based ethanol production plant.

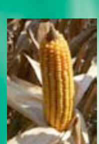
Source: US DoE National Renewable Energy Lab

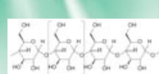


$0.60 cost advantage to starch based ethanol

Source: USDOE

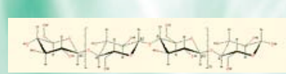
Basic similarities between starch & cellulose





25% Amylose alpha-linked 1-4 D-glucose

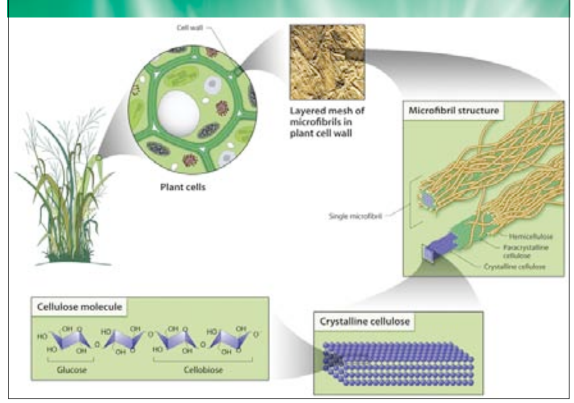
75% Amylopectin

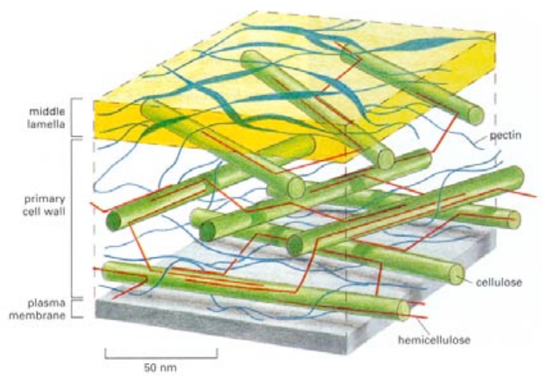


Cellulose- Beta linked 1-4 D-glucose

Cellulose is somewhat similar to starch
β-(1 4)-D-glucopyranose units in 4C1 conformation
Cellobiose, which consists of a pair of glucose residues (one right side up and one upside down is the repeating polymer of cellulose).

Source: US DoE





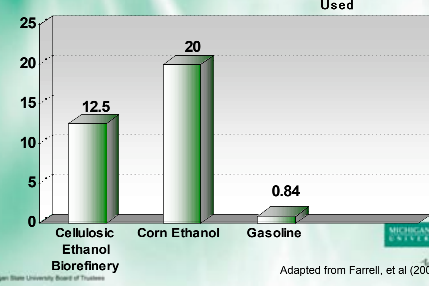
Why cellulosic ethanol production may be closer than you think

Two Primary Drivers

- Energy Security
- Environmental (GWP) Security

Petroleum Replacement Ratio: *the Primary Energy Security Driver*

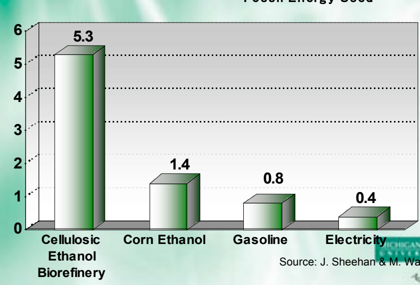
Petroleum Replacement Ratio (PRR) = $\frac{\text{Liquid Fuels Delivered to User}}{\text{Petroleum Energy Used}}$



Adapted from Farrell, et al (2006)

Fossil Energy Replacement Ratio: *the Primary Climate Security Driver*

Fossil Energy Ratio (FER) = $\frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$



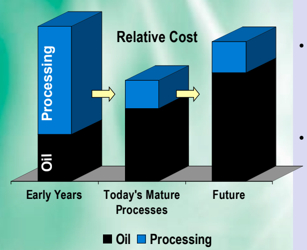
Source: J. Sheehan & M. Wang (2003)

Cellulosic ethanol closer than you think.

- Better Technologies
  - Better & cheaper pretreatments-AFEX for example
  - Better & cheaper enzymes
  - Better fermentation micros that ferment & produce enzymes
  - Consolidated bioprocessing (CBP) is coming right along
  - Better integration of these technologies
- Venture capital & (we hope) more research funding
- Heightened awareness of oil “externalities”
  - Potential for climate change
  - Economic development driver
  - 9/11 and terrorism
- RFS & other help from “big brother”: ethanol from corn
- Testing platforms: pulp mills & corn mills
- $60 per barrel oil

Source: B. Dale, MSU

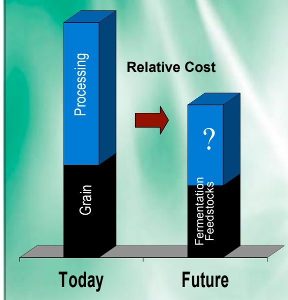
Impact of Processing Improvements: Oil's Past & Future



- Historically, petrochemical processing costs exceeded feedstock costs
- Petroleum processing efficiencies have increased and costs have decreased dramatically but reaching point of diminishing returns
- Petroleum raw materials have long-term issues
  - Costs will continue to increase as supplies tighten
  - High price variability
  - Impacts national security
  - Climate security concerns
  - Not renewable
- Not a pretty picture for our petroleum dependent society

From J. Stoppert, 2005

Impact of Processing Improvements: The Future of Biomass Conversion

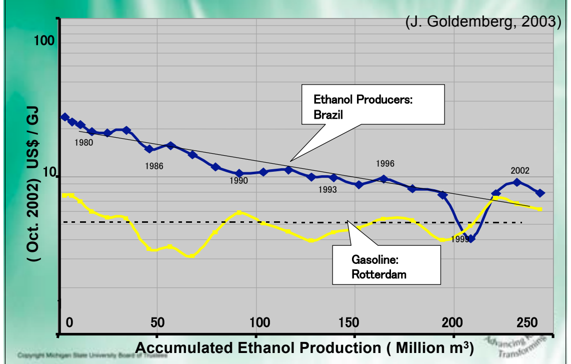


- Processing is dominant cost of biofuels today
- Cellulosic raw material costs should be stable or decrease
- Processing costs dominated by pretreatment, enzymes & fermentation
- Biomass processing costs will decrease: deserves high priority to make it happen sooner rather than later
- Much more attractive future
  - Domestically produced fuels
  - Environmental improvements
  - Rural/regional economic development

Adapted from J. Stoppert, 2005

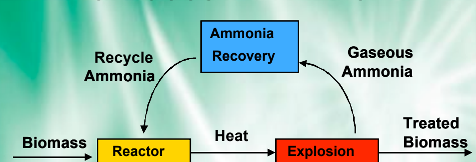
Learning Curve: Sugar Ethanol Production Cost

(J. Goldemberg, 2003)



Recent Process Improvements for Cellulosic Ethanol Production

How does AFEX work?

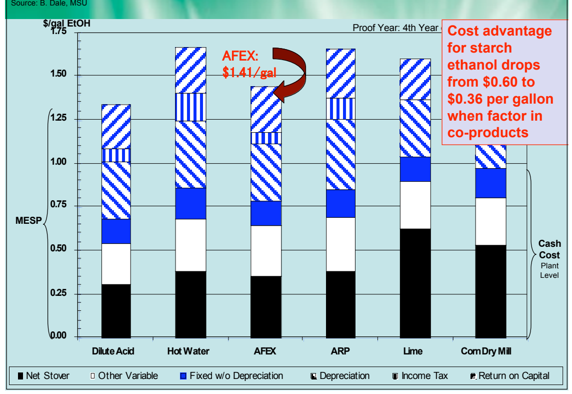


- Biomass heated (~100 C) with concentrated ammonia
- Rapid pressure release ends treatment
- 99% of ammonia is recovered & reused, remainder serves as N source downstream for fermentation
- Little sugar degradation, relatively mild conditions
- Few sugar monomers, mostly xylooligomers formed

Source: B. Dale, MSU

Pretreatment Economic Analysis:CAFI Team

Source: B. Dale, MSU



Cost advantage for starch ethanol drops from $0.60 to $0.36 per gallon when factor in co-products

February 2007

Range Fuels, a Colorado based company announced construction of a cellulose (wood waste & byproducts) ethanol production plant in Treutlen County Georgia.

Biomass Cropping Systems

Expected Biofuel Yields

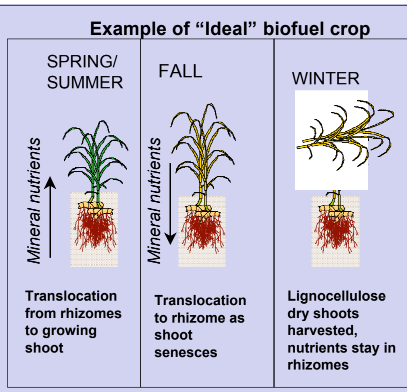
Crop	Ps	Bu/wt	Crop Yield	Biofuel	EtOH or oil/bu	EtOH or oil yield/A
Corn	C4	56 lb	150 bu/a	EtOH	2.8 gal	420 gal
**Corn + Stover		56 lb	150 bu/a 3.5 ton	EtOH	2.8 gal 72 gal/ton	420 252 672 gal
Switchgrass	C4	NA	8 ton/a	EtOH	72 gal/ton	576 gal
Soybean	C3	60 lb	40 bu/a	Diesel	1.5 gal	62 gal
Sunflower	C3	27 lb	50 bu/a	Diesel	1.5 gal	77 gal
Canola	C3	50 lb	42 bu/a	Diesel	2.9 gal	120 gal

**Not sustainable on all corn acreage. Need ~ 4 ton crop residue (root + shoot) annually just to maintain current SOM levels. Soybean residue (root + shoot) = 2 ton/year so need 4 ton + 2 ton from corn to cover soybean year in 2 yr rotation)

Ideal ecological traits of a biomass energy crop

- C_4 photosynthesis
- Long canopy duration
- Perennial
- No known pests or diseases
- Rapid spring growth (out compete weeds)
- Sterility
- Partitions nutrients to roots in fall
- High water use efficiency

Source: Raghu et al. Science 313:1742



Modified slide Courtesy of Dr. Steve Long, 2005

Will available water limit biomass yields?

Species	Et g/kg	Source	Notes
Miscanthus	7.8 – 9.5	Beale et al. 1999	Southern U.K.
Miscanthus	3.4 - 4.1	Uffe Jorgensen	Denmark
Switchgrass	4.8 – 5.9	Byrd & May 2000	8 cultivars
Corn	3.0	Howell et al. 1988	
51 C3 plants	1.6	Stanhill 1986	

 +  = 

Example

Field located in Clinton County MI

Soil water holding capacity:
Blount loam 0.17 cm per cm soil water holding capacity in top 36 inches of soil.

36 inches x 0.17% = 6.12 inches of available soil water

Average rainfall: 15.46 inches expected rainfall
15.46 inches expected + 6.12 inches soil available = 21.6 total in.

Species	Et g/kg	Yield @ 21.6 " H_2O
Miscanthus	7.8 – 9.5	19 – 23 dton/A
Miscanthus	3.4 - 4.1	8 – 10 dton/A
Switchgrass	4.8 – 5.9	12 – 14 dton/A
Corn	3.0	7 dton/A
51 C3 plants	1.6	4 dton/A

Production Costs with BioFuel Crops

Hay, Grass

1,000 Lb Round Bales

	Quantity	Unit	Price per Unit	Total per Acre
REVENUE SOURCES				
Grass hay	8	ton	$ 50.00	$ 400.00
TOTAL REVENUE				**$ 400.00**
CASH EXPENSES				
Fertilizer				
Nitrogen	70	lb	$ 0.39	$ 27.30
Phosphate	40	lb	$ 0.36	$ 14.40
Potash	85	lb	$ 0.23	$ 19.55
Lime	0.25	ton	$20.00	$ 5.00
Insecticides				$ 3.75
Twine, wrap	16	bales	$1.50	$ 24.00
Fuel, oil, lube [1]	7	gal	$1.73	$ 12.08
Equipment repairs				$ 8.00
Utilities, phone				$ 0.50
Stand establishment	1/5			$ 27.20
TOTAL SELECTED CASH EXPENSES				**$ 141.78**
REVENUE ABOVE SELECTED CASH EXPENSES				**$ 258.23**
Family and regular hired labor, hours [2]				5.0
Dry hay equivalent, tons [3]				8.0

Corn Grain (following corn)

150 Yield Goal
Conventional Cultural Practices

	Quantity	Unit	Price per Unit	Total per Acre
REVENUE SOURCES				
Grain	150	bu	$ 3.80	$ 570.00
TOTAL REVENUE				**$ 570.00**
CASH EXPENSES				
Seed	30,000	kernel	$ 90.00	$ 33.75
Fertilizer [1]				
Nitrogen	155	lbs	$ 0.39	$ 60.45
P_2O_5	45	lbs	$ 0.36	$ 16.20
K_2O	75	lbs	$ 0.23	$ 17.25
Lime				$ 8.00
Herbicides [2]				$ 29.25
Insecticides [3]	5	lbs	$ 2.50	$ 12.50
Drying	150	bu	$ 0.25	$ 37.50
Fuel, oil, lube [4]	5	gal	$ 1.73	$ 8.63
Repairs				$ 22.00
Utilities				$ 6.00
Trucking	150	bu	$ 0.15	$ 22.50
Marketing	150	bu	$ 0.05	$ 7.50
TOTAL SELECTED CASH EXPENSES				**$ 281.53**
REVENUE ABOVE SELECTED CASH EXPENSES				**$ 288.48**
Family and regular hired labor, hours				3.6
Corn grain equivalent, bu				150.0

Crop Cash Production Costs per Gallon of Ethanol Produced

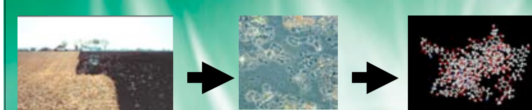
Crop	$/A	Field yield	Ethanol	$/ g EtOH
Corn grain	281.53	150 bu/A	2.8 g/bu	$0.67
Switchgrass	141.78	8 ton/A	72 g/ton	$0.25
Corn + *Stover	351.53	150 bu + 3 ton	2.8 + 72	$0.55

*Based on removal of 3 ton residue at a cost of $40.00 acre (USDoE) + increased fertilizer at $30.00 an acre. Does not include lost carbon.

Production cost advantage of cellulose ($0.42 gal) may exceed process cost advantage of starch.

Transport Costs!!!!

What About Soil Carbon ??



Crop residue
8400 lb/A

Soil microbes
crunch, munch
(80% conversion cost)

Soil organic matter
1400 lb/A

The problem is that in addition to feeding the soil microbes 80% of our crop residue to convert it to SOM we also have to feed them ~2.0 to 2.5% of the SOM (SOM decay factor)

(@2.8% SOM level)
56,000 lb SOM x 2.25% = 1260 lb SOM x 6 = 7560 lb crop residue

Need 7560 lb crop residue/A/yr (3 ¾ tons) to cover SOM decay

Assume: Corn above ground biomass yield of 9 ton/A
Harvest index: 50%
Whole plant C content in corn of 43%
Root rhizoshpere C deposition = 29% shoot C
Need 7560 lb to maintain current SOM level

Total residue root + shoot = 5220 lb root + 9000 lb stover = 14,220 lb/A
14,220 lb/A – 7560 lb/A required = **6600 lb/A** available for bioenergy harvest.

If corn soybean rotation: 3110 lb/A deficit in plant material
3550 lb/A corn stover available for bioenergy harvest

Consistent with Nelson @ 1.4 ton/A and Purlack & Turhollow 2.5 ton/A.

Current equipment constraints limit maximum harvestable corn stover at 70% (Schechinger and Hettenhaus) ---6300 lb/A

Perennial grasslands used for grazing or forage net 900 lb C (equivalent to 2093 lb residue) annually

source: CAST

Can Soil Carbon Losses be Compensated for with Management Practices ???

Main effect means for Soil C GWP, soil GHG flux, input GHG flux, and net GWP at East Lansing in the SCS rotation

Trt	Soil C GWP	Res. C	Soil GHG flux	Input GHG flux	Net GWP	Net GWP -R
	-----------------------------		g CO_2 m^{-2} y^{-1}	-------------------------		
Cmpst	-1999	-1358	988	1404	-964	394
Manure	-1006	-2406	2234	19	-1159	1247
None	36	-482	1459	10	1022	1505
LSD	528	449	220	-	556	618
None	-977	-1286	1217	476	-570	716
Rye	-1002	-1545	1904	479	-164	1381
LSD	NS	NS	180	-	NS	534

Great potential for improved genetics

- Soluble sugars in biomass crops similar to sugar cane.
- Low fiber content similar to brown mid-ribs.
- Oil expression outside the embryo.
- Process enzymes (amylase and hydrolosis enzymes) present in the plant tissue.
- etc.

Biomass Processing Logistics

Ruminant Animals & Biorefineries

Mobile Cellulose Biorefinery (a.k.a. Cow)

Stationary Cellulose Biorefinery

Ruminant Bioreactor:

Biomass Input ~ 20 Lb/Day*

Capacity ~ 40 Gal Fermentor

SSCF Bioreactor:

Biomass Input ~ 5,000 Dry Ton/Day = 10 M Dry Lb/Day

Capacity ~ 45 M Gal Fermentor

Source: B. Dale, MSU

Cow is 3x more efficient than bioreactor

Biomass Processing Challenges

- Water use ~ 3.5 g H_2O per g EtOH
  - Recycling lowers H_2O use considerably
- Travel $ limit production area to 50 m.
  - Pelletizing & on-farm pretreatment
- Truck traffic – 100 mil g biomass plant = 200 trucks/day
  - Pelletizing & on-farm pretreatment

Conclusions

- **Both starch and cellulosic ethanol feedstocks are needed to meet federal renewable fuel goals.**
- **Corn stover supply is limited by soil erosion and soil carbon factors.**
- **Cellulosic ethanol processing improvements are continuing.**
- **Genetic improvement to energy crops is in its infancy.**

Thank you

for your attention