Environmental Health Impacts of Ethanol Production

The Good, The Bad, and Future Solutions

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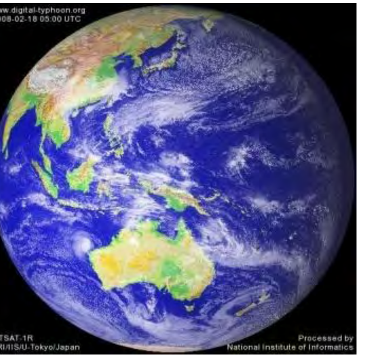
Sigma Xi Chapter, University of Nebraska, 29 October 2008

Presentation outline

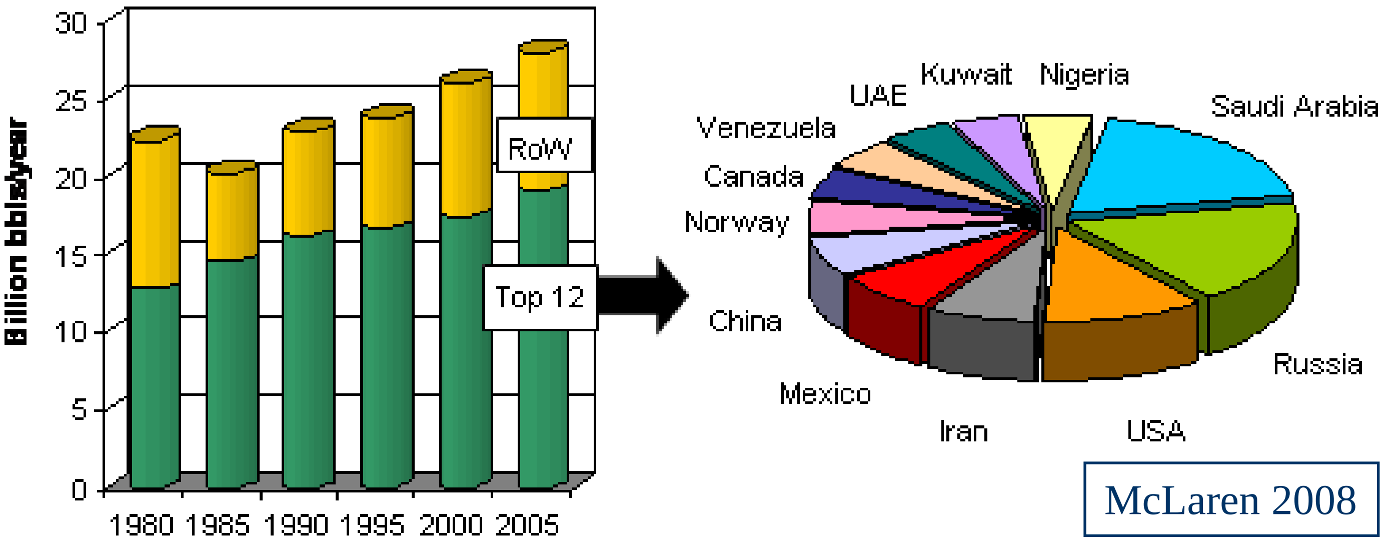


- Guiding questions:
  - ***How do environmental impacts of ethanol production & use compare with those of gasoline?***
  - ***What solutions & alternatives exist?***
- Broad-based survey of ethanol & the environment
  - Current state of energy
  - Ethanol: background
  - Environmental impacts of corn-based ethanol production
  - Alternatives & potential solutions

Current state of energy: Global & US

- Production
- Demand increasing, supply decreasing
- US energy use & imports

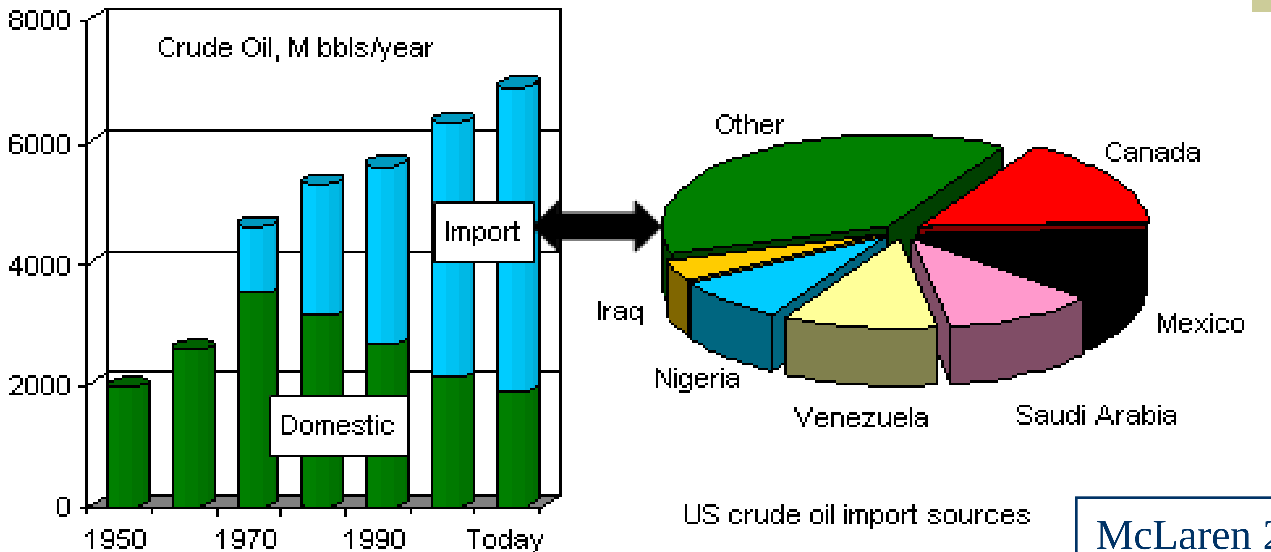
Crude oil: Global production



McLaren 2008

- Improved living standards worldwide → increasing reliance on finite oil reserves for transportation, heating, industry
  - "Finite" – new oil forms in geological time-scales
- Total <u>production</u> mirrors total <u>consumption</u>: 30B bbls/yr
  - At this rate, proved reserves will deplete in 40 years

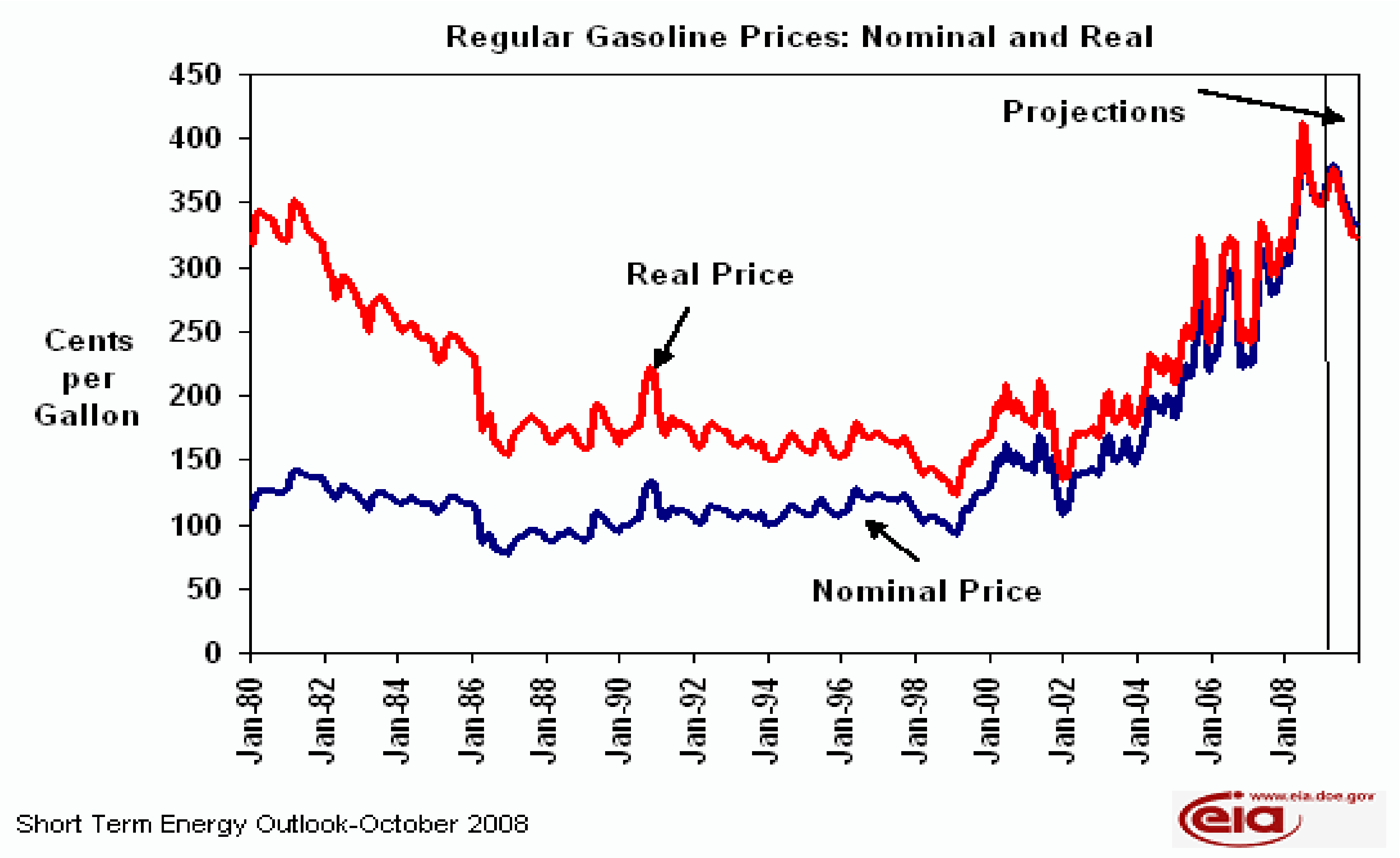
Crude oil: US trends



McLaren 2008

- U.S. largest global user of oil energy (albeit efficiently)
- Increasingly, we rely on imported crude oil
- High % import from politically unstable regions
- → **Security** of future energy supply crucial policy issue

Gasoline prices increased dramatically since 1990s



Oil price affects agricultural production costs

- 2007: high petroleum costs affect US ag. expenditures (USDA 2008)
- Petroleum → fuel, fertilizers, chemicals, transportation, crop prices

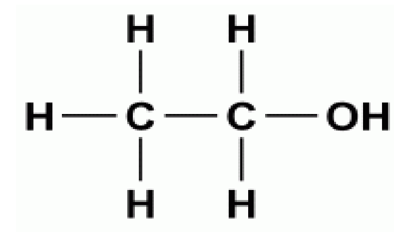
	Total cost	**% increase from 2006**
US farm production expenditures (total)	$260 billion	9.3%
Per farm:		
Fertilizer, lime, soil	$8,070	26%
Feed	$18,412	22%
Fuel	$6,137	15%
Agricultural chemicals	$4,832	12%

… so US government looks to renewable fuels such as ethanol

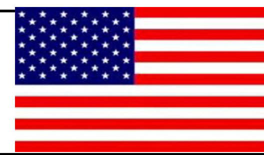
- "America is addicted to oil."
  - -President Bush, 2006 State of the Union Address

- Background on ethanol
  - What is ethanol?
  - Ethanol production trends in US
  - Ethanol use in vehicles
  - US policies supportive of ethanol

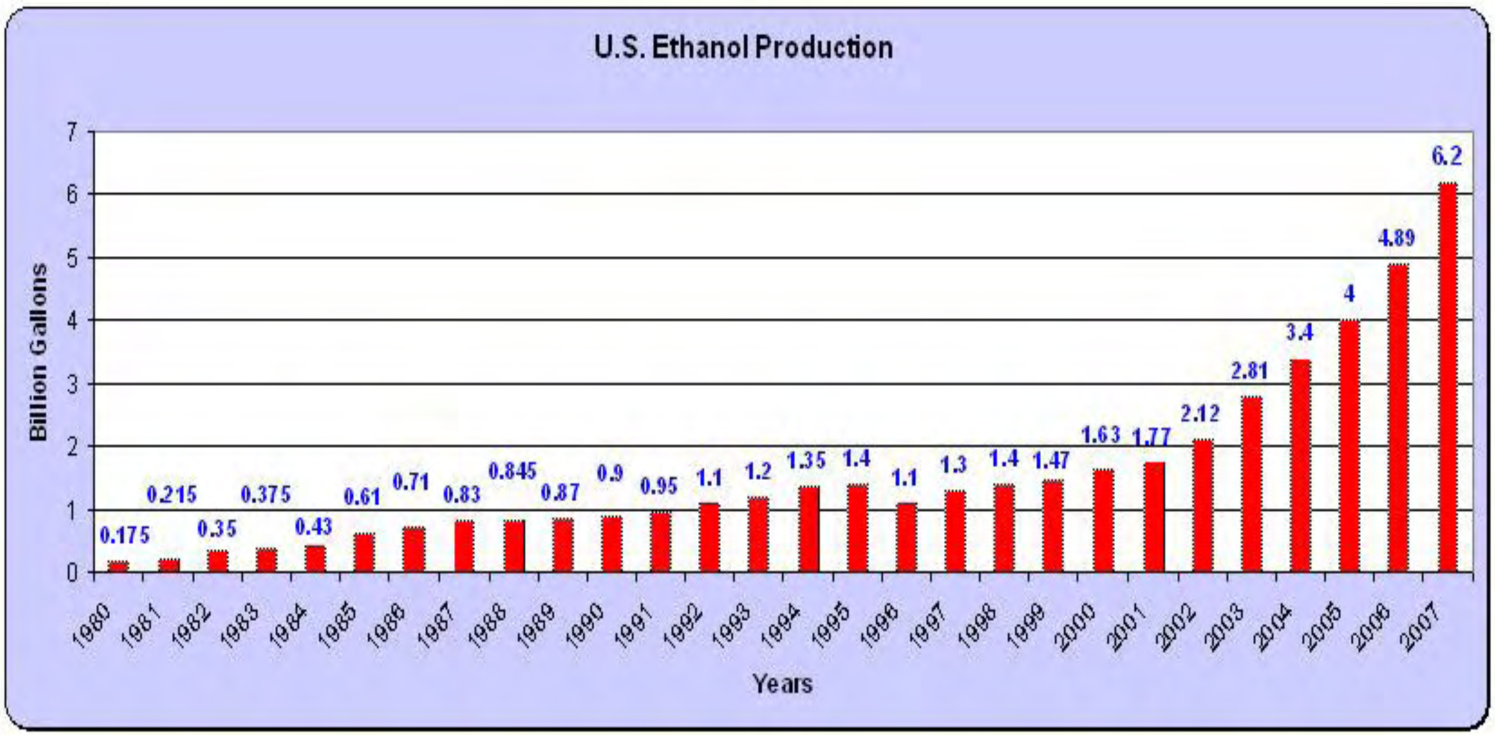
Ethanol: background



- Pure alcohol, grain alcohol, drinking alcohol
- Fermentation of sugar into ethanol "earliest organic reaction known to humanity"
- Uses
  - Consumption
  - Flavorings & scents
  - Medicines
  - Solvent in chemistry
  - **FUEL** (98% from corn)

	**2007 actual**	**2015 expected**	**2020 potential**
Ethanol produced (B gal)	6.2	15.0	20.0
Corn yield (bu/A)	151	180	200
Corn produced (Mbu)	13,062	16,200	18,000
Corn used for ethanol	1670 (13%)	3866 (24%)	5150 (29%)
Corn available for other uses (Mbu)	11,392	12,334	12,850

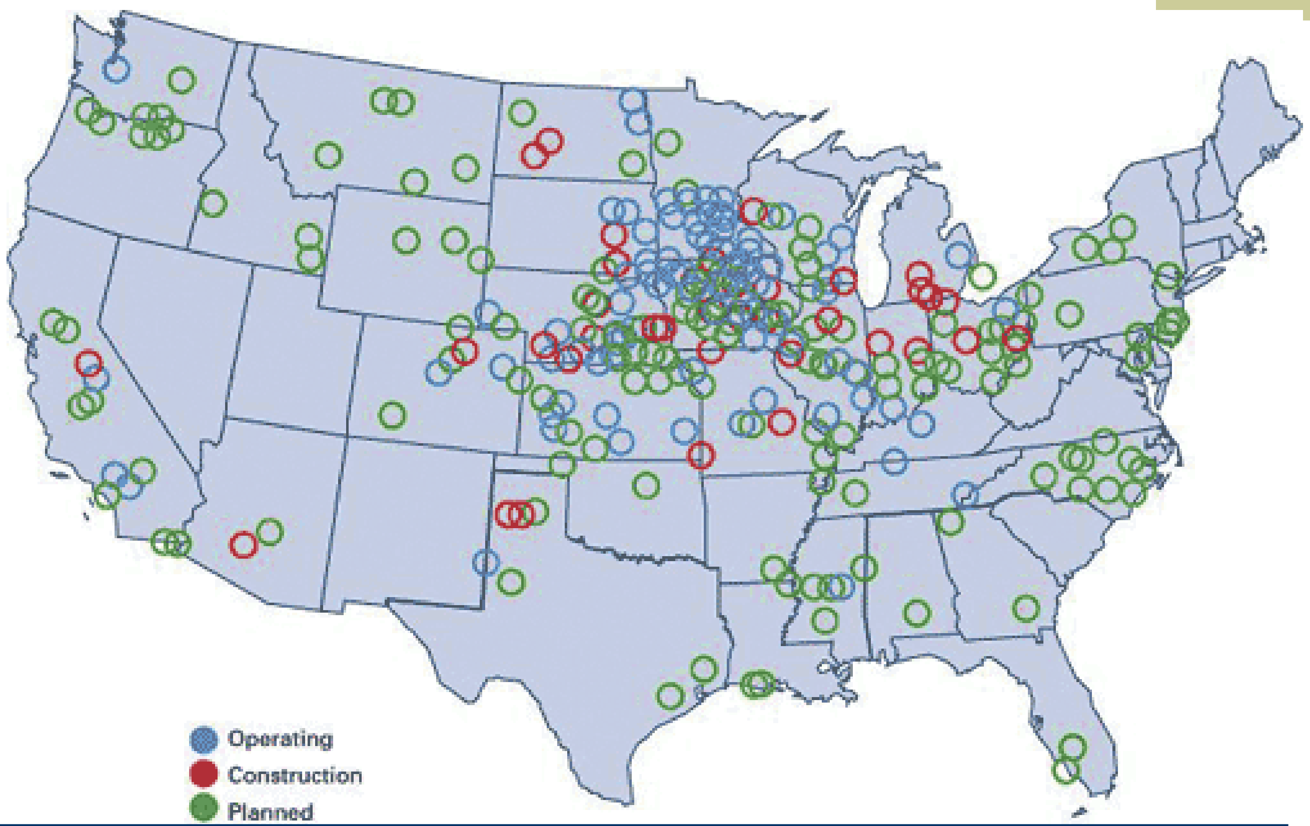
Corn-based ethanol production in U.S. (millions of gallons)



1 bu corn yields 2.7 gallons ethanol: 2.3B bu corn in 2007

U.S. goal: **15 x 15 x 15** (yield, ethanol, 2015)

Existing & planned ethanol plants



Today: 134 existing plants; 77 under construction

Ethanol doesn't replace gasoline…

- … but complements it
- Flex-fuel vehicles (FFV): 0-85% ethanol mixed with gasoline
  - E.g., E10 (10% ethanol, 90% gasoline), E85
    - ~7.3 million US cars in use compatible with E85 (out of 65 million)
    - 68% Americans didn't know they owned E85 FFV (2005 survey)
    - ~13.7 million E85 FFVs in Brazil
  - Gasoline-powered cars can use E10

Ford Model T: Earliest FFV

Modern US postal FFV (E85)

Policy support for ethanol

- 2007 "20-in-10" initiative:
  - Reduce gasoline consumption by 20% in 10 years
- Subsidies: $0.51/gal (now $0.45/gal) tax credit to refiners
- Congressional mandates to produce:
  - 4B gallons by 2006, 7.5B gallons by 2012
  - Recent legislation: 36B gallons by 2022
- DOT: Fuel-economy compliance credits for new E85 vehicles
  - E.g., Chevy S-10 that gets 25 mpg counted for federal compliance purposes as if it gets 40 mpg

  - 2007: Portland, OR: 1st city to require all gasoline sold within city limits contain ≥10% ethanol
  - Jan 2008: 3 states require ethanol blends: MO, MN, HI

National Biofuels Action Plan (USDA/DOE)

- Released Oct. 7, 2008
- Interagency Biomass R&D Board focuses on 7 Action Areas:
  - Sustainability
  - Feedstock production
  - Feedstock logistics
  - Conversion science & technology
  - Distribution infrastructure
  - Blending
  - Environment, health & safety
- Many of these areas have strong **environmental** component

Environmental health impacts of corn-based ethanol production

- Food supply
- Air quality
- Soil & water quality
- Energy use
- Carbon emissions
- Animal feed quality

Food vs. fuel debate

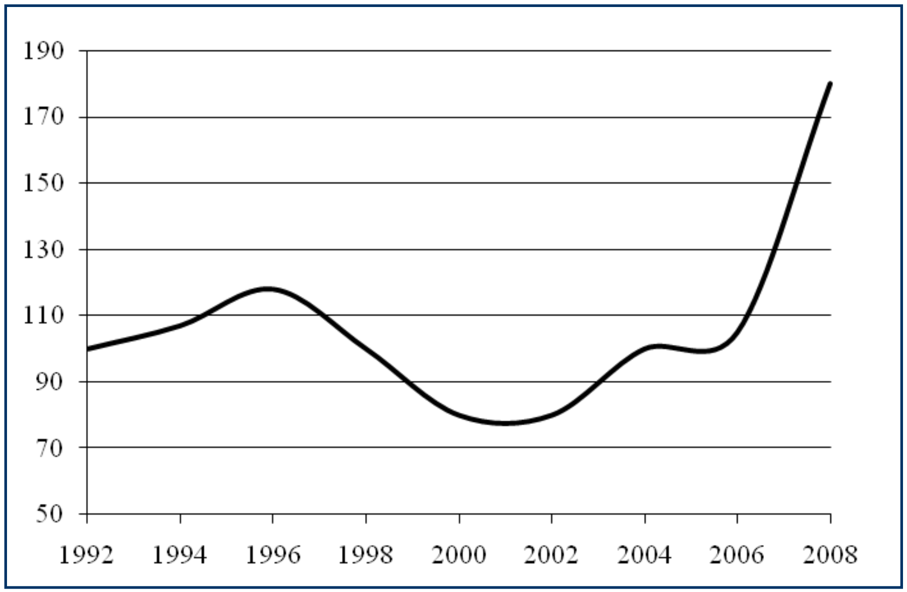
- **“Does corn → ethanol compromise food supply?”**
- Not in US…
  - Most US corn production → animal feed
  - Corn for human consumption: high-fructose corn syrup
  - 5-10% increase in meat prices (Dale 2008)
- …But possibly in poorer, corn-trading nations
  - Food corn same type as US animal feed
  - High food prices → Feb 2007 Mexico riot over tortilla price
  - Food demand will double in 50 years (Tilman 2007)
    - Population increases to 9 billion & meat consumption increases

Increased meat consumption in China & India

- 1 lb meat requires 10 lbs vegetable
    - ~90% corn, 10% soybean meal
- "Middle class" growing
- Statistics:
    - China: 1.33 billion people
    - India: 1.15 billion people

- If each person ate 3 lbs more meat/yr, would need 67 billion lbs more corn → 1.2 billion bushels
    - ~10% of U.S. corn production
    - High all-around demand for corn will raise prices

Other factors also account for increased food prices



Food commodity prices rose >60%
in last 2 years. Index: Jan 1992 = 100.

- Higher fuel prices: increased input & transportation costs
- Increased food demand as people in developing countries improve diets
- 2 years of drought: poor harvest in some world regions

Air quality & health
(excluding CO_2)

- Air pollution 7th-leading cause of death worldwide (WHO 2008)
- Effects of ethanol (E85) vs. gasoline vehicles
  - Ethanol use **increases**:
    - Ozone (2.14X as much as gasoline!)
    - Acetaldehyde
    - Formaldehyde
  - Ethanol use **decreases**:
    - CO
    - NO_2, SO_2
    - Benzene
    - Butadiene
  - No significant change in particulate matter

- If Los Angeles → E85 vehicles (Jacobson 2007):
  - 9% increase in ozone-related mortality! (asthma, bronchitis, heart attack)
  - No decrease in NO_2, SO_2, benzene / butadiene-related illness (e.g., leukemia)

Soil & water quality

- Soil overuse: erosion, nitrogen depletion
- Water use
  - 1 gal ethanol production requires 3-5 gal water
    - Problem for ethanol plants in arid locations
  - Irrigating new dedicated fields needs massive amounts of water
- Water quality: runoff of pesticides and fertilizers
  - >1000 kg nitrogen fertilizer / km^2 corn into Mississippi River (Schnoor 2008)
    - Hypoxia in Gulf of Mexico: reduced O_2 → fewer fish, shrimp, crabs

"Carbon neutrality" and biofuels

- Main concern: Carbon dioxide's contribution to global warming
- **Carbon neutral**: New Oxford American Dictionary's Word of the Year, 2006
  - Carbon emissions from fuel consumption offset by carbon capture & sequestration (e.g., by planting crops)
    - Growing plants remove CO_2 from air
    - Carbon in plants turned into biofuel (e.g., ethanol)
    - When biofuel combusted, CO_2 released back into air
  - → If made properly, biofuels can be carbon neutral

Per unit energy, ethanol trumps gasoline (Farrell et al. 2006)

	Net fossil input	**Net fossil ratio**	**Petroleum input**	**GHG emissions**
	MJ_{fossil} needed for each MJ_{fuel}	MJ_{fuel} made for each MJ_{fossil} input	$MJ_{petroleum}$ needed for each MJ_{fuel}	g CO2 emitted per MJ_{fuel}
Gasoline	**1.19**	**0.84**	**1.10**	**94**
Corn ethanol	**0.77**	**1.30**	**0.04**	**77**
Cellulosic ethanol	**0.10**	**10.0**	**0.08**	**11**

Biofuels & carbon debt: Land use change

- Land in undisturbed ecosystems (esp. Americas & Asia) converted to:
  - Biofuel production
  - Food production, when agricultural land used for biofuel
- Converting native habitats to cropland releases CO_2 by burning plants & soils
  - ~50 years: decay of leaves & roots further releases CO_2
  - This is “carbon debt”
- Over time, biofuels on converted land can repay carbon debts, if their greenhouse gas (GHG) emissions are less than GHG emissions of fossil fuels they displace.

How many years for biofuels to repay carbon debt?

Ethanol production type (*Searchinger et al. 2008*)	**# years of increased GHGs**
Corn-based	**167**
Corn-based, improved yield & tech	**34**
Switchgrass-based (corn land)	**52**
Brazilian sugarcane (tropical rain forest)	**45**
Brazilian sugarcane (grazing land)	**4**

Ethanol production type (*Fargione et al. 2008*)	**# years of increased GHGs**
Corn-based (central grassland)	**93**
Corn-based (abandoned land)	**48**
Switchgrass-based (marginal cropland)	**0**
Brazilian sugarcane (wooded land)	**17**

Ethanol production impacts on animal feed quality

- Ethanol produced from corn → **Mycotoxins** (toxins of fungal origin) concentrated up to 3X in co-products

- → 90% co-products fed to livestock & poultry in animal feed
  - Usually as Dried Distillers Grains plus Solubles (DDGS)

→

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- *What is the impact to animal health?*

Mycotoxins of concern in corn

Fumonisin	*Fusarium verticillioides, F. proliferatum*
Aflatoxin	*Aspergillus flavus, A. parasiticus*
Deoxynivalenol (DON, vomitoxin)	*F. graminearum, F. culmorum*
Zearalenone	*F. graminearum, F. culmorum*

Multiple adverse animal health effects

Left to right:
Fusarium ear rot,
Gibberella ear rot,
Aspergillus ear rot
(photos: Gary Munkvold)

DDGS risk to animals

- Impact to livestock industry ~$10 millions annually in reduced animal weight alone
  - (Wu F, Munkvold GP, *J. Agric. Food Chem* 56:3900-3911, 2008)
- But not much economic incentive to change this
  - Ethanol plants want to sell DDGS to livestock producers…
    - 10-20% revenues come from DDGS: $1.5 billion in 2006
    - Significant source of revenue for ethanol plants
  - … and livestock producers want to keep buying it
    - High corn price → turn to cheaper feedstuffs
    - Currently, DDGS cheap: ~85% of cost of corn

Summary: Environmental impacts of corn ethanol, compared to gasoline

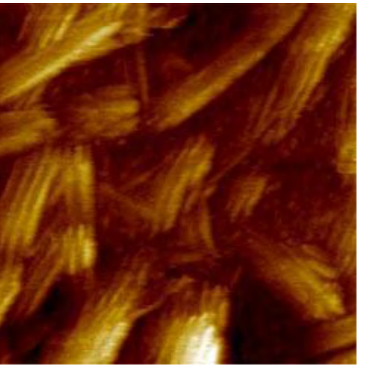
Food supply	Both implicated in higher food prices: Potential risk in poorer nations
Air quality	Increased respiratory mortality & morbidity
Water use & quality	Similar water use, risks to water quality from increased runoff
Energy use	Per unit improvement over gasoline
GHG emissions	Over time, will result in lower emissions
Animal feed	Potentially increased mycotoxin risk

Corn growers already adopting environmental solutions…

- No-till farming
  - Slows erosion, builds soil organic matter
- Advanced fertilizer technology
  - Improves crop nitrogen capture
- Cover crops
  - Sequester soil carbon, intercept nitrate & phosphorus runoff
- Crop genetic improvements
  - Reduce pesticides & mycotoxins, can increase stress tolerance & nutrient efficiency

- **Beneficiaries:**
  - Corn growers: lower input costs
  - Ethanol plants: lower grain costs
  - Environmental sectors: reduced chemicals → reduced hypoxia & water pollution, more efficient land & water use

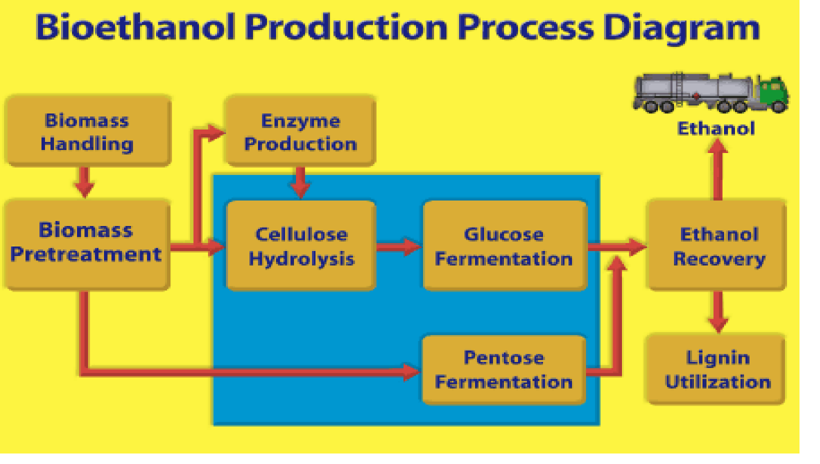
Lignocellulosic ethanol: Introduction



- "Lignocellulosic": biomass composed of cellulose, hemi-cellulose (carbohydrates), & lignin (cell wall component)
- Can be converted to ethanol
- Sources
  - Agricultural residues (e.g., corn stovers, wheat straw)
  - Dedicated energy crops: switchgrass, hybrid poplars (cottonwoods), hybrid willows
  - Wood residues (e.g., sawmill & papermill discards)
  - Municipal paper waste

Lignocellulosic ethanol production
(Image source: DOE 2008)

- Barriers to ethanol production
  - Sugars for fermentation trapped inside lignocellulose
  - High % of pentose vs. hexose in hemicellulose: difficult to ferment
- Solutions
  - Pretreatment: open cell wall materials for enzymatic attack
  - Enzymatic hydrolysis (cellulase): converts cell walls to sugars
  - Fermentation: to convert sugars to ethanol → engineered yeast to degrade pentose



Energy return on investment for ethanol

- r_E = ratio of energy in a gallon of ethanol to the nonrenewable energy required to make it

- $r_E = E_{out} / E_{in,nonrenewable}$
  - r_E always < 1 for nonrenewables like gasoline: at least some gross energy input is lost when refining energy product
  - If $r_E > 1$, we've captured some renewable energy value
  - If $r_E > 0.76$, it consumes less nonrenewable energy than gasoline

- Meta-analysis of ethanol studies (Hammerschlag 2006):
  - **$0.84 \leq r_E \leq 1.65$** for corn-based ethanol
  - **$4.40 \leq r_E \leq 6.61$** for cellulosic ethanol

Lignocellulosic ethanol: Promises

- May 2008 Farm Bill: subsidies for cellulosic ethanol
  - Refiners: $1.01 / gallon
  - Growers: $45 / ton of biomass
- Potential environmental benefits:
  - Can grow cellulosic crops on marginal lands
  - Reduces (doesn't completely solve) "food vs. fuel" dilemma
  - Perennial crops do not have high water / pesticide / fertilizer requirements
  - Reduces GHG emissions

Lignocellulosic ethanol: Potential issues

- Logistics: Harvesting, storage, preprocessing / grinding, transportation ~20% of current cost

- What to do with co-products?
  - Animals can't eat wood / paper residues
  - Ethanol plants prefer to make profit from all parts of feedstocks

- Even dedicated crops pose environmental concerns
  - Use of marginal land can destroy biodiversity
  - Some proposed crops are exotic or invasive: further threats to local biodiversity
  - "Food vs. fuel": if profitable enough, may displace food crops

Win-win: Alternatives & potential technology / policy solutions

- How to achieve environmental quality without making any sector worse off? Solutions in:
  - Transgenic (genetically modified) crops
  - Alternative biofuels
  - Improved conversion processes
  - Other renewable energy sources
  - More energy-efficient lifestyles

Transgenics: Bt corn & other crops

Photo: G Munkvold

- Bt corn can provide benefits in both starch & lignocellulosic feedstocks
- Through reduced insect damage:
  - Increase in yield
  - Increase in biomass
  - Reduction of mycotoxins → more efficient conversion, healthier co-products for animal feed
  - *Munkvold, Wu, Pometto, USDA Biotechnology Risk Assessment Grant (2008-2011)*
- Other transgenic possibilities:
  - Stress-tolerant, drought-resistant crops to grow on marginal lands
  - Improved fuel conversion (e.g., more easily fermentable starch)

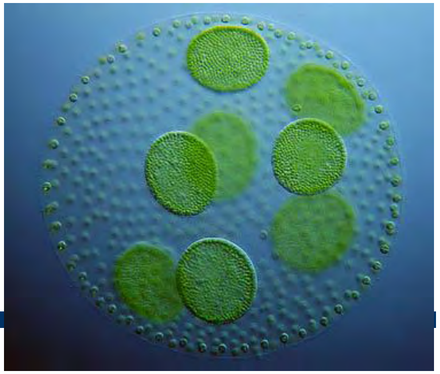
New biofuels

- Butanol
  - Produced via fermenting biomass
  - Good energy density, but too costly to produce pure butanol
- Mixed alcohols
  - Mixture of microorganisms digest biomass to acids
  - Acids converted into corresponding alcohols (ethanol, butanol, etc.)
  - Needs pH control & massive biomass in silage-like piles
- Biogas (methane)
  - Generated by anaerobic conversion of waste residues
  - Methane combusted in furnace → heat or steam
  - Useful if liquefied natural gas more common as transport fuel

Syngas → ethanol

- New progress in thermochemical conversion processes through improved catalysis
  - Synthetic gas, “syngas,” can be converted to ethanol
  - Syngas (CO & H_2) made by gasification of carbon-based materials
    - High temperature / pressure, oxygen-controlled atmosphere
- DOE / Ames laboratory & ISU: develop nanotechnology-based catalyst to react with syngas to form ethanol
  - Avoids producing unwanted waste products
  - Advantages: can convert almost any carbon-based material to syngas (similar to feedstocks of cellulosic ethanol)

Algae as biofuel source



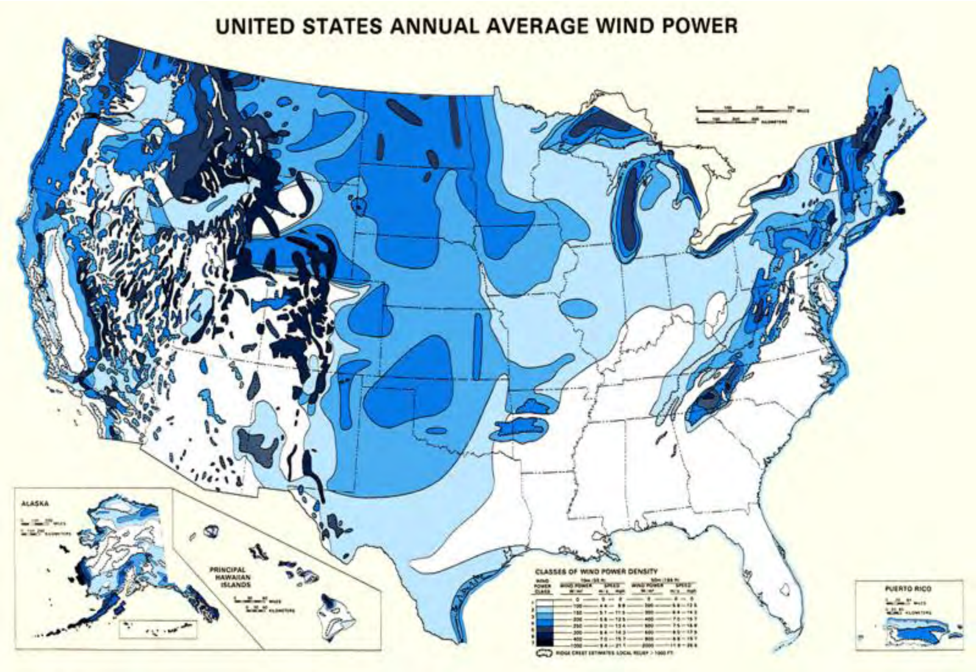
- “Algaculture”: farming algae for biofuels
- Algae can be metabolically altered to generate high levels of oil
  - ~6000 gal biofuel/A
- Environmental benefits:
  - Doesn’t need freshwater, can use ocean or wastewater
  - DOE: If algal fuel replaced all petroleum fuel in US, would only require area equivalent to size of Maryland
- Challenges:
  - Containment, temp. control, high infrastructure costs

"True renewables": Wind and solar energy

- Benefits
  - Wind & solar energy are plentiful, renewable, widely distributed, clean, & in theory have zero GHG emissions
- Current issues
  - Infrastructure costs
  - Siting & transmission lines

Windmills and Pickens' Plan

- T. Boone Pickens (July '08)
- Invest **$1 trillion** in wind turbine farms in Great Plains Wind Corridor
- Turbines connect to power grid
- Displaced natural gas can fuel vehicles



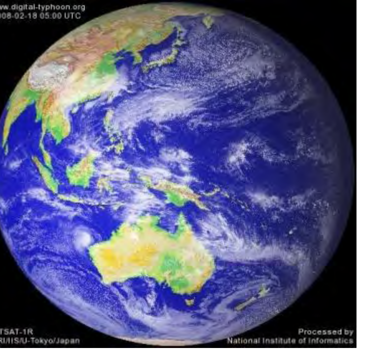
- Could supply <20% US electricity
- Could save US **$300 billion** annually in foreign oil
- Could reduce GHG emissions (natural gas lower-polluting)
- Issues: transmission lines expensive, natural gas still need for peak electricity demand

More energy-efficient lifestyles

- Our energy demands drove up price of oil…
- Transport
  - Fuel-efficient vehicles
  - Mass transit
  - Bicycling / walking

- Buildings
  - Use as much energy as transportation, release twice as much greenhouse gas (Tilman 2007)
  - Natural lighting, compact fluorescents, turning off lights & appliances, smaller homes ("Small House Society")

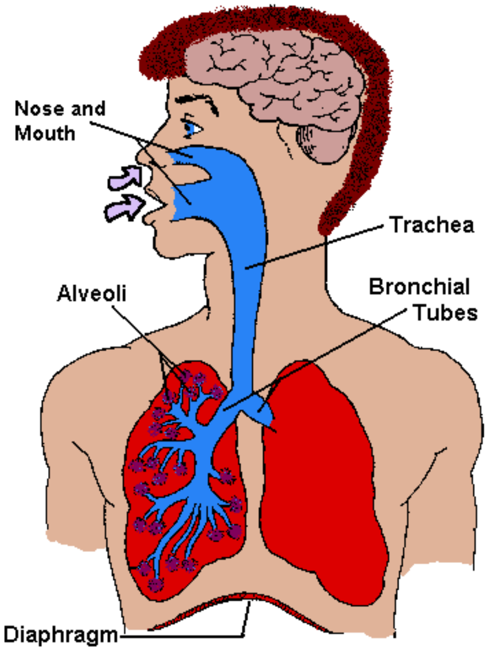
Summary



- We can avoid a global energy crisis through renewable fuel sources
- Ethanol has unique environmental health benefits & risks compared with gasoline
- Technology & appropriate policies can make win-win situations for multiple sectors
- Other renewable sources & lifestyle changes should be considered in conjunction with ethanol for energy-secure future

Final thoughts

- Ethanol & climate change: well-characterized
- But ethanol & ozone-related mortality:
  - **We need to pay more attention!**
- Many environmental solutions focus on how to produce ethanol more efficiently…
  - But **how to reduce ozone pollution**?
  - Focus technology $ and policy here
- Get government agencies & universities to "reach across the aisle"



Acknowledgment

- Donald Beermann: Sigma Xi President, University of Nebraska chapter
- Gary Munkvold: Iowa State University
- Paul Bertels, Geoff Cooper: National Corn Growers Association
- Thomas Biksey, Judith Lave, George Leikauf, Yan Liu, Conrad Volz: University of Pittsburgh
- Daniel Morris: General Dynamics