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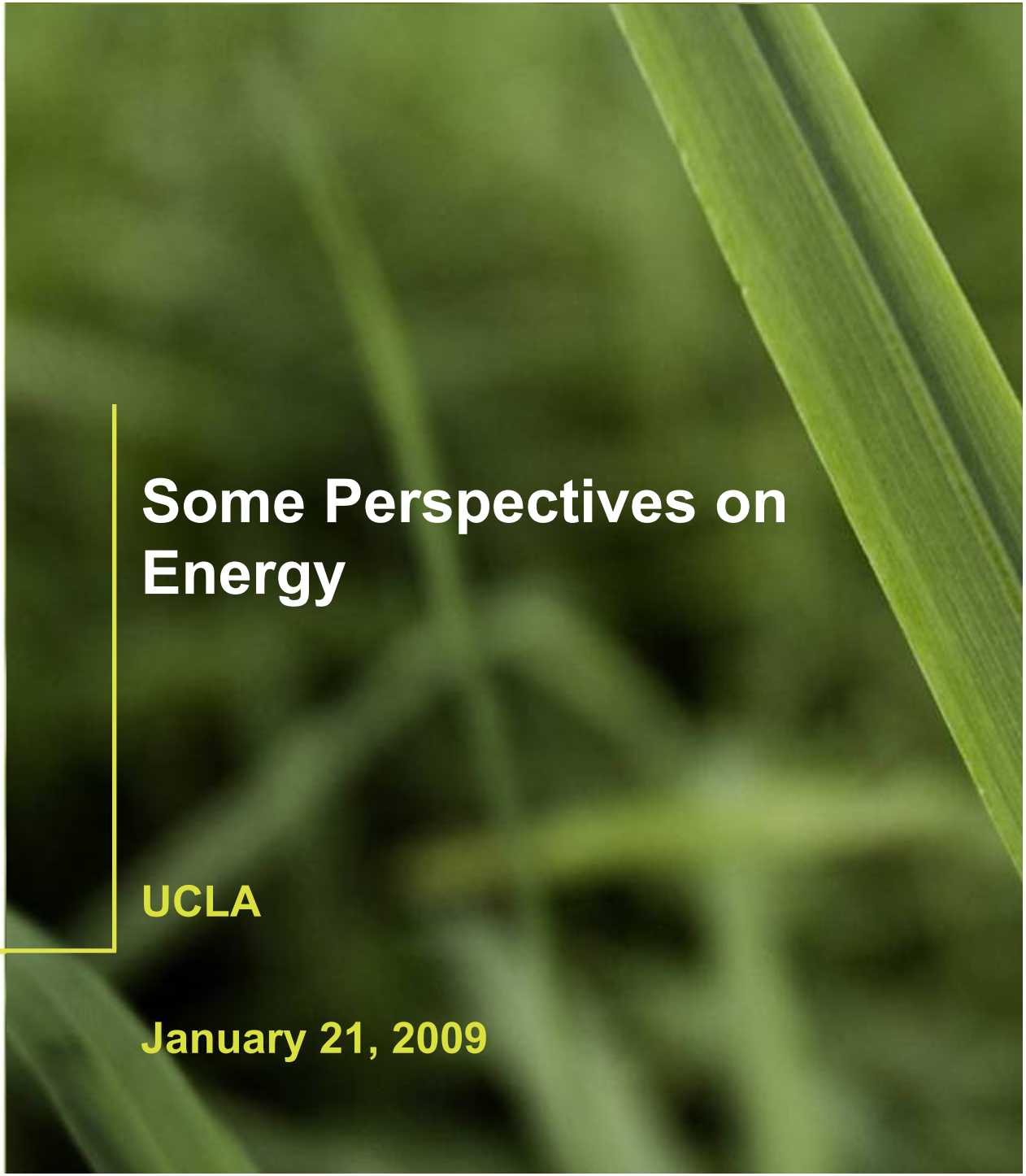


Some Perspectives on Energy

UCLA

January 21, 2009

The Perfect Storm…

Demand Trends
- Consumption outpacing discovery
- China & India

Supply Trends
- Nationalization of reserves
- High oil prices
- Peak production

Energy Security
- Little domestic supply
- Unrest in producing regions

Environmental
- Carbon emissions
- Drilling/mining

Where will we find a significant, renewable, domestic source of transportation fuels?

In the Future….

We will get most of our transportation fuels from:

A) Electric cars
B) Hydrogen
C) Conventional oil and gas
D) Biofuels
E) Hot air from UCLA professors

Aren't "Clean Electrons" The Answer?

...

CSP | Photovoltaic | Wind | Geothermal | Nuclear? | Clean Coal?





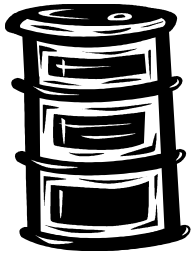



Solar currently 0.01%; Wind currently 0.75% of US grid. More electrons means more coal

Where Does A Barrel Of Oil Go?








Only ~44% of a barrel is used to produce gasoline
Only 48% of gasoline use is passenger cars (21% of the barrel)
Of that 21%, how much can be replaced with "electrons"?

Hybrids – YES! All Electric – Unlikely!

2010

Range: 40 miles (electric only)
Internal Combustion Engine – Yes!
4 cylinder – 1.0 liter
Increased mpg – Yes
Still needs liquid fuel? - absolutely

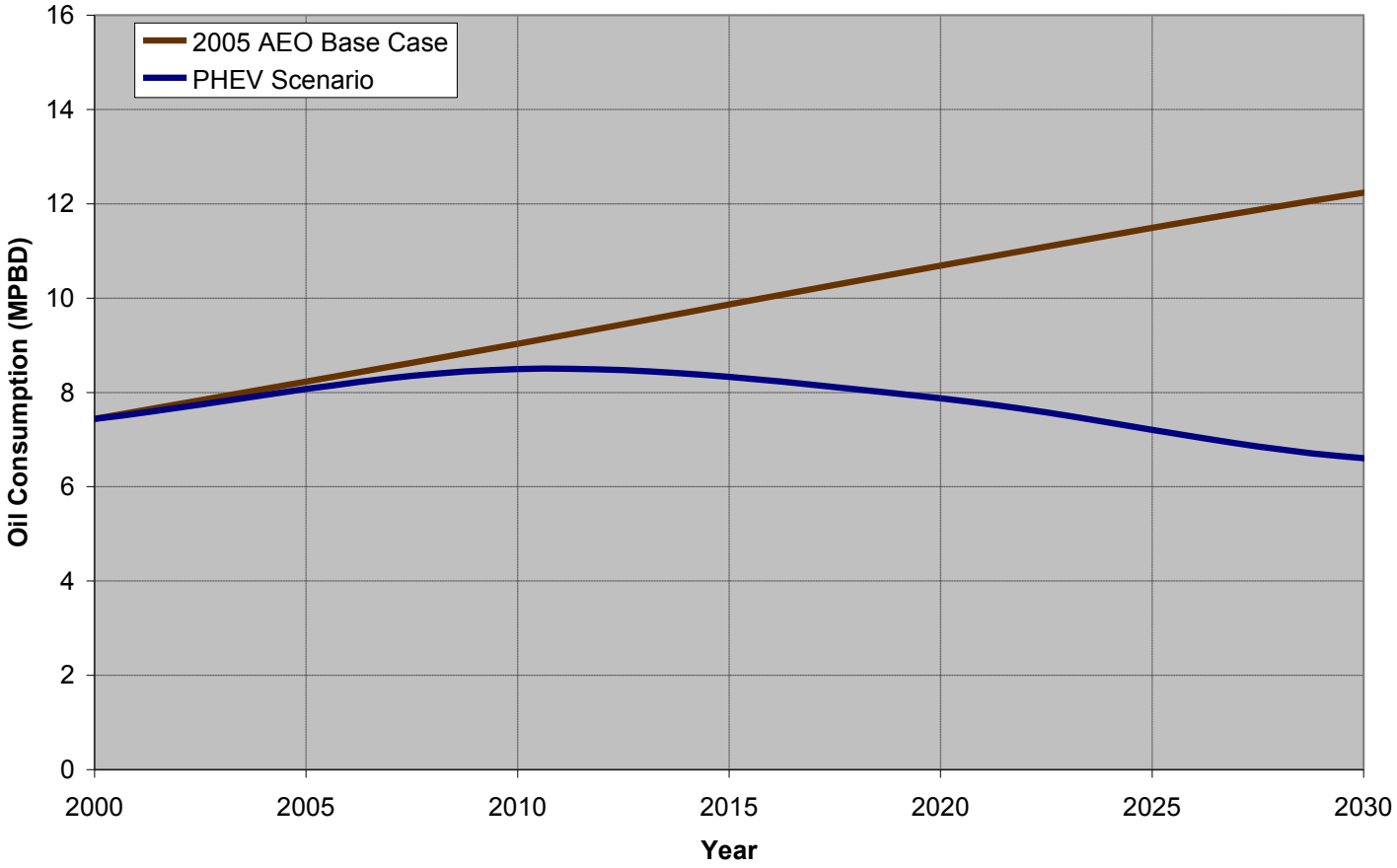
202?

Crash test performance?
Range?
Heater?
Air conditioner?
Stuck in traffic?
DVD player?

We can significantly increase fuel efficiency, but we cannot do away with fuel

Can PHEV's Replace Oil?

Light Duty Fleet Oil Use - Impact of PHEVs on Consumption



Assumptions: 2010 new car sales are 100% hybrids; 2020 new cars are 50% PHEV

Meanwhile…

Global demand growth for low cost, internal combustion transportation is likely to outpace increases in fuel efficiency

In the Future….

We will get most of our transportation fuels from:

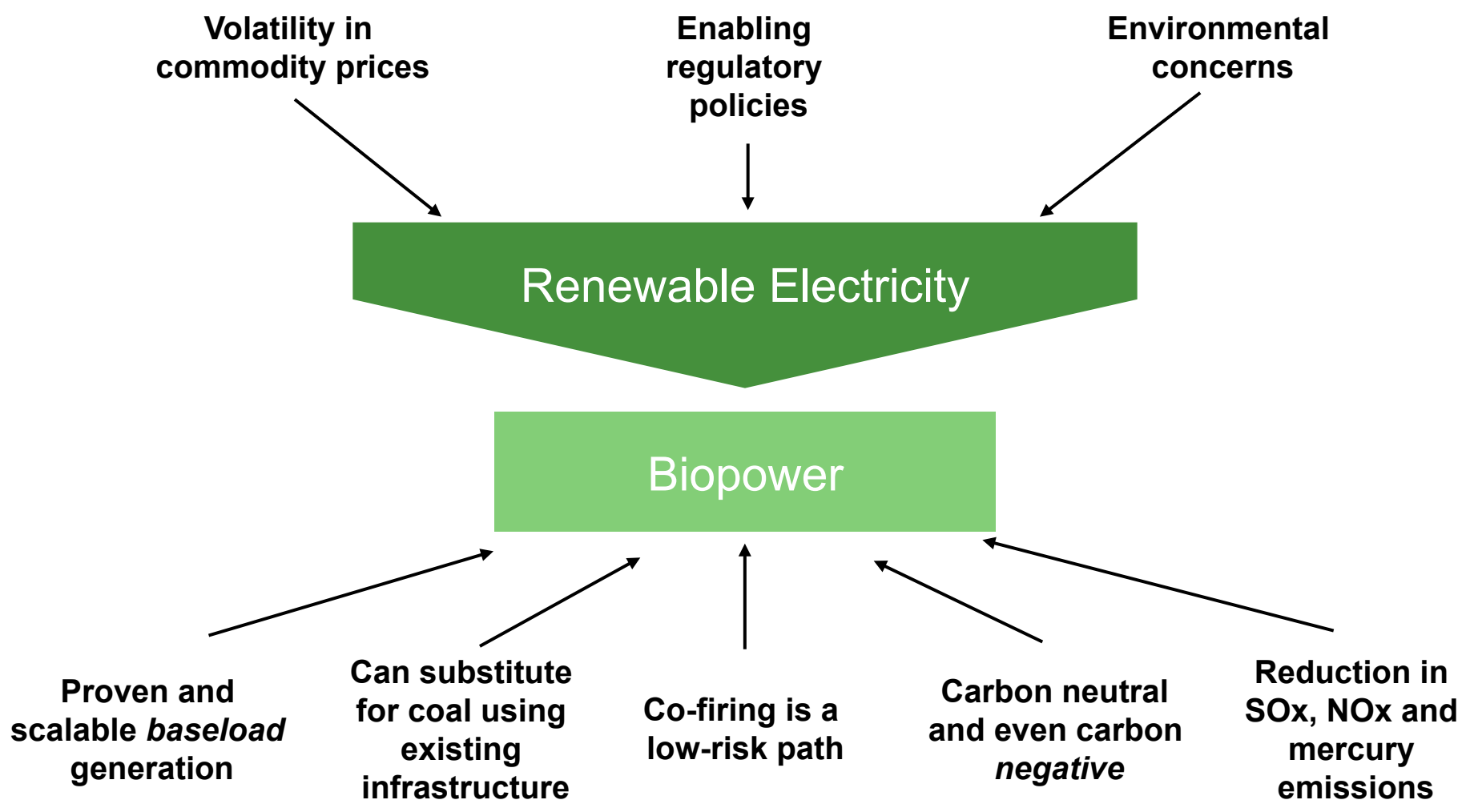
A) Electric cars
B) Hydrogen
C) Conventional oil and gas
D) Biofuels
E) Hot air from UCLA professors

In the Future….

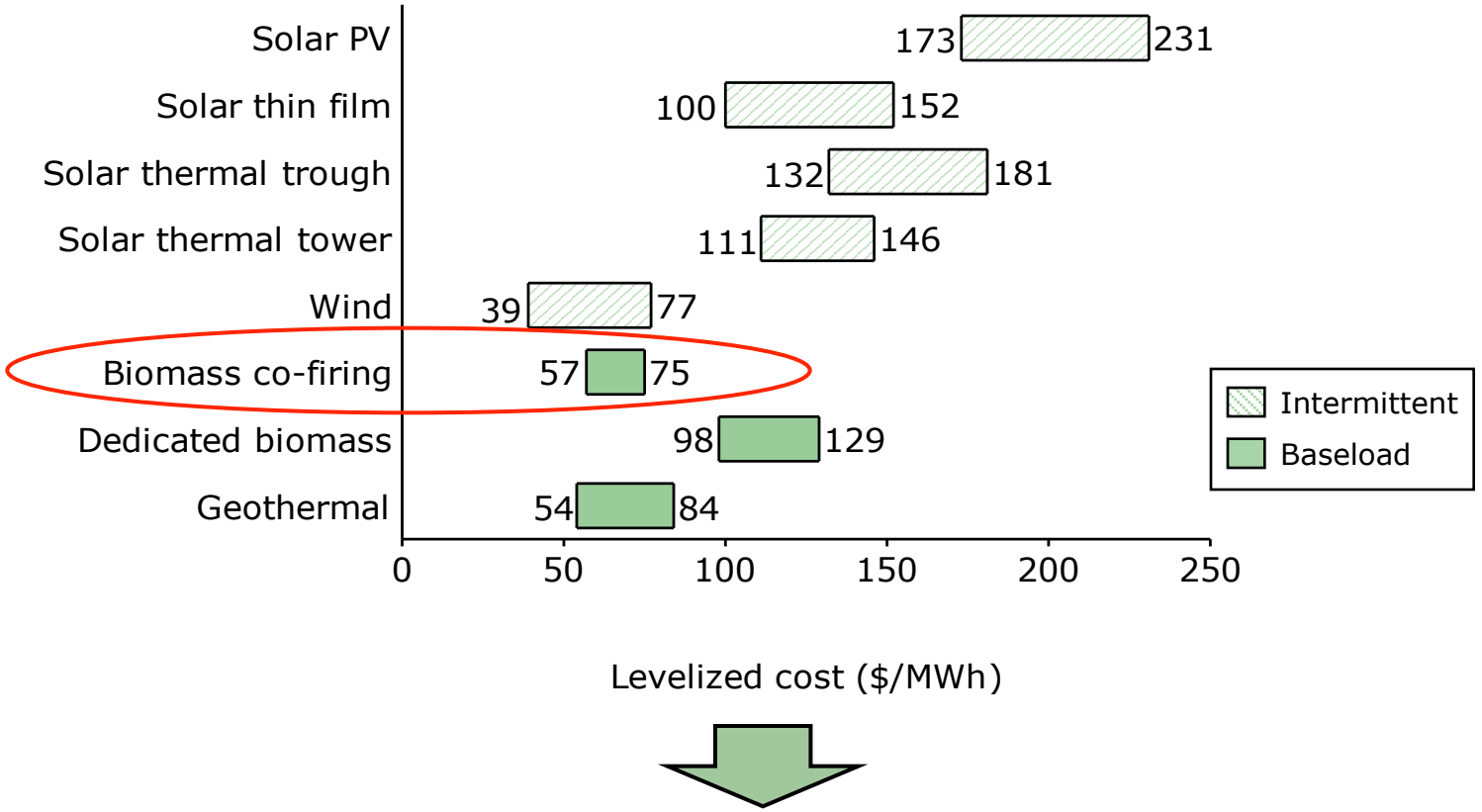
We will get most of our power from:

A) Solar and wind
B) Conventional coal and gas
C) Nuclear
D) Biopower
E) Hot air from UCLA professors

The Perfect Storm for Biopower



Co-firing is Cheaper than Solar and is Baseload Unlike Wind or Solar



Co-firing becomes even more attractive once carbon offsets from biomass and SOx and NOx reductions are considered.

In the Future….

We will get most of our power from:

A) Solar and wind
B) Conventional coal and gas
C) Nuclear
D) Biopower
E) Hot air from UCLA professors

The Biggest Drawback of Biofuels is:

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A) They cause food prices to rise
B) They will starve the poor
C) They threaten the world's forests
D) They can't scale
E) They cause childhood obesity

The Opportunity for Biofuels

With plausible technology developments, biofuels could supply some *30% of global demand…*

To realize that goal, so-called advanced biofuels must be developed from *dedicated energy crops*, separately and distinctly from food.

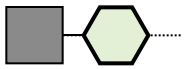
Steven E. Koonin
Chief Scientist, BP

Basic Carbohydrate Biochemistry

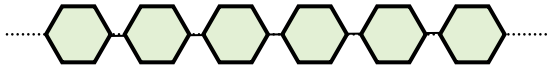
Sucrose (sugarcane)

Starch (corn grain)

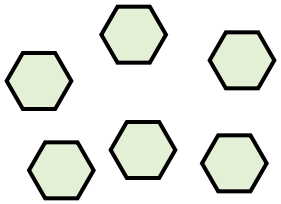
Cellulose (cell walls)



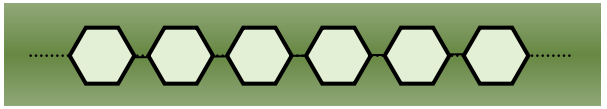
Hydrolysis /
C_6 fermentation /
distillation



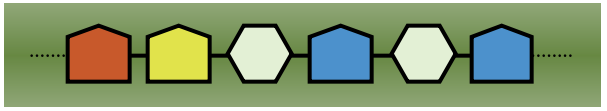
amylase /
glucoamylase



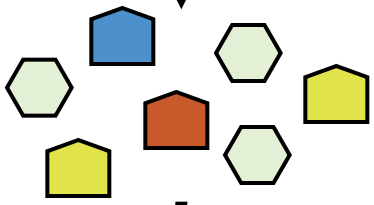
C_6 fermentation/
distillation



Hemicellulose (cell walls)



Cellulases | **Hemicellulases**



C_5/C_6 fermentation/
distillation

Biofuels

Biofuels

Biofuels

Not all sources are the same

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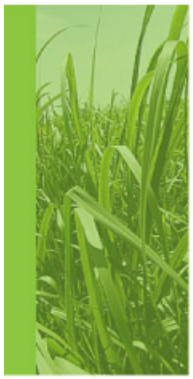
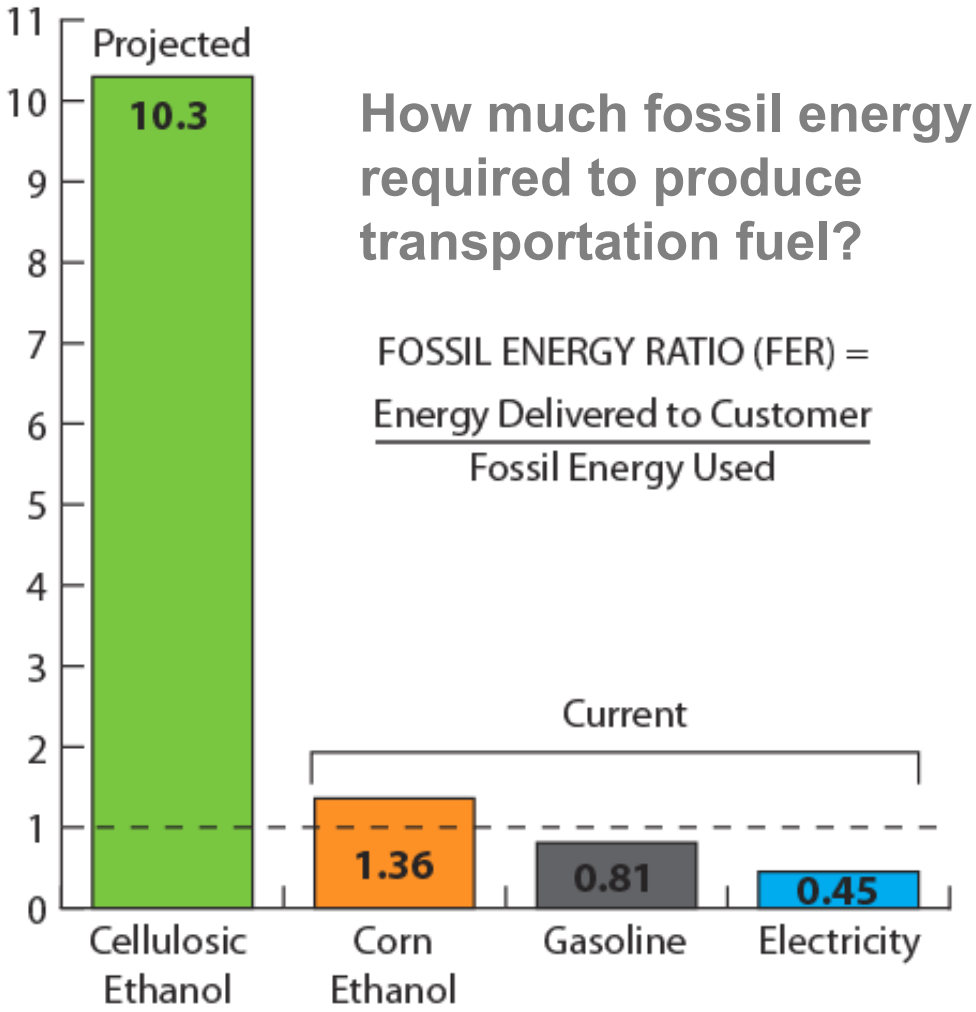


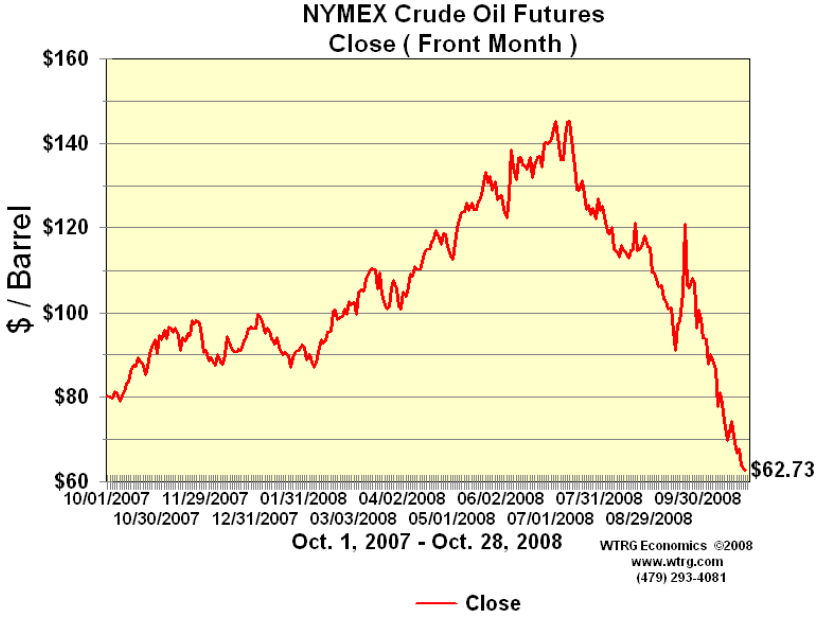


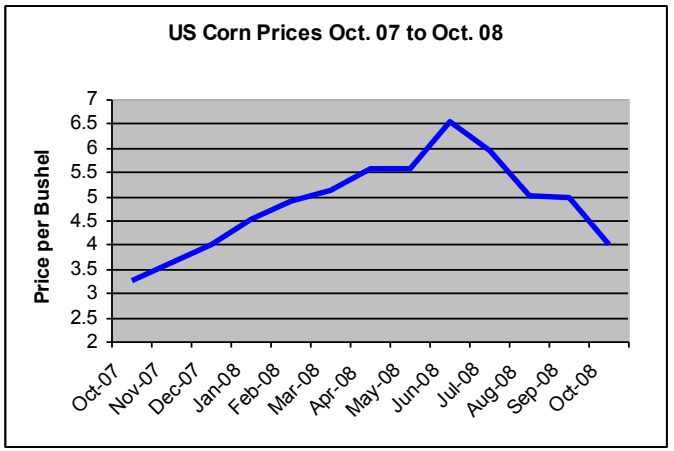
How much fossil energy is required to produce transportation fuel?

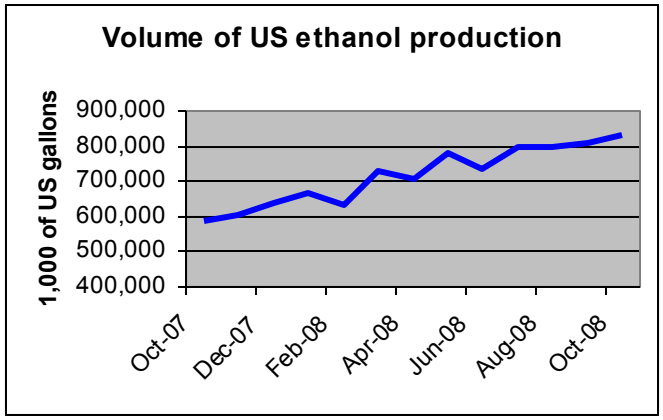
$$\text{FOSSIL ENERGY RATIO (FER)} = \frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}$$

Source: Biofuels Joint Roadmap, June 2006, DOE; data derived from Brinkman et al. 2005

It's the OIL, not the Ethanol



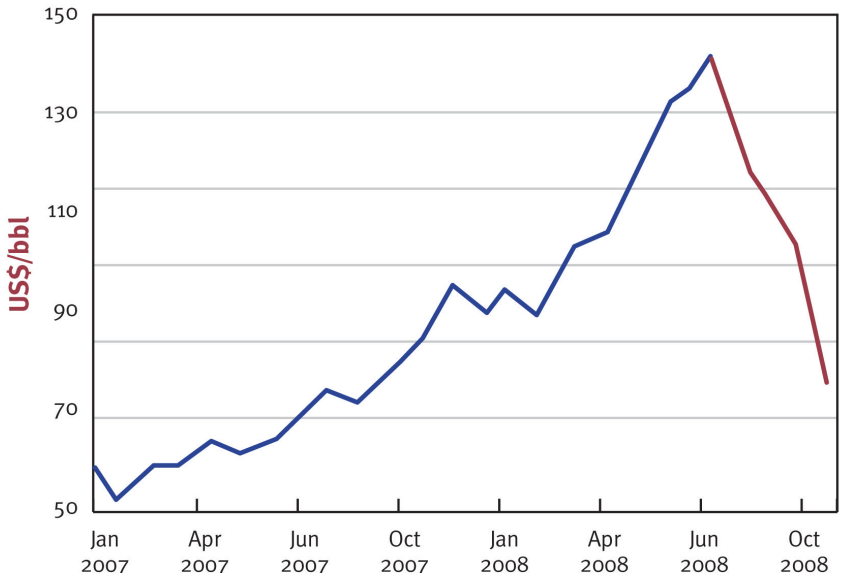




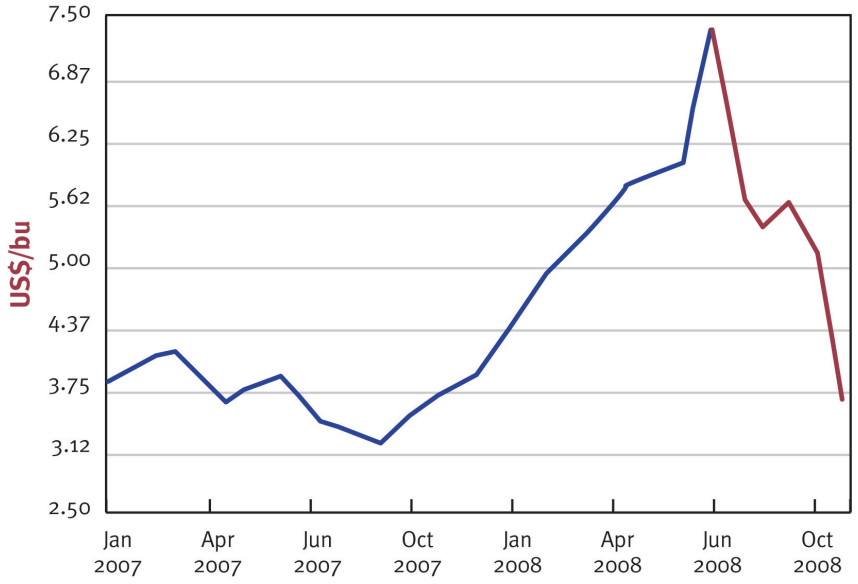
Higher commodity prices (like corn) are driven by OIL prices, not ethanol production volumes!

Sources: NYMEX, USDA, RFA

Why Do Corn Prices Track Oil?



Crude Oil Price (NYMEX)
January 2007 to October 2008



Corn Price (CBOT)
January 2007 to October 2008

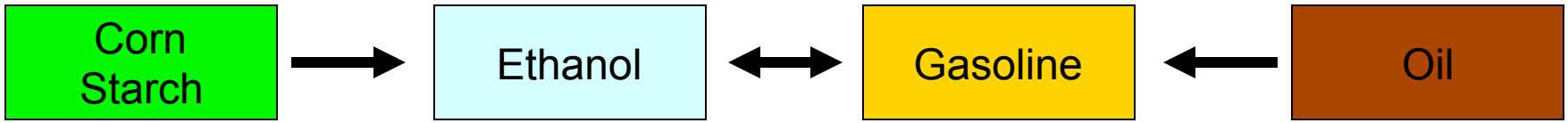
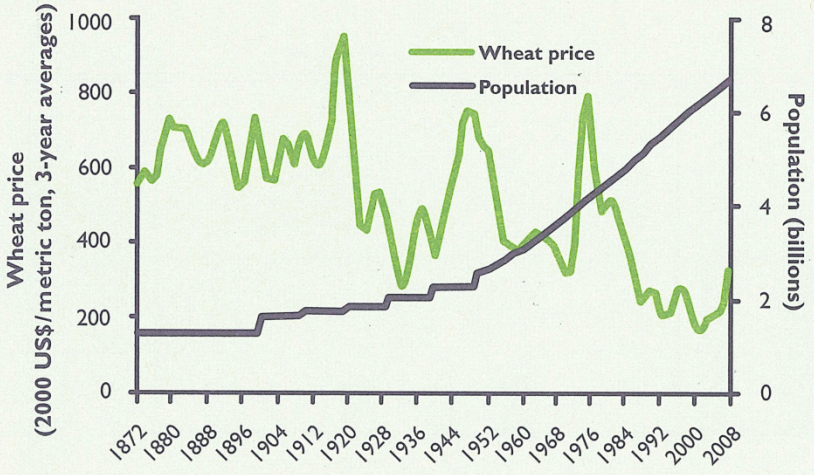
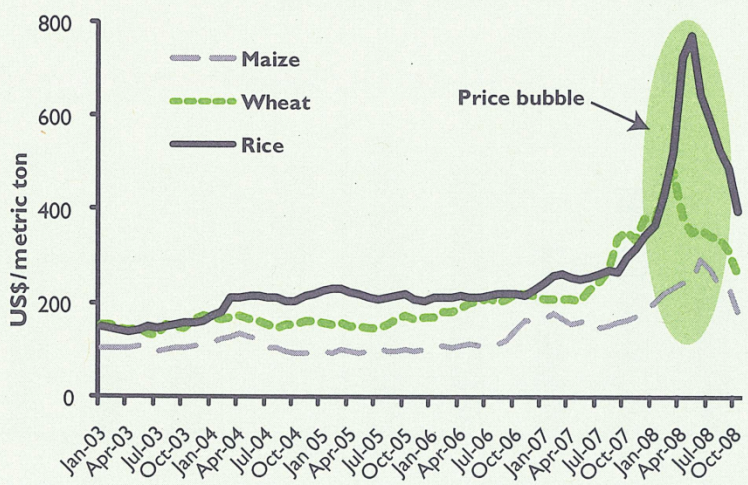


Figure 2—Global food prices in the long and short run

Wheat prices and population, 1872–2008

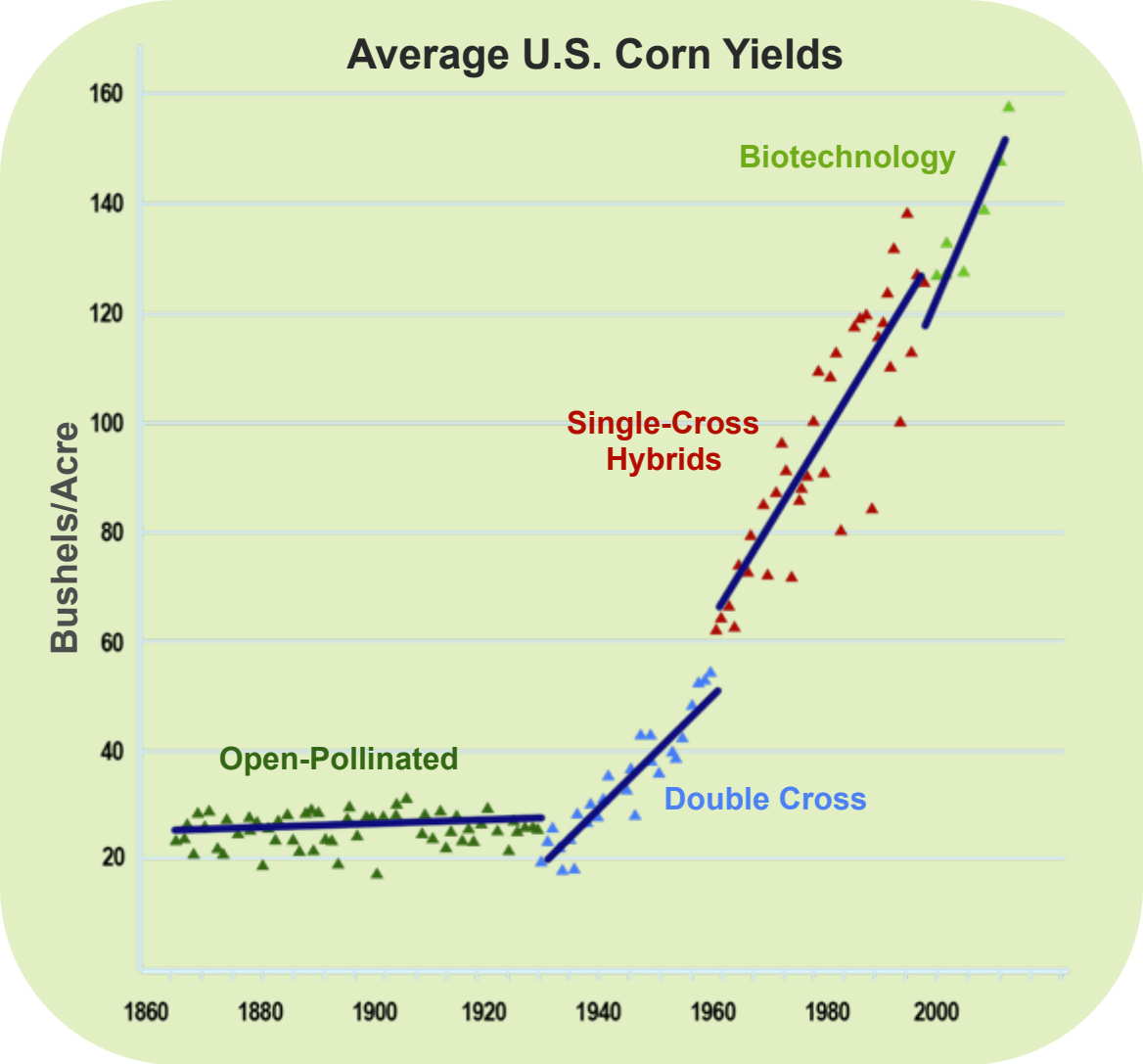


Grain prices, 2003-2008



Sources: The historical data are compiled and interpolated by the author from data from BLS 2008, Godo 2001, NBER 2008, OECD 2005, U.S. Census Bureau 2008, and United Nations 1999; the recent food price data are from FAO 2008a.

Agriculture is NOT Static…



Hybrid genetics & biotechnology have driven a **five-fold increase** in average U.S. corn yields since 1940.

Data Source: USDA

Not Enough Food in the World?

- **Clinically obese (>30%) outnumber malnourished by 2:1 margin (1.6B to 0.8B)**
- **Only 60% of global corn acres are hybrid varieties**
- **Less than 50% of global rice acres are hybrid varieties**
- **Increased yield is the answer for both food and fuel crops**

Incentives, innovation and technology can make it more sustainable

Is Food Too Expensive?

Source: USDA Economic Research Service

The Real "Crime Against Humanity"

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Corn Yield Trends (Bushel Per Acre)			
	1990	2000	2005
World Average	59	70	75
USA	113	137	149
Argentina	60	93	109
China	74	78	80
Brazil	33	47	54
India	23	29	31
Sub-Saharan Africa	22	24	25

Source: Monsanto/Doane Forecast

A Brief History of Life…

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Event	Years Ago
Formation of Earth	4,600,000,000
Unicellular life	3,500,000,000
Photosynthesis	3,000,000,000
Multicellular life	1,000,000,000
Cambrian explosion	600,000,000
Land plants	400,000,000
Flowering plants	150,000,000
K/T extinction	65,000,000
Hominids	7,000,000
End of last Ice Age	18,000
Agriculture	10,000
Green Revolution	40

Agriculture is not "natural", it is a distinctly human activity

Should We Have Agriculture?

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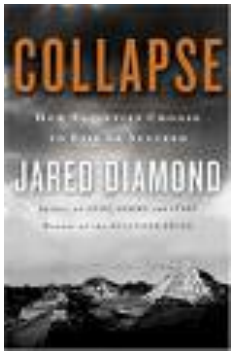
The Worst Mistake In The History of the Human Race

"…a catastrophe from which we have never recovered"

-Jared Diamond



or

Agriculture -The Basis of Civilization

"The single, decisive factor that made it possible for mankind to settle in permanent communities was agriculture"

-Encyclopedia Britannica

Plants Did Not Evolve To Serve Man

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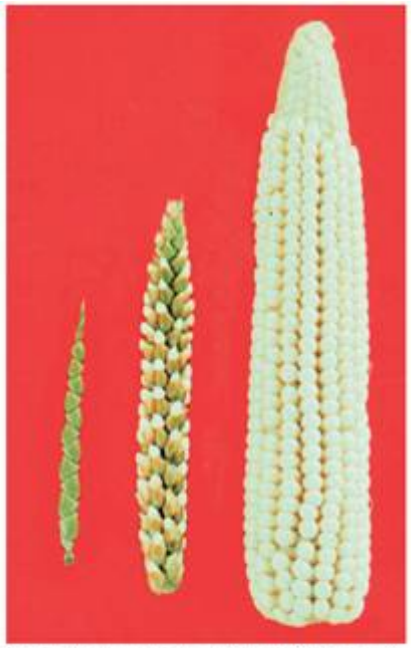


Figure 2. Modern corn hybrid (right), its wild relative teosinte (left), and their hybrid (cob in the center). (Photo kindly provided by John Doebley.)

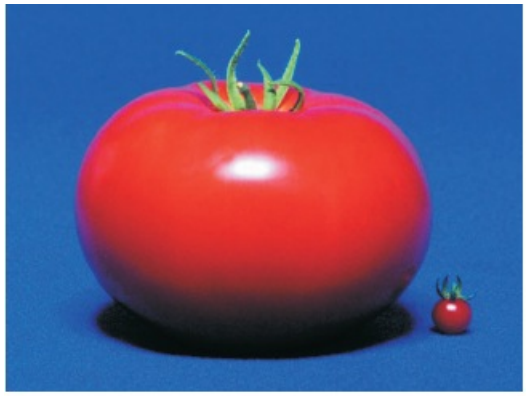
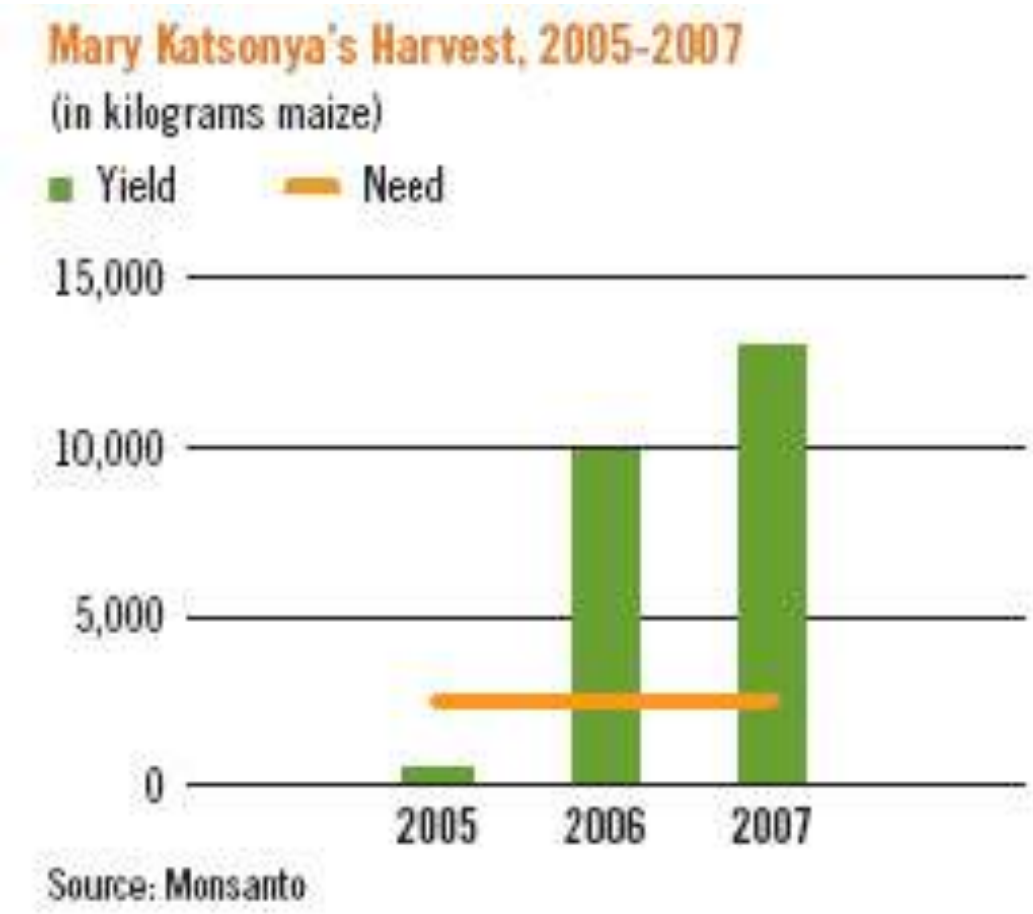


Figure 1. Cultivated tomato (left) and its wild relative *Lycopersicon pimpinellifolium* (right; approximate diameter of smaller tomato = 1 cm). (Photo kindly provided by Steve Tanksley.)

Genetic manipulation or “breeding” has been instrumental

Plant Physiology, May 2001, Vol. 126, pp. 8–15, www.plantphysiol.org © 2001 American Society of Plant Physiologists

A Tale Of One Malawi Farmer…



2005 – Non-hybrid varieties from saved seed

2006 - $70 of hybrid seed and fertilizer

2007 – Chose hybrids, not saved seed

FAO STAT: Malawi maize yields average 1,200 kg/hectare vs. over 8,000 for USA

Is Food A Market Good Or Public Good?

Critics seem to think that U.S. corn farmers should feed the world by producing at or below their production costs…

Yet, no one seriously expects that the Saudis will fuel the world by selling oil at or below their production costs…

Is Food a…

A) Market good

B) Public good

Healthcare, higher education, home ownership?

Beware Malthusian Myths…

"For the great enemy of the truth is very often not the lie – deliberate, contrived and dishonest, but the myth, persistent, persuasive, unrealistic. We enjoy the comfort of opinion without the discomfort of thought."

- John F. Kennedy

The Biggest Drawback of Biofuels is:

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A) They cause food prices to rise
B) They will starve the poor
C) They threaten the world's forests
D) They can't scale
E) They cause childhood obesity

"Farming looks mighty easy when your plow is a pencil, and you are a thousand miles from the corn field."

- Dwight Eisenhower

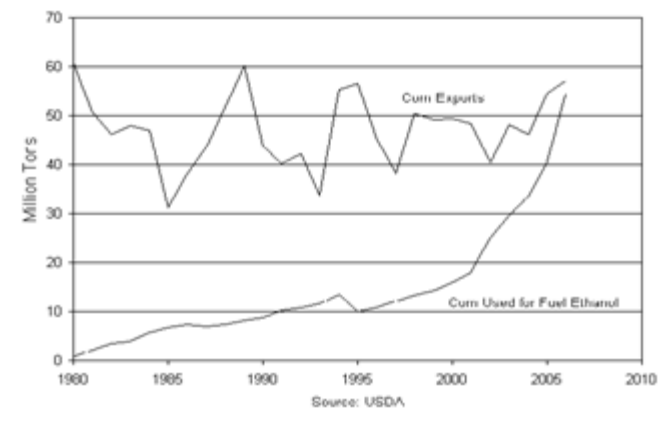
Indirect Land Use Conversion (ILUC)

Are U.S. Farmers….

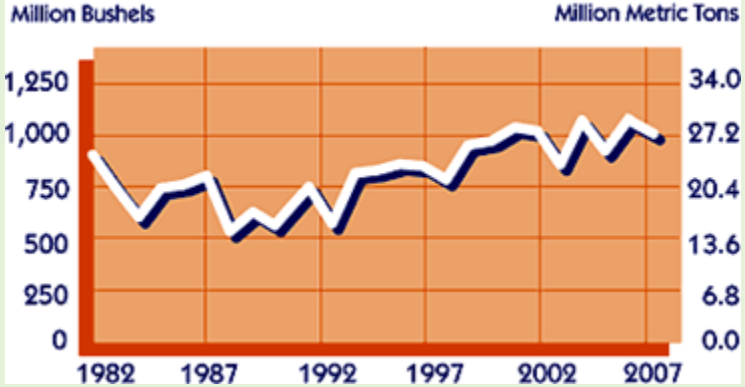
Responsible For Brazilian Deforestation?

Indirect Land Conversion?

U.S. Corn for Ethanol and for Exports



U.S. Soybean Exports



Land use changes are NOT driven by lack of US grain exports or increased US ethanol production

A Few Problems With ILUC Models….

- **Conventional wisdom**
  - CW on biofuels has proven to be wrong. Current ethanol production volumes are not driving up food prices; oil prices drive food prices.

- **"The Science is settled"**
  - Science is generating hypotheses, testing them against the available data and choosing those that best fit the data. ILUC models (hypotheses) do NOT fit the historical data (they do not backcast) and should not be used to forecast nor referred to as "science".

- **Yield, yield & yield**
  - ILUC models dramatically underestimate potential increases in global agricultural yield and productivity e.g. 700% corn yield increases in Africa

- **Follow the money**
  - ILUC models hold U.S. producers economically responsible for foreign land owner's use decisions

- **Will ILUC penalties slow deforestation? – Highly unlikely**
  - All land use change is direct and land owners (like the Brazilian government) should be held directly responsible. Think coffee, orange juice, chicken, cattle, soybean, banana, etc. Penalize these, not U.S. biofuels producers

Indirect Land Use Impact?

Worlds largest photovoltaic installation in Waldpolenz Solar Park, Germany…
Where did all the trees go? Shouldn't we be using the land to grow food?

If You Were A Bird, Would You Prefer….

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Bird nest woven into a switchgrass stand growing in northern Georgia.

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Some thoughts on Agriculture…

Should We Have Agriculture?

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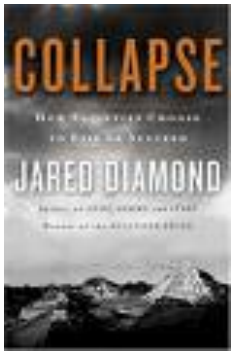

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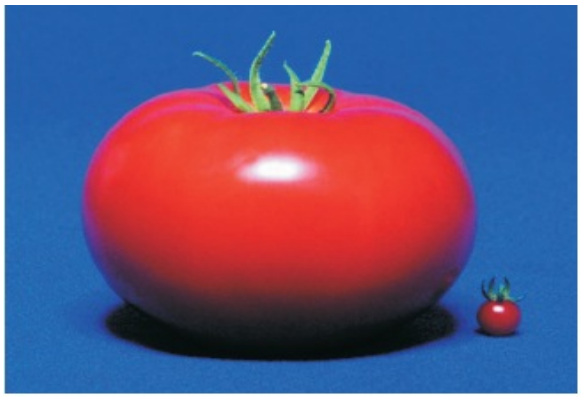

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Plant Physiology, May 2001, Vol. 126, pp. 8–15, www.plantphysiol.org © 2001 American Society of Plant Physiologists

What Limits Crop Yields?

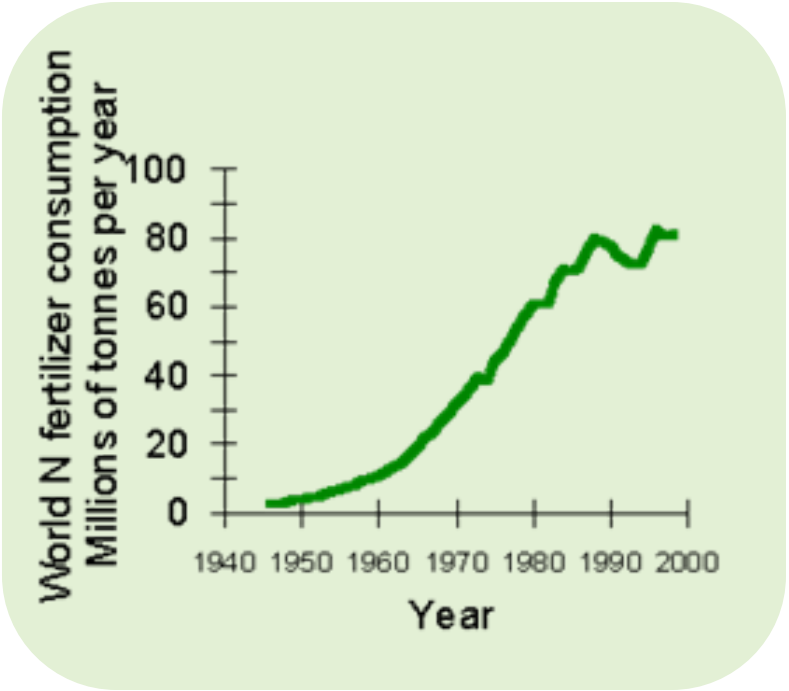
- **Germplasm**
  (genetics)

- **Biotic stress**
  - Weeds
  - Insects
  - Fungi

- **Abiotic stress**
  - Drought
  - Nitrogen
  - Temperature

Agriculture Is Not Perfect…

- Loss of biodiversity
- Energy inputs
- Nitrogen run off



But It Can Feed Many People

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One bushel of corn produces 92,797 calories

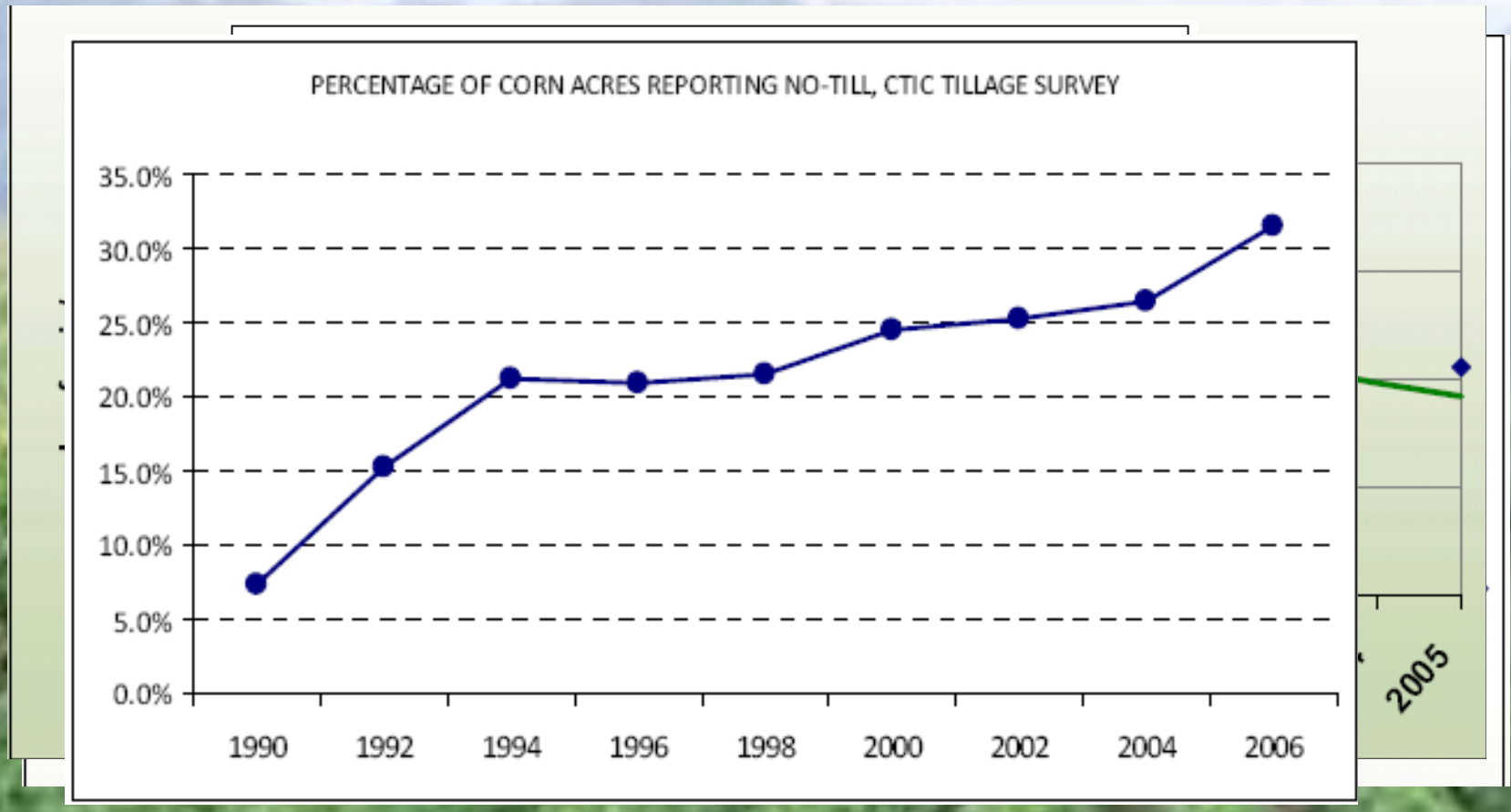
One human requires 1,800 calories per day

- IF *only* the world's corn farmers (146M hectares) achieved the US *average* yield (358 bu/ha) = we could feed 7.46B on corn alone

- IF all the world's corn farmers duplicated the top 10% of US corn yields (~700 bu/ha in 2006) = we could feed over 14B people on corn alone

Incentives, innovation and technology can make it more sustainable

Technology: More Yield / Less Impact



Source: NCGA

Food versus Fuel versus Corn glut…

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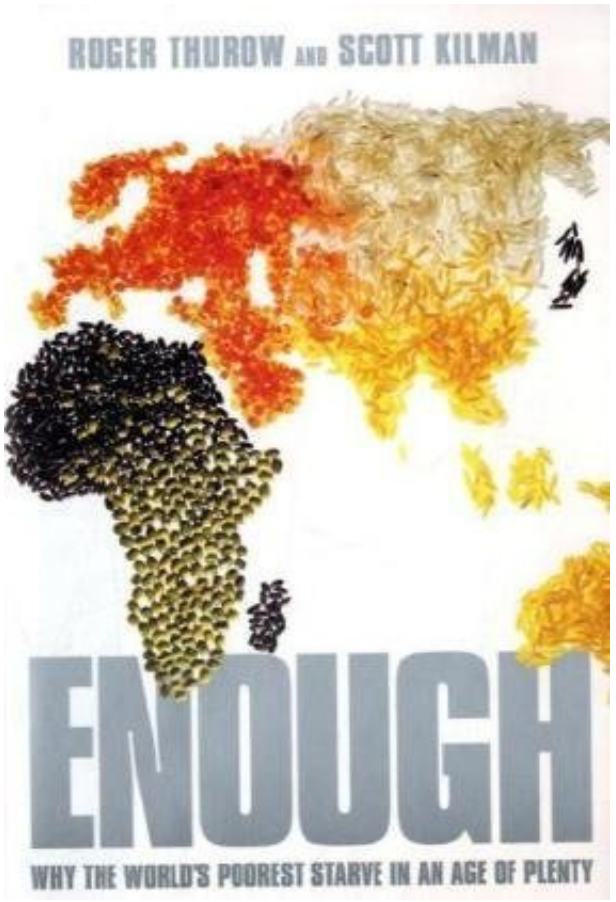
USDA Report: Farmers Shatter Corn Production Records on Fewer Acres

(January 12, 2010) Washington – The final report from the U.S. Department of Agriculture on the 2009 corn harvest is one for the record books. Despite poor planting conditions, a cool, wet growing season, and an abysmal harvest that still sees corn standing in fields, American farmers shattered records for both yield per acre and total production.

In the January Crop Production report, USDA estimates farmers averaged 165.2 bushels of corn per acres, up from its previous estimate of 162.9 and shattering the previous record of 160.4 in 2004. Notably, average yields are more than 11 bushels per acre higher (7 percent) than last year's average yield. In addition, this record yield helped produce the largest corn crop ever – 13.2 billion bushels. All of this occurred despite one of the slowest and most challenging harvests on record.

Farm Productivity and Poverty



Hunger is caused by poverty…not a lack of crop land

What Is Biotechnology?

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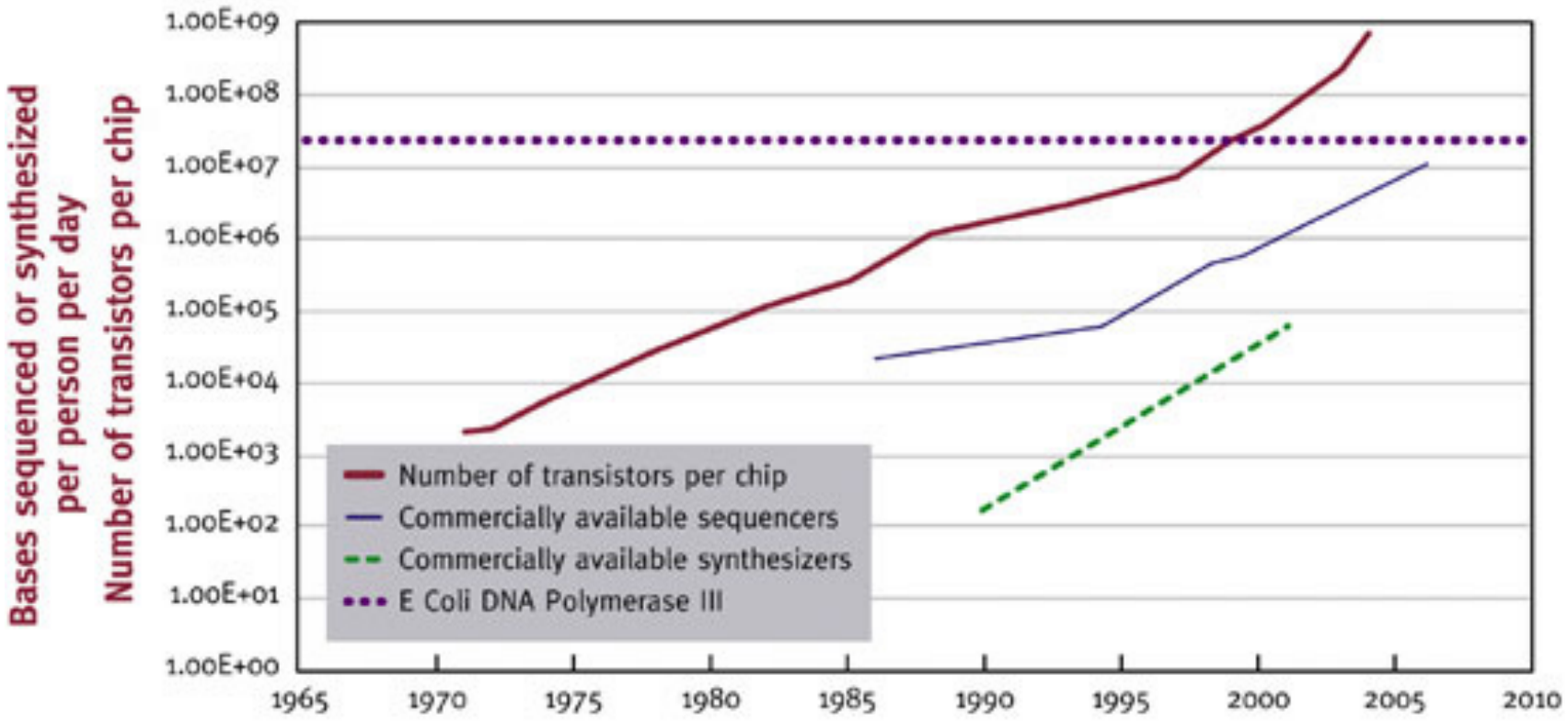
Genetic engineering or recombinant DNA technology to directly alter the structure and characteristics of genes, circa 1980's

Genomics - the study of an organism's entire genome by determining the entire DNA sequence of organisms and fine-scale mapping efforts, circa 1990's

Marker assisted selection or **breeding** is a process whereby a DNA marker (morphological, biochemical or one based on DNA/ RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest, circa 2000

Synthetic biology – genetic engineering on an organism-level scale. Combines molecular biology and engineering principles to design and build ("synthesize") novel biological functions and systems, circa 2010

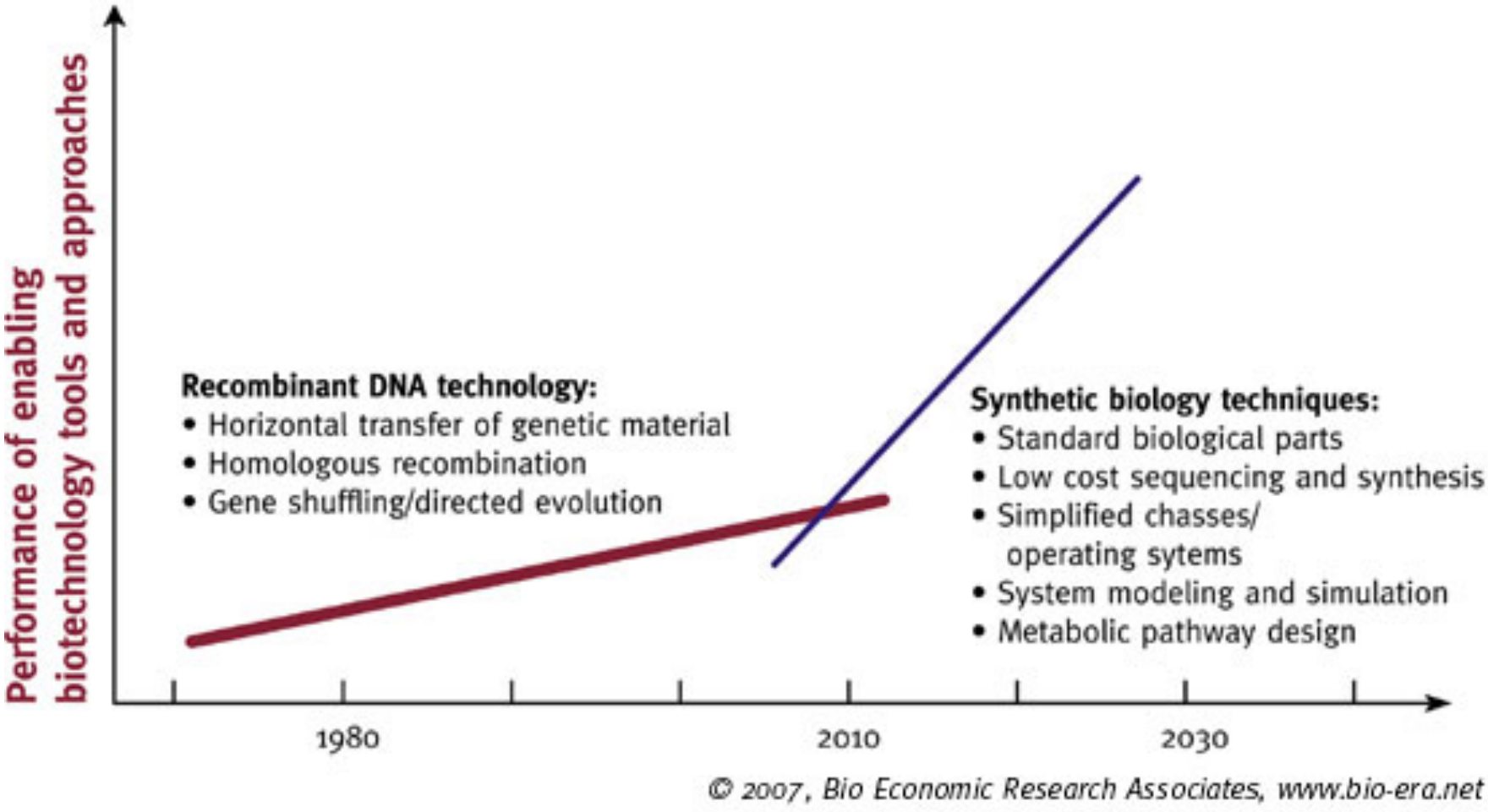
Technology Improves…



Source: R. Carlson, Bio-era

© 2007, Bio Economic Research Associates, www.bio-era.net

And Accelerates…

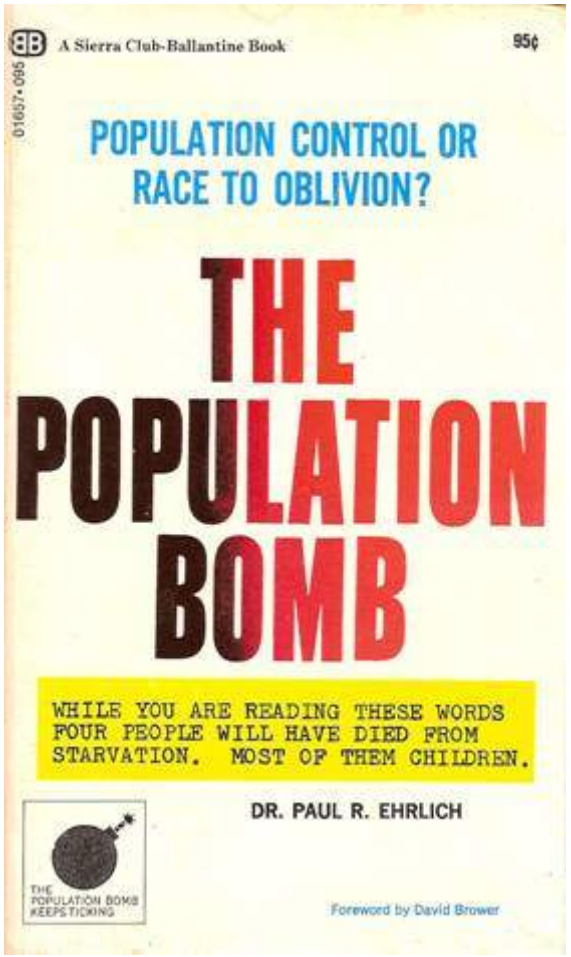


Essay On The Principle of Population

Thomas Robert Malthus
1766 - 1834

"The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race…"

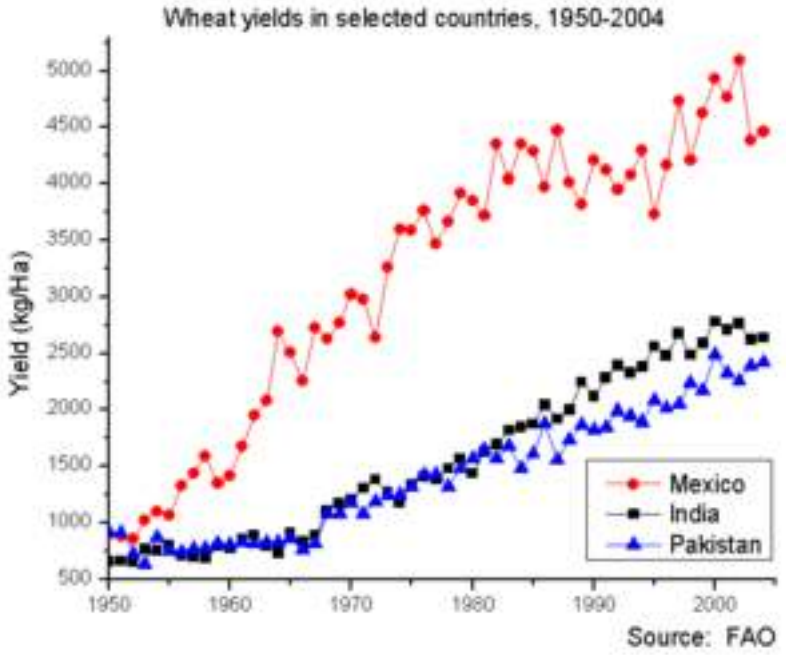
Some Predictions in 1968…



- "the battle to feed all of humanity is over”
- “In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now."
- "India couldn't possibly feed two hundred million more people by 1980,"
- "I have yet to meet anyone familiar with the situation who thinks that India will be self-sufficient in food by 1971."

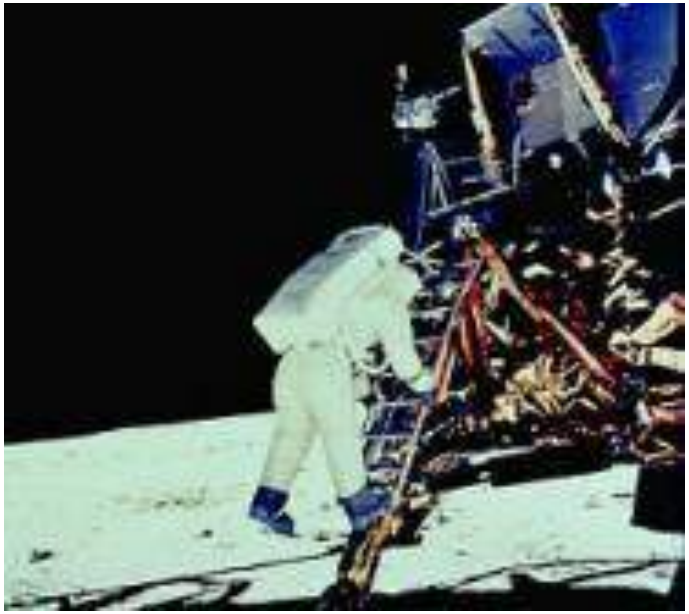
Other activities in 1968…

Nobel Laureate Dr. Norman Borlaug



Innovation is game changing…

The Best Way to Predict the Future…

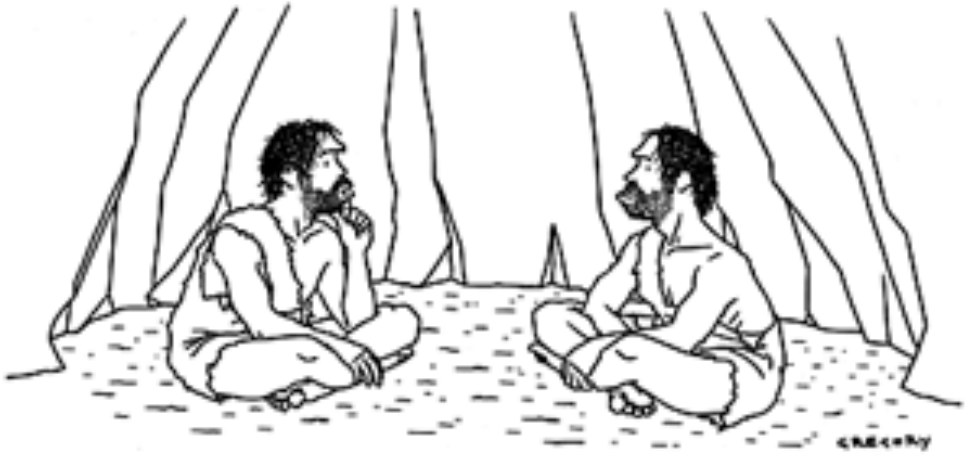


December 17, 1903 ⟵ 66 yrs ⟶ July 20, 1969

…is to create it!

Look Forward, Not Backwards

© Cartoonbank.com



"Something's just not right—our air is clean, our water is pure, we all get plenty of exercise, everything we eat is organic and free-range, and yet nobody lives past thirty."

Some "Recent" Events…

- 1900 - Rediscovery of Mendel's Laws
- 1935 - Hybrid genetics
- 1953 - Structure of DNA
- 1983 - Biotechnology in plants
- 1995 - Marker-assisted breeding
- 2001 - First plant genome sequenced

- What will the next 66 years bring?

Some Predictions…by a Techno-Optimist

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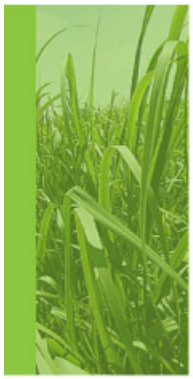
- **Near term**
  - Accelerated yield increases from markers
  - Broader adoption of hybrids
  - Drought tolerance (<5 yrs)
  - Improved nitrogen use efficiency (<10 yrs)



- **Mid-term**
  - Doubling of average US corn yields by 2030
  - Quadrupling of global grain yield averages by 2030

- **Long Term** (within the next 66 years…)
  - Nitrogen fixing grain crops
  - Perennial grain crops

- All will require genetic manipulation; breeding, markers, mapping, genomics, transgenes, cisgenes and…R&D funding, political will, positive regulatory environments

In the Future….

We will get most of our transportation fuels from:

A) Electric cars
B) Hydrogen
C) Conventional oil and gas
D) Biofuels
E) Hot air from UCLA professors

"The history of every nation is eventually written in the way in which it cares for its soil."

- Franklin D. Roosevelt

Switchgrass has a Expansive Root System

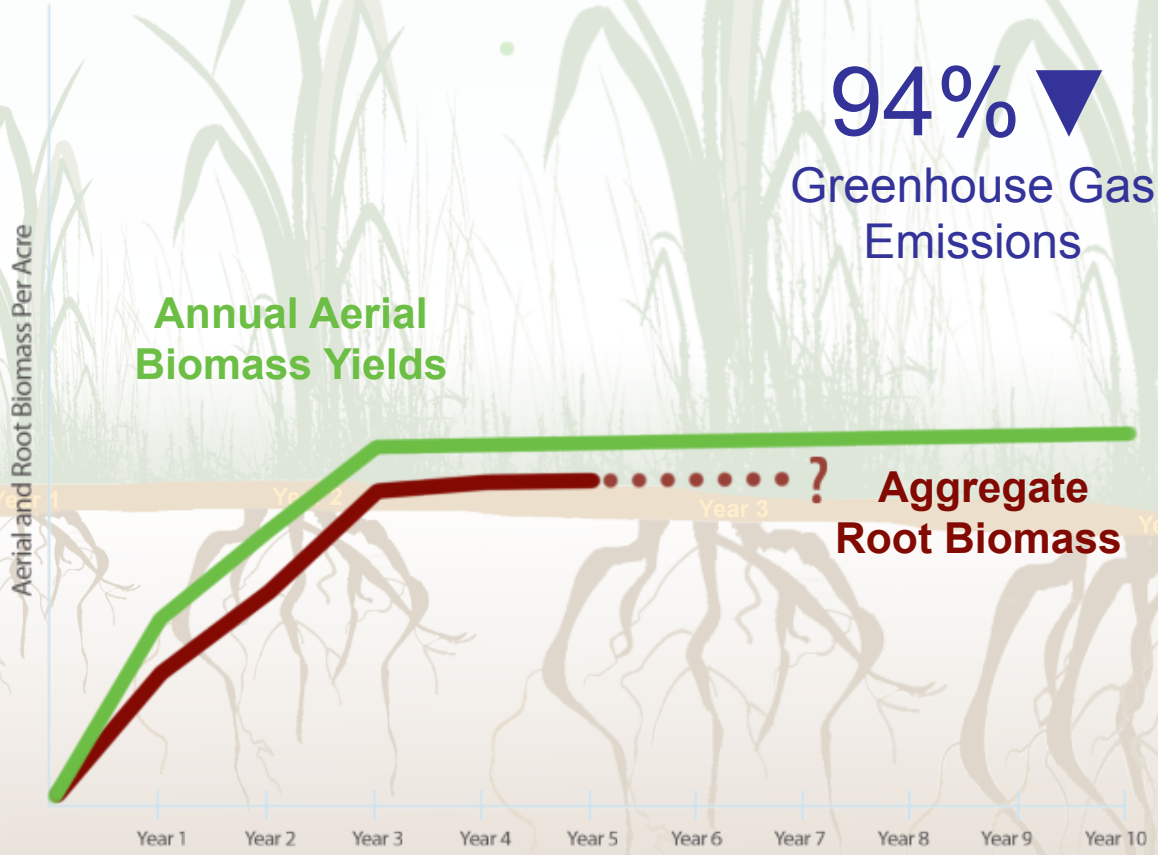
Photo courtesy of The Land Institute

Carbon-Negative Energy Crop Systems?

94% ▼
Greenhouse Gas Emissions

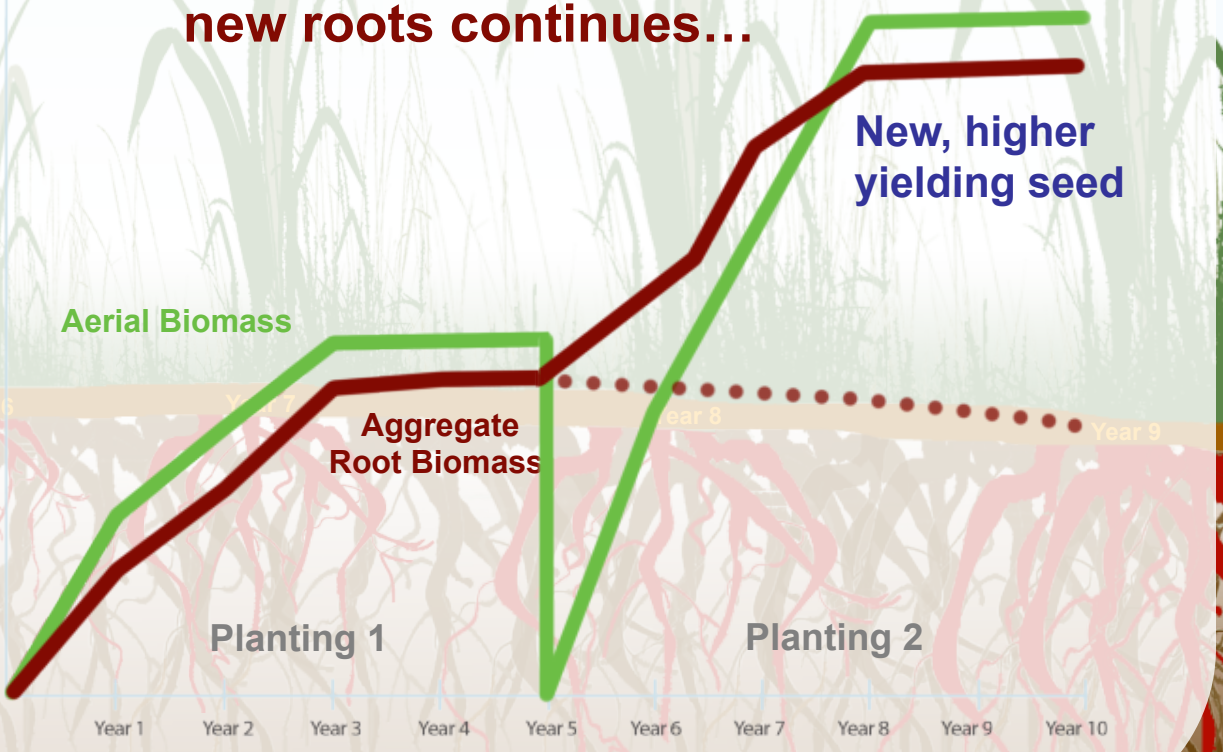
Annual Aerial Biomass Yields

Aggregate Root Biomass



Repeat No-Till Planting Over Old Roots

Increases in soil organic carbon from new roots continues…



A Good Start…

Soil Carbon Storage by Switchgrass Grown for Bioenergy

M. A. Liebig · M. R. Schmer · K. P. Vogel · R. B. Mitchell

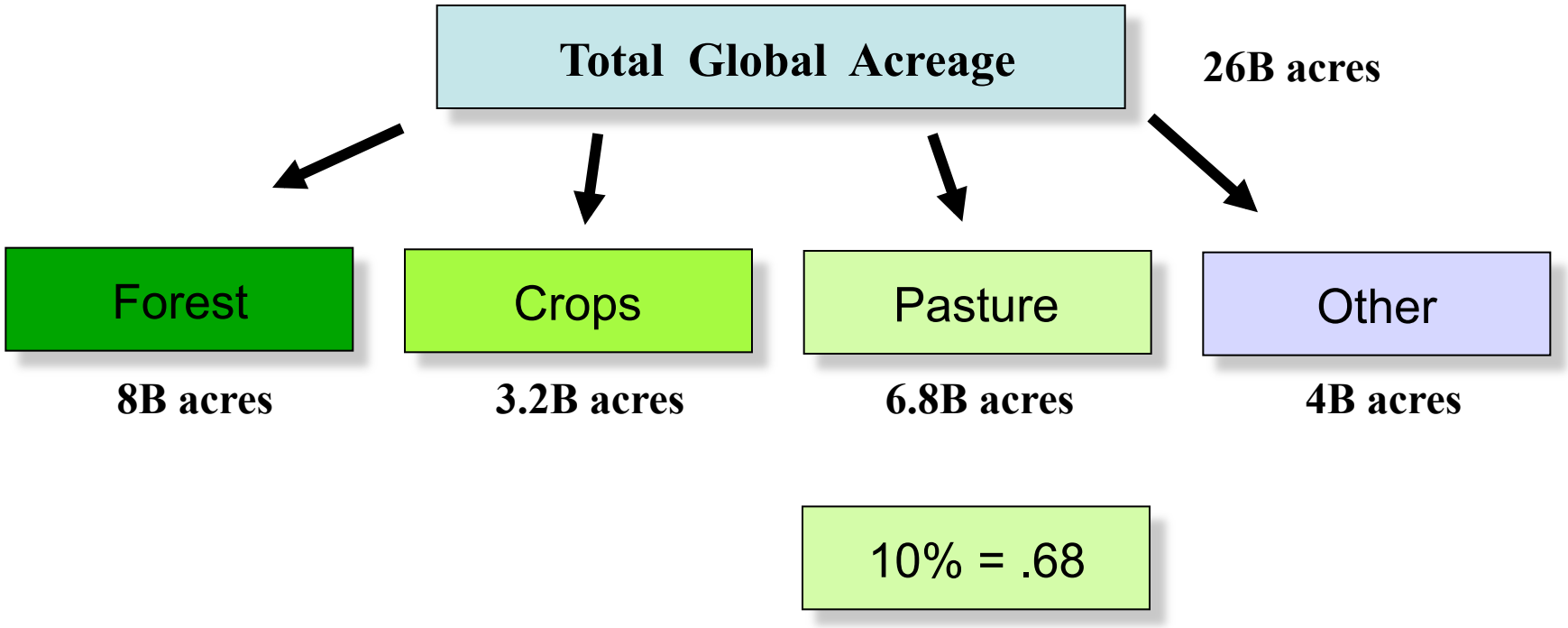
Abstract Life-cycle assessments (LCAs) of switchgrass (*Panicum virgatum* L.) grown for bioenergy production require data on soil organic carbon (SOC) change and harvested C yields to accurately estimate net greenhouse gas (GHG) emissions. To date, nearly all information on SOC change under switchgrass has been based on modeled assumptions or small plot research, both of which do not take into account spatial variability within or across sites for an agro-ecoregion. To address this need, we measured change in SOC and harvested C yield for switchgrass fields on ten farms in the central and northern Great Plains, USA (930 km latitudinal range). Change in SOC was determined by collecting multiple soil samples in transects across the fields prior to planting switchgrass and again 5 years later after switchgrass had been grown and managed as a bioenergy crop. Harvested aboveground C averaged 2.5 ± 0.7 Mg C ha^{-1} over the 5 year study. Across sites, SOC increased significantly at 0–30 cm (P=0.03) and 0–120 cm (P=0.07), with accrual rates of 1.1 and 2.9 Mg C ha^{-1} $year^{-1}$ (4.0 and 10.6 Mg CO_2 ha^{-1} $year^{-1}$), respectively. Change in SOC across sites varied considerably, however, ranging from −0.6 to 4.3 Mg C ha^{-1} $year^{-1}$ for the 0–30 cm depth. Such variation in SOC change must be taken into

Current cultivars with existing management practices have been shown to sequester ~5 tons/acre/year

Further research is necessary to understand what is possible with improved genetics and new cultivation strategies

Bioenerg. Res. (2008) 1:215–222
DOI 10.1007/s12155-008-9019-5

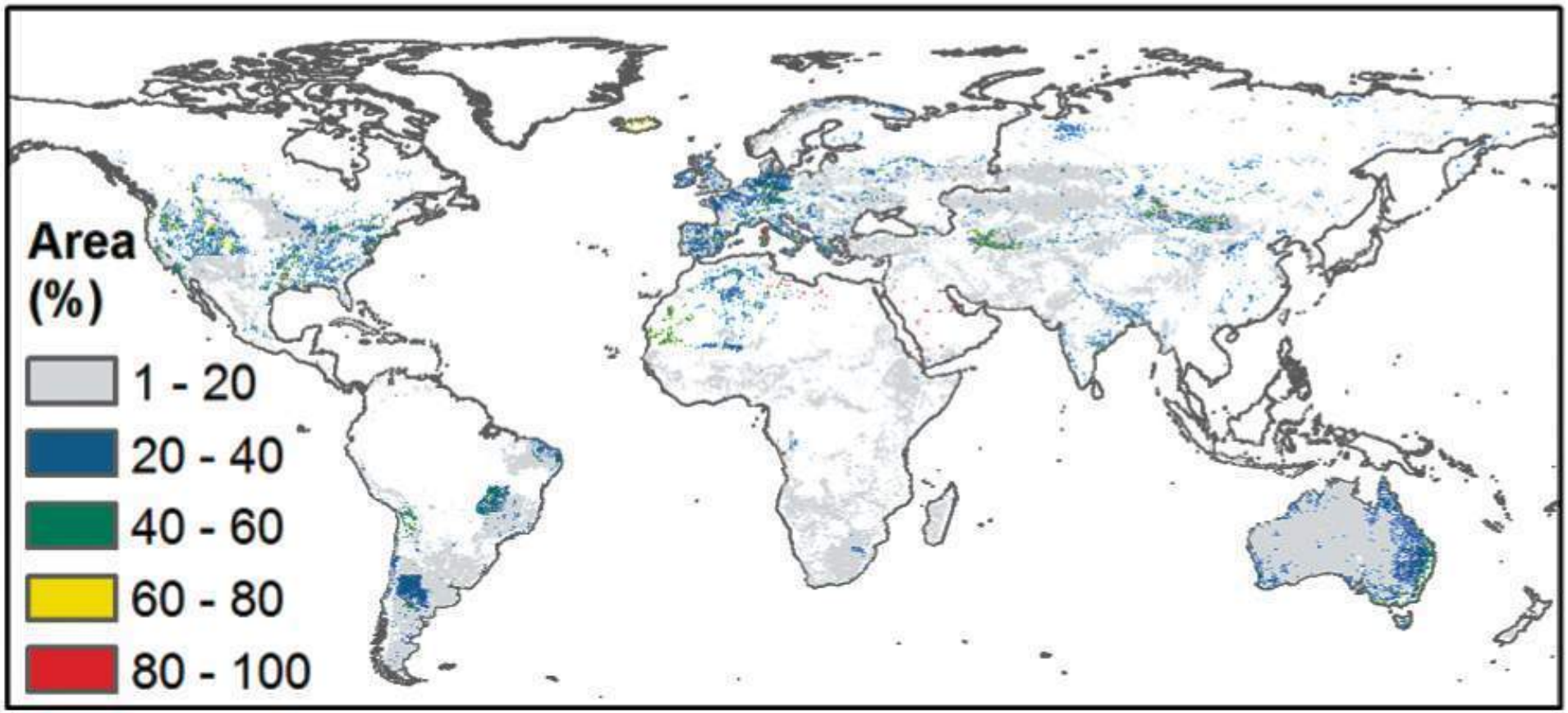
Not Enough Land For Biomass?



0.675B acres X 20t/ac X 2.38B/t = 88M barrels per day

Source: FAO Stat database

>>A Billion Acres Of Abandoned Agricultural Land



Campbell et al., Env. Sci. Technol. (2008) **ASAP Article**, 10.1021/es800052w

Feedstocks Are All Fungible?

- Is there such a thing as a non-food acre?
- Does food = feed = fiber = fuel?
- Is energy production an illegitimate use of land?

- Most of the corn in the grocery store…is in the meat aisle

Cellulosic biorefineries

J. Benemann, 5th Annual World Congress on Industrial Biotechnology, Chicago, April 30, 2008

99% of Algae is grown for food…

Food, Feed or Fuel?

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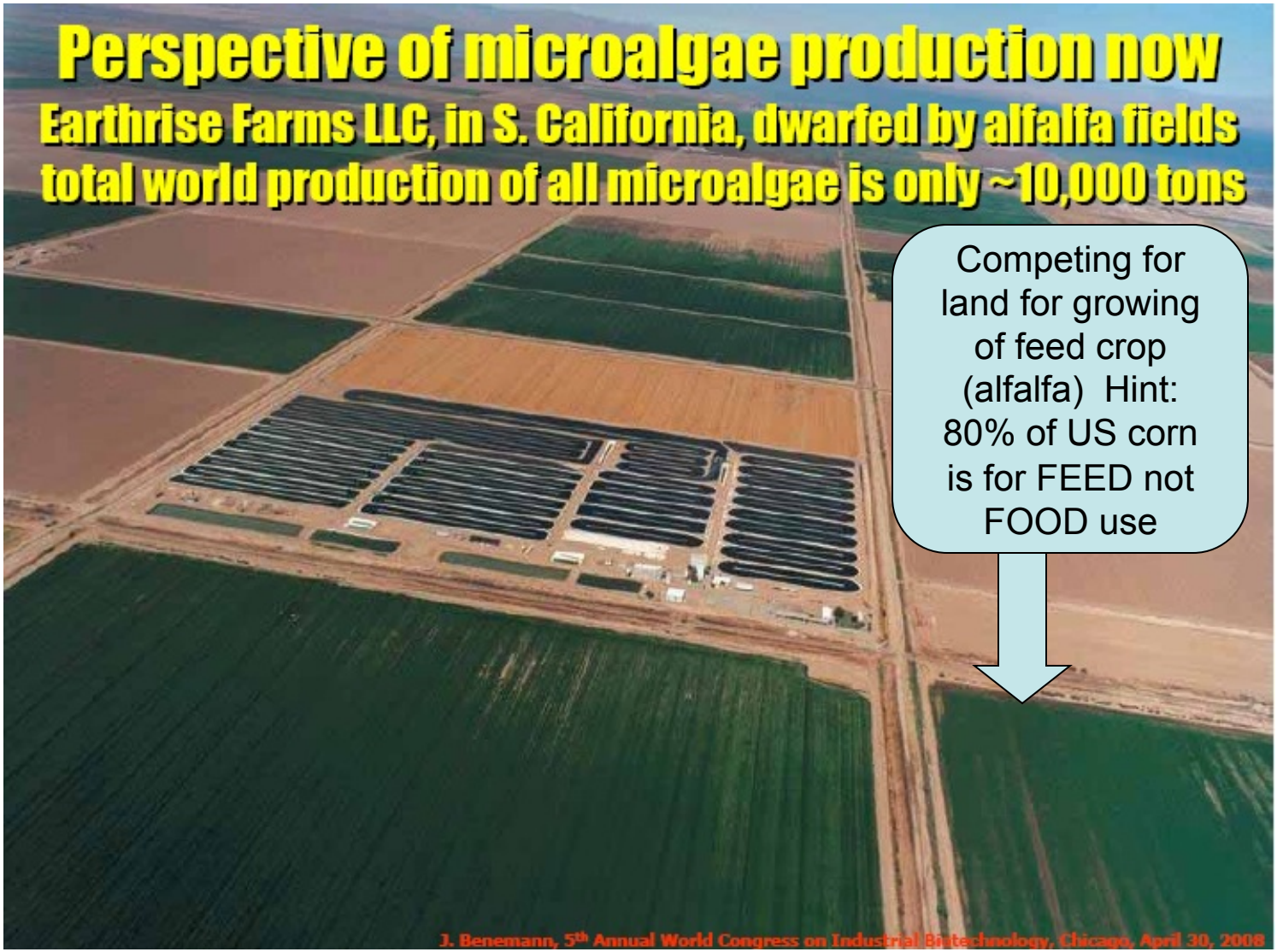
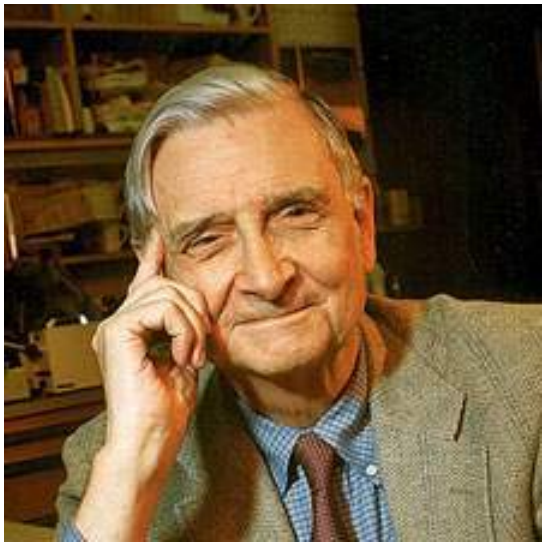
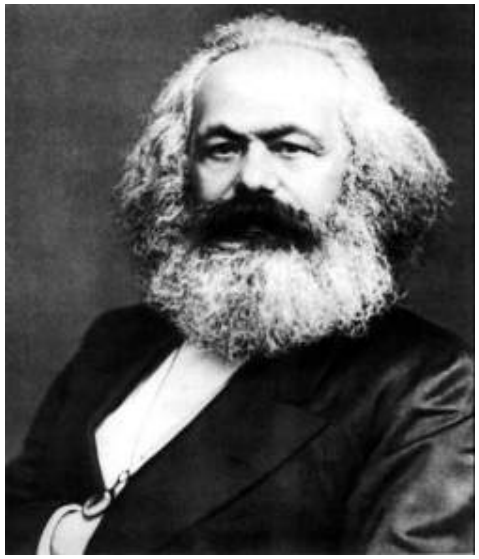


Where is Humanity Headed?



E.O. Wilson



Karl Marx

"Wonderful theory…wrong species"

Two Different Visions of the Future

- A global population of 10 billion (grandchildren)
- High protein diets (meat)
- Personal mobility (cars)
- Energy availability (power)

- A global population of ~1 billion
- Vegan diets
- Limited mobility
- Limited power

"Wonderful theory…wrong species"

Start With The End In Mind?

- If Scenario A is correct, where do we need to make investments?
  - Agricultural productivity
  - Agricultural sustainability
  - Inexpensive low-carbon power
  - Advanced biofuels (Hint: no electric jets…)
- If Scenario B is correct?
  - Massive sterilization and mandatory birth control
  - Religion-based dietary restrictions

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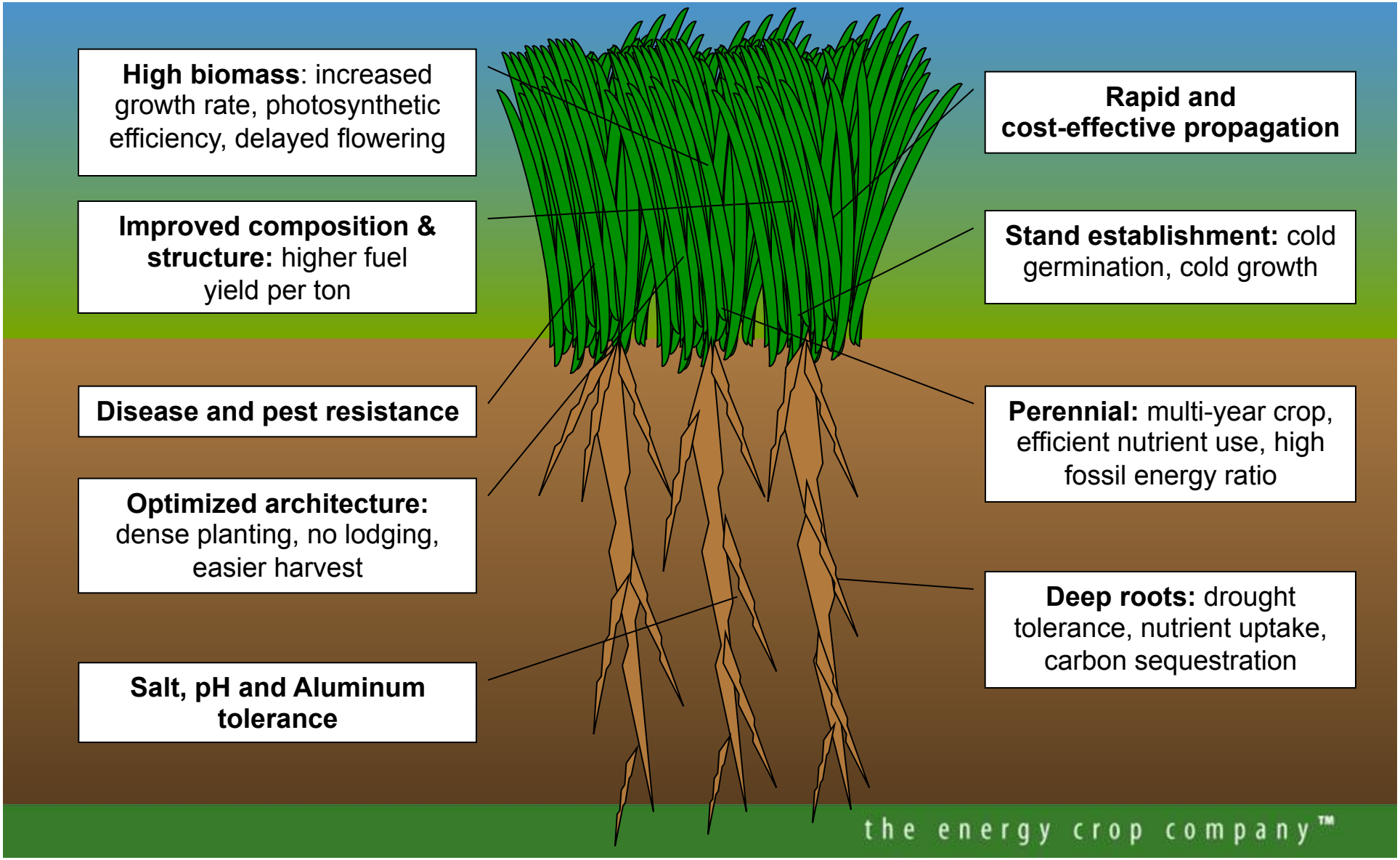
Building a Better Biofuel

www.ceres.net

The Perfect Energy Crop



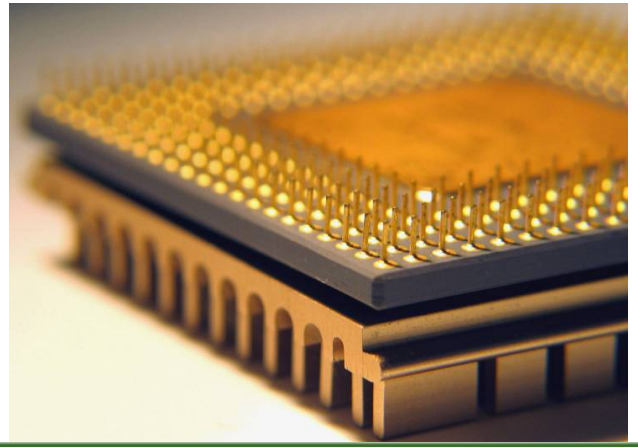
A Third Technological Revolution

"Changes that will have effects comparable to those of the Industrial Revolution and the computer-based revolution are now beginning. The next great era, a genomics revolution, is in an early phase.

Thus far, the pharmacological potentials of genomics have been emphasized, ***but the greatest ultimate global impact of genomics will result from the manipulation of the DNA of plants****.*

Ultimately, the world will obtain most of its food, fuel, fiber, chemical feedstocks, and some of its pharmaceuticals from genetically altered vegetation and trees."

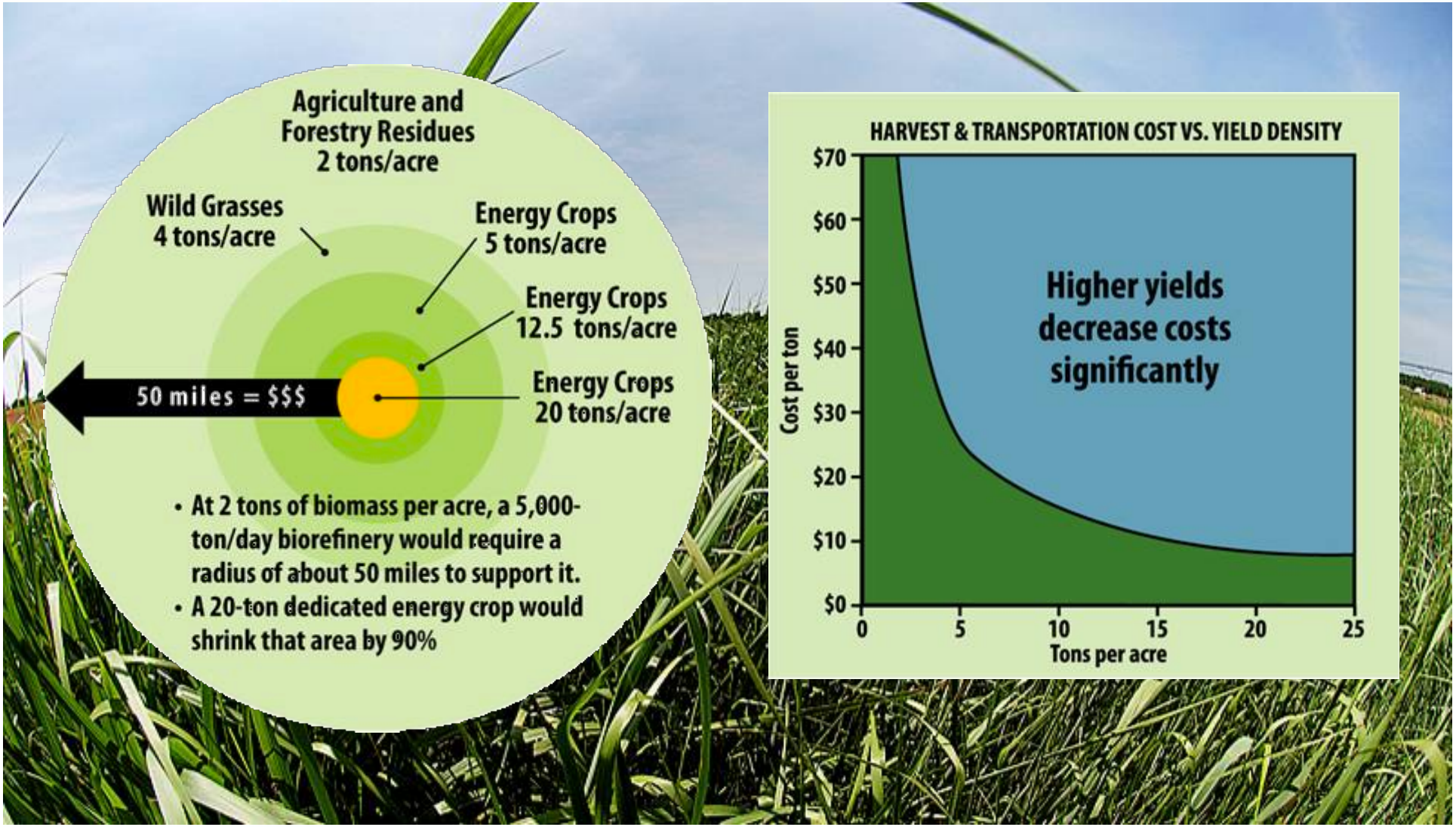
Philip H. Abelson, Editor
Science, March 1998



Plant Genomics is Game Changing

Parts of the Equation	Relevant Traits	Impact
Acres	• Stress tolerance	• Marginal acreage
Tons per acre	• Increased yield	• Cut production and transport costs; • Increased carbon sequestration
Dollars per acre	• Nutrient requirements	• Lower fertilizer costs • Less N_2O emissions
Gallons per ton	• Composition & structure	• Increase yield of fuel per ton of biomass
Capital cost of refinery & variable cost per gallon	• Composition, structure & enzyme production	• Eliminate need for acid hydrolysis, • Less enzymes • Bring yields closer to theoretical
Co-products	• Metabolic engineering & sequestration	• Enhance overall economics

Biomass Yield Matters



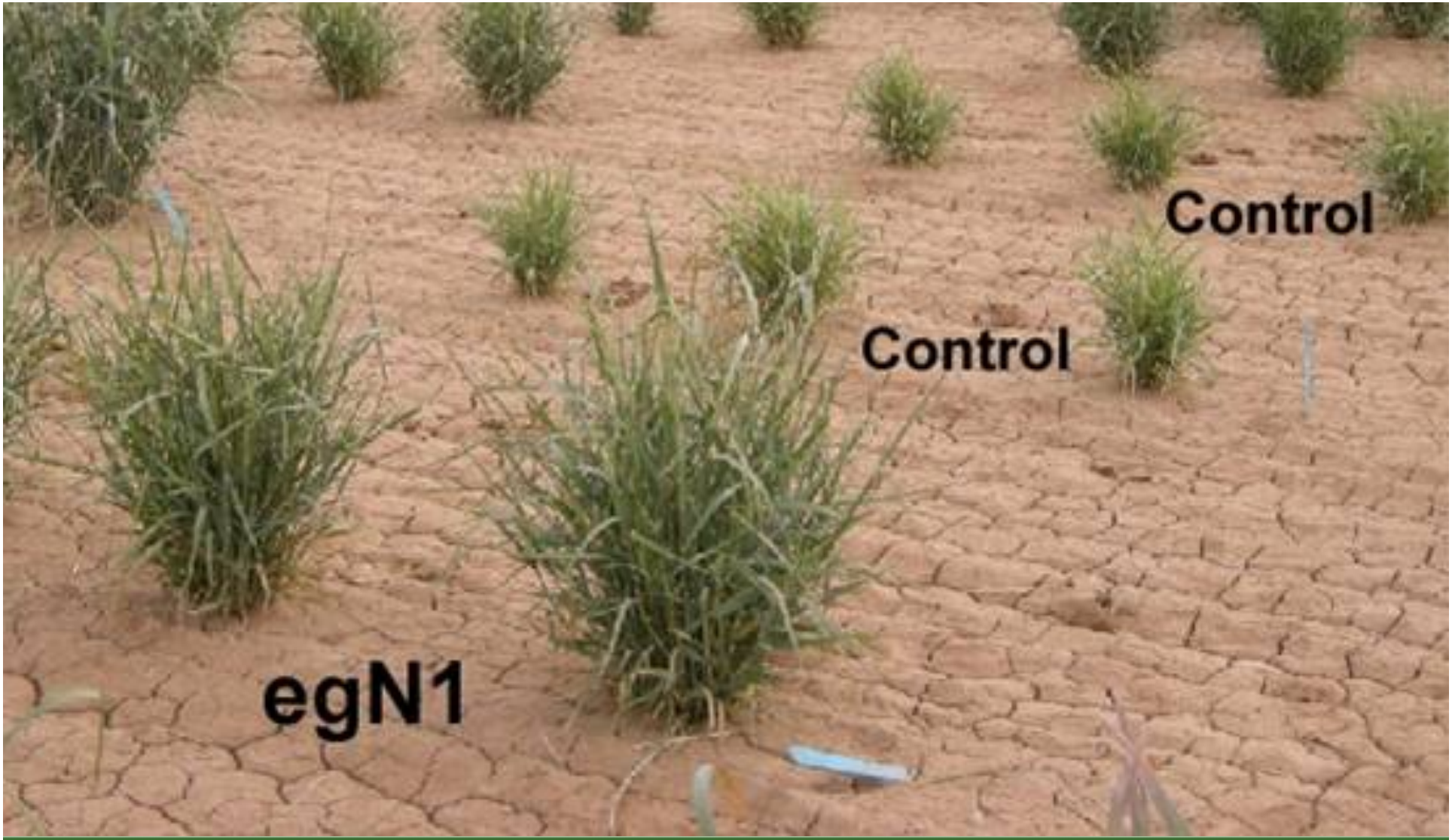
*graphic not to scale

Ceres Has Applied Genomics to Dramatically Increase Plant Biomass

Wild-type Improved

- Ceres has identified **>1,000 genes** that affect plant biomass
- Many are being field tested in rice, a grass model for energy crops
- Energy crop transformation and field testing is in progress

Nitrogen Use Efficiency and Biomass in Switchgrass



Salt-Tolerant Switchgrass (~seawater)

Decaying Roots

Healthy Roots

Trait: Drought-Tolerance in Switchgrass

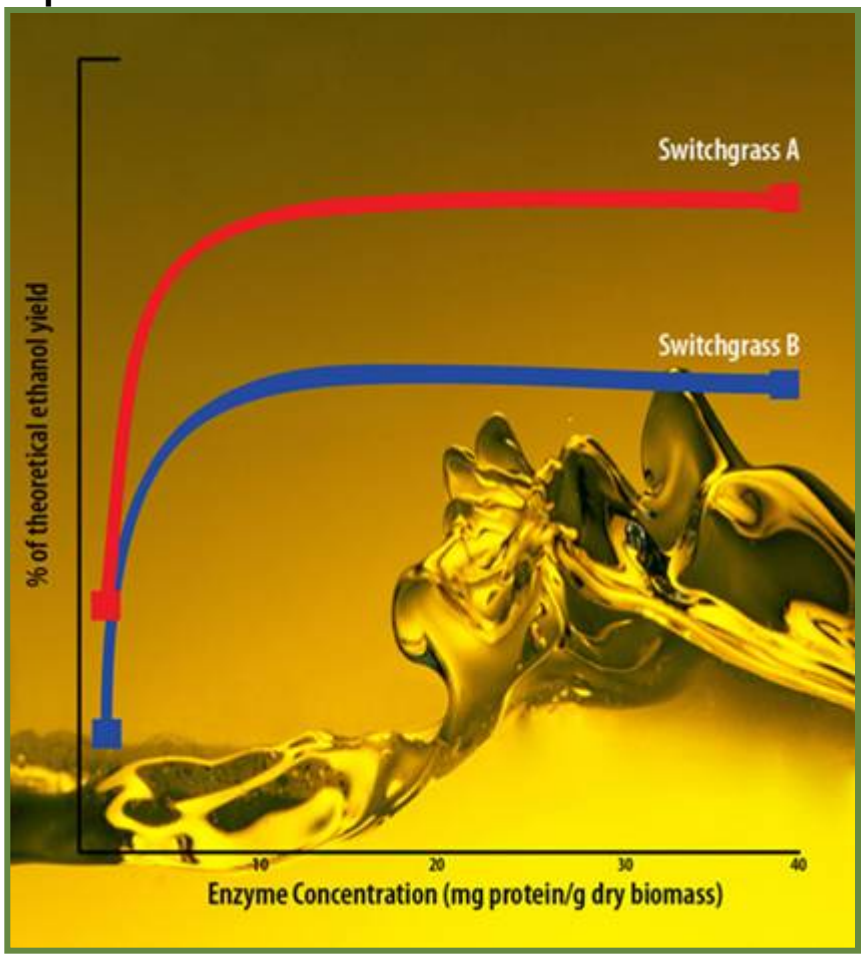
Securing high yields on marginal land

Time-Lapse Photography Over Two Days

Control ***Drought-Tolerance Trait***

Improved Biomass Composition & Conversion

Impact of Different SWG Cultivars on Conversion



Increasing enzyme concentration does not overcome differences in biomass composition in this assay

- **Crop Variations**
  - Composition, processing performance and energy content
- **Impact**
  - Increased productivity
  - Reduced enzyme cost
  - Reduced capital costs

Switchgrass

- Indigenous prairie grass
- Well adapted to US
- Perennial
- Propagates from seed
- Low input requirements
- Current yields ~10 t/acre

High-Biomass Sorghum

- High first year yields
- Annual
- Drought tolerant
- High seed yield
- Propagates from seed
- Yields of ~15 t/acre

Miscanthus

- Asian grass
- Hybrid
- Sterile
- Low nitrogen requirements
- Propagates from cuttings

First Energy Crop Seed Brand

We Work with Large End-Users to Establish Closed-Loop Biomass Systems

Big Cajun II Generating Station, New Roads, LA

In the Future….

We will get most of our transportation fuels from:

A) Electric cars
B) Hydrogen
C) Conventional oil and gas
D) Biofuels
E) Hot air from UCLA professors

In the Future….

Societies should embrace the use of plant biotechnology to increase crop yields for food, feed, fiber and fuel:

A) Yes

B) No

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Thank You

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Biomass as a Renewable Reserve

21 year contract

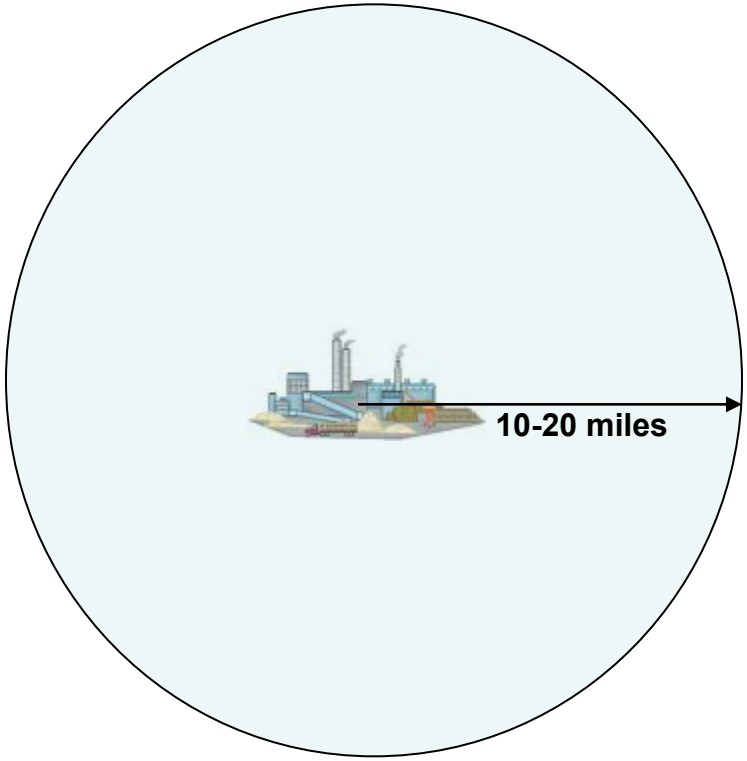
20 tons / acre

100 gallons per ton

= 4.2 X 10^4 gallons/acre

42 gallons per barrel

= 1,000 barrels per acre



How many biorefineries, how many acres on a global basis?

Hint: >16M US corn acres currently used for biofuel production

Biomass as Renewable Reserves

1 acre	=	1,000 barrels of oil*
10M acres	=	10 billion barrels

	Proven Reserves (billion barrels)
Exxon Mobil	22.20
BP	18.50
Royal Dutch Shell	12.98
Chevron	9.95
Conoco Phillips	7.60

* Assumes 21 yr contract
Source: Energy Intelligence (data as of end of 2004)