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….seeding a sustainable future

Plant Biotechnology and Cellulosic Ethanol Production

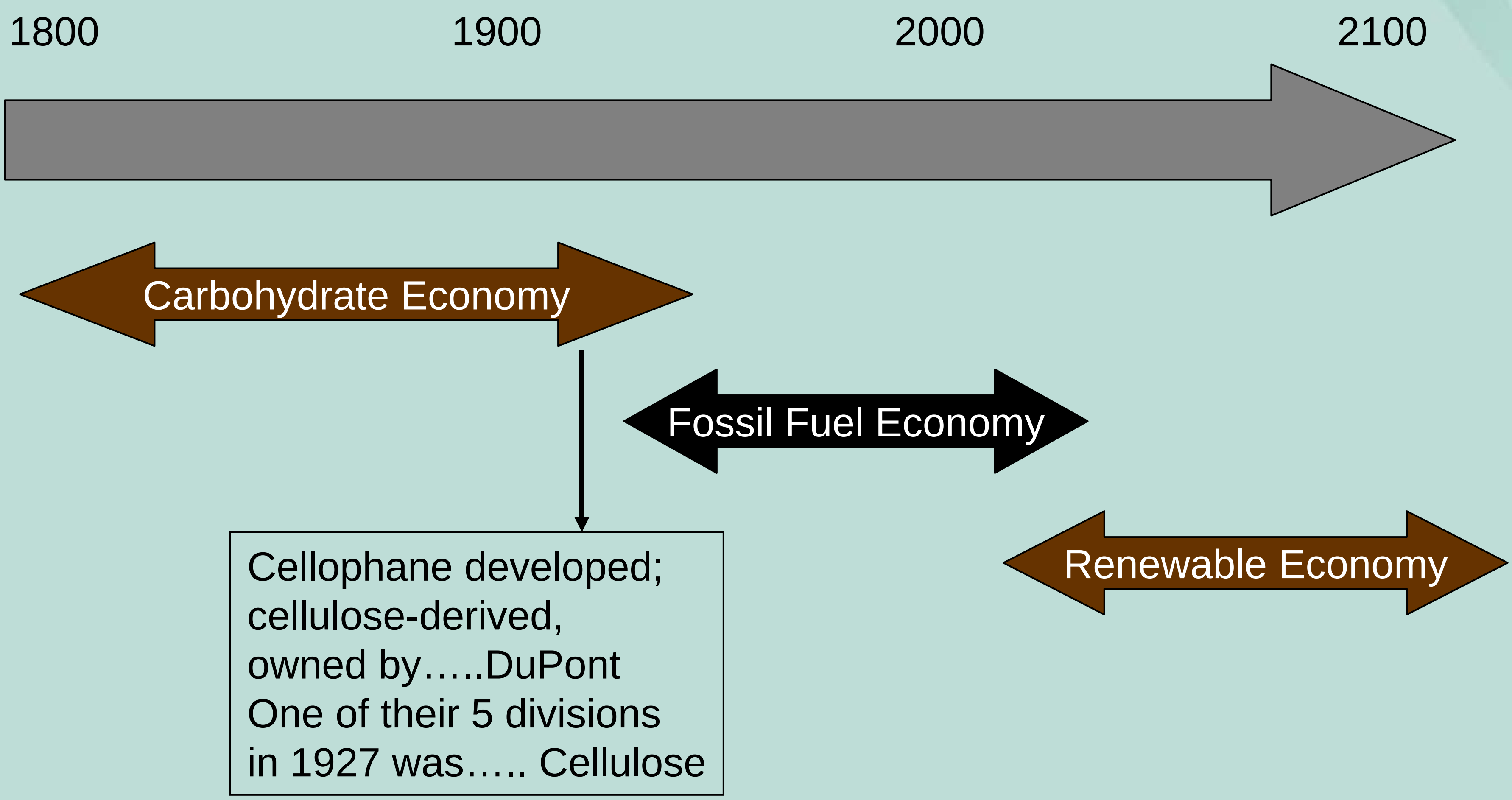
Neal Gutterson

Second Decade of Crop Biotechnology

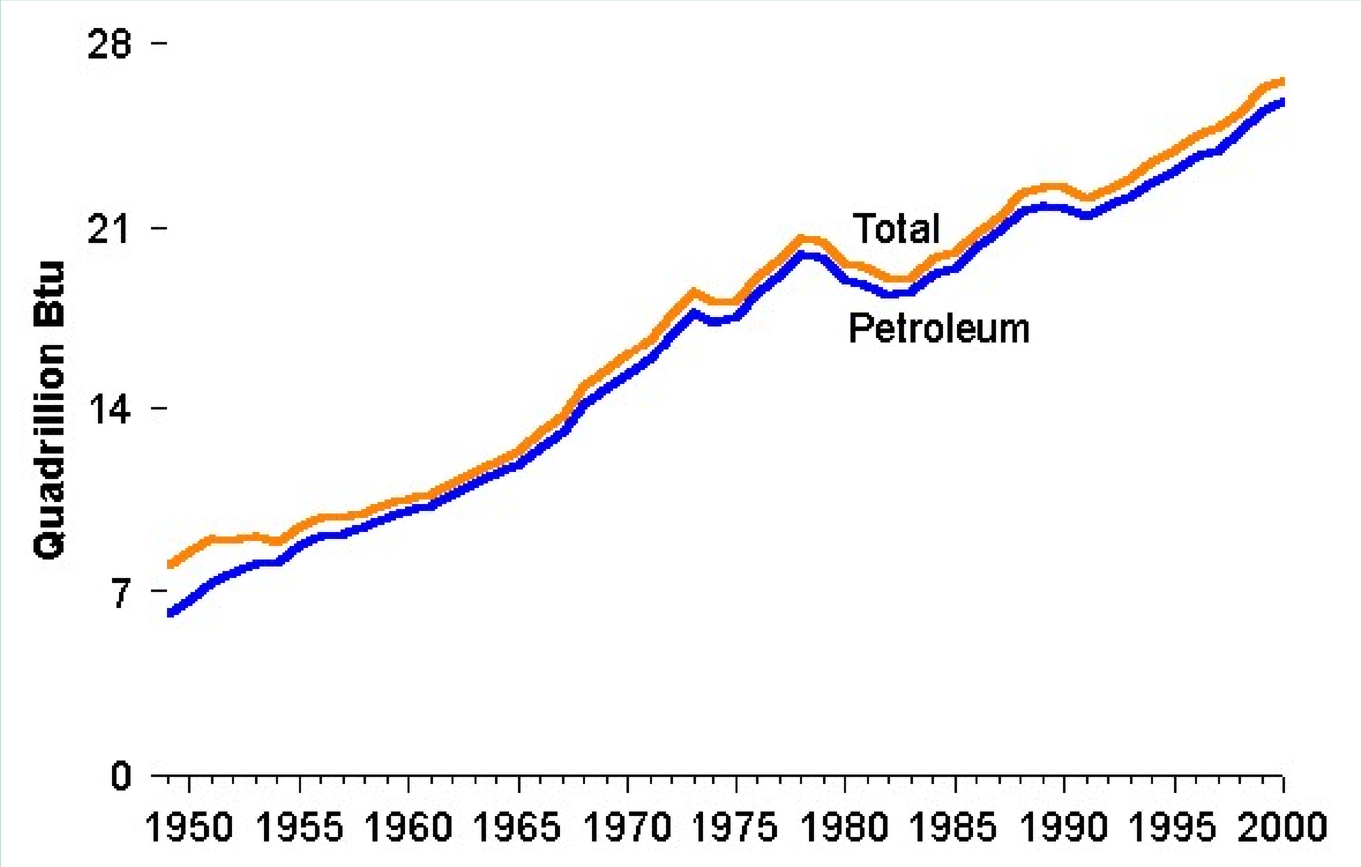
It's tough to make predictions....

.....especially about the future!

We're in the early stage of a major change in the global economy



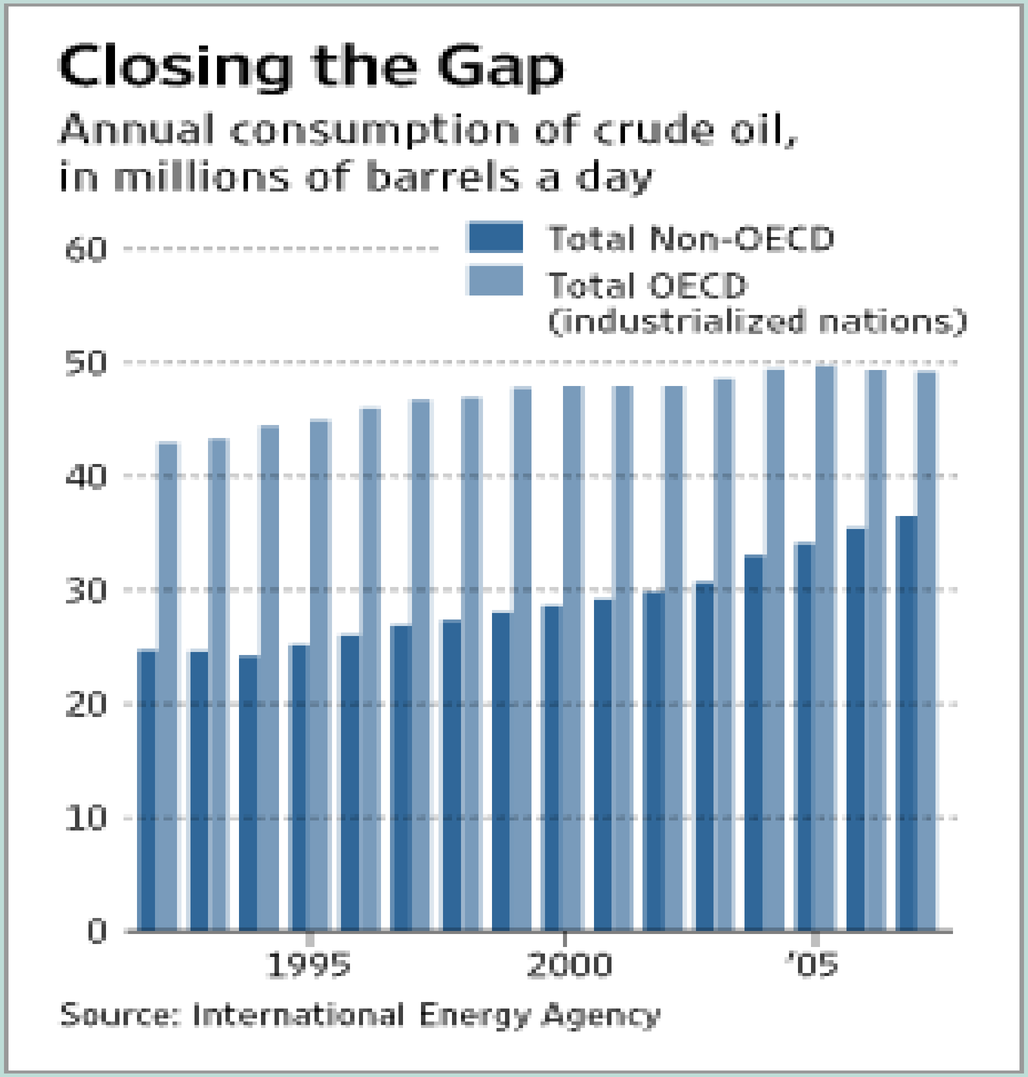
Transportation energy use grows…



http://www.eia.doe.gov/emeu/aer/eh/frame.html

Need: Replace petroleum with other, renewable liquid transportation fuels.

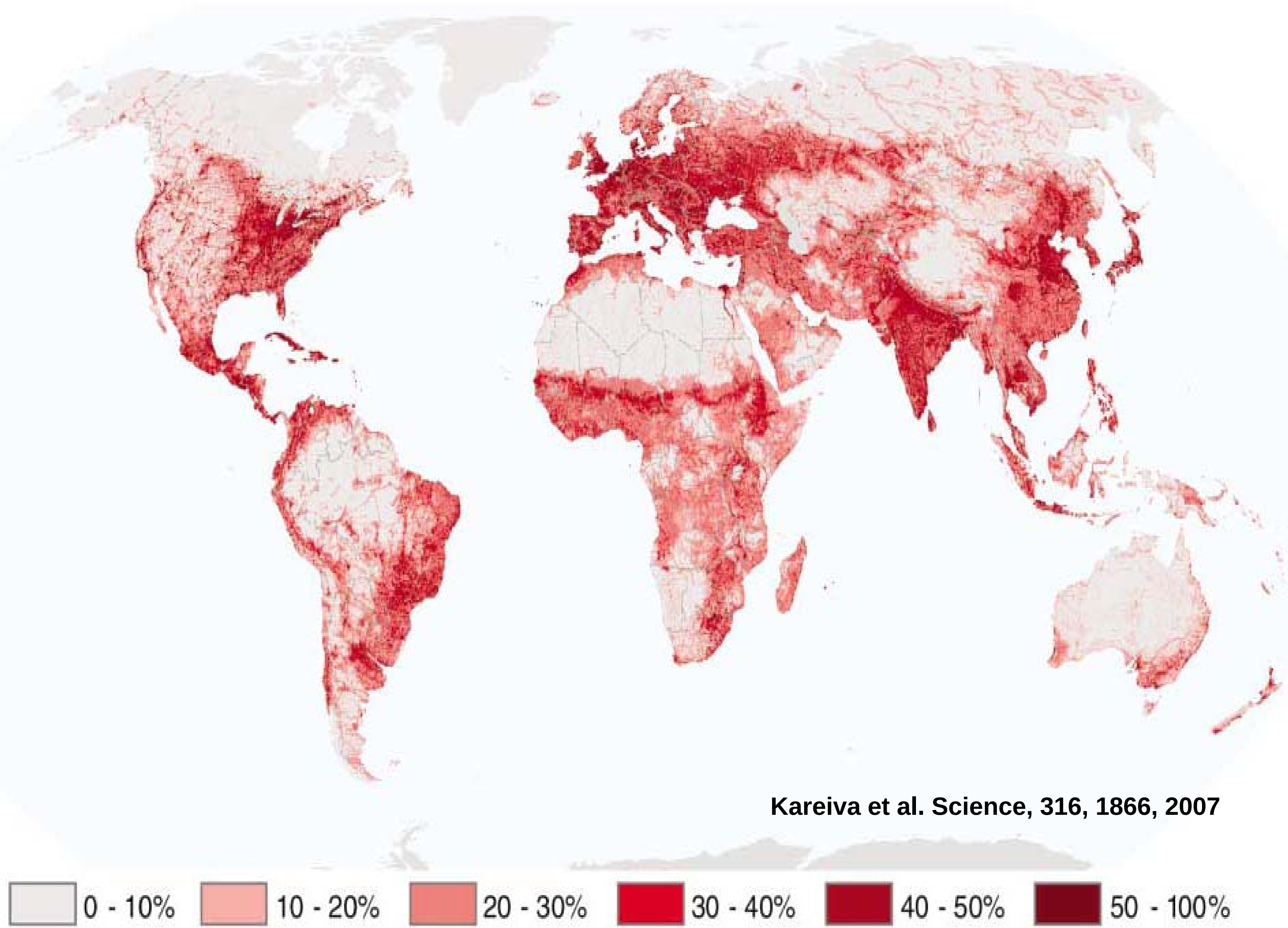
…particularly in developing world



The Challenge:

- Produce large amounts of readily convertible biomass at high-enough yields to minimize any adverse impact on the global environment

- Don't replace one problem (CO_2 levels) with another problem (degradation of land; loss of biodiversity; etc.)



Kareiva et al. Science, 316, 1866, 2007

Inappropriate changes in land use patterns can exacerbate climate change

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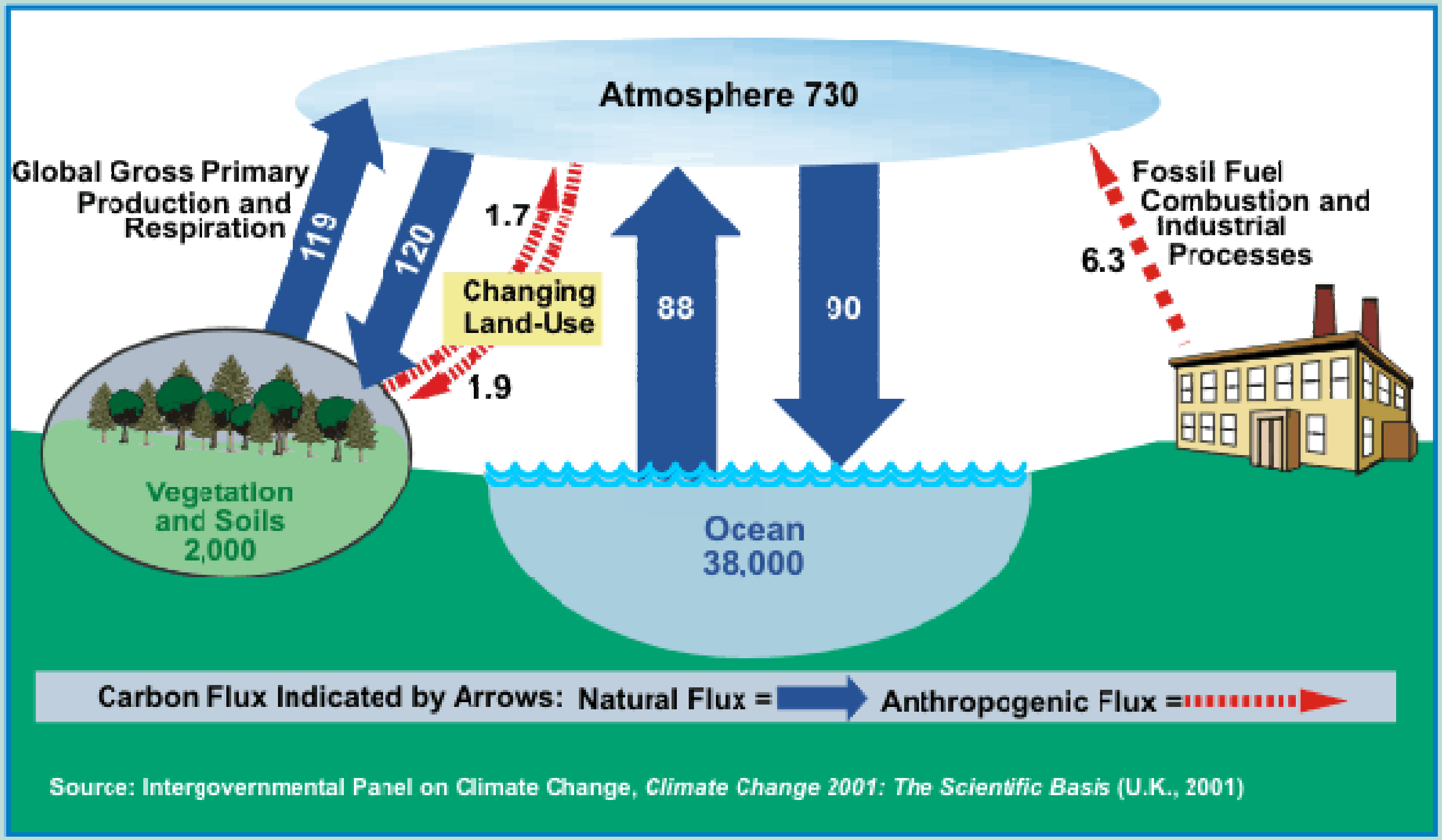
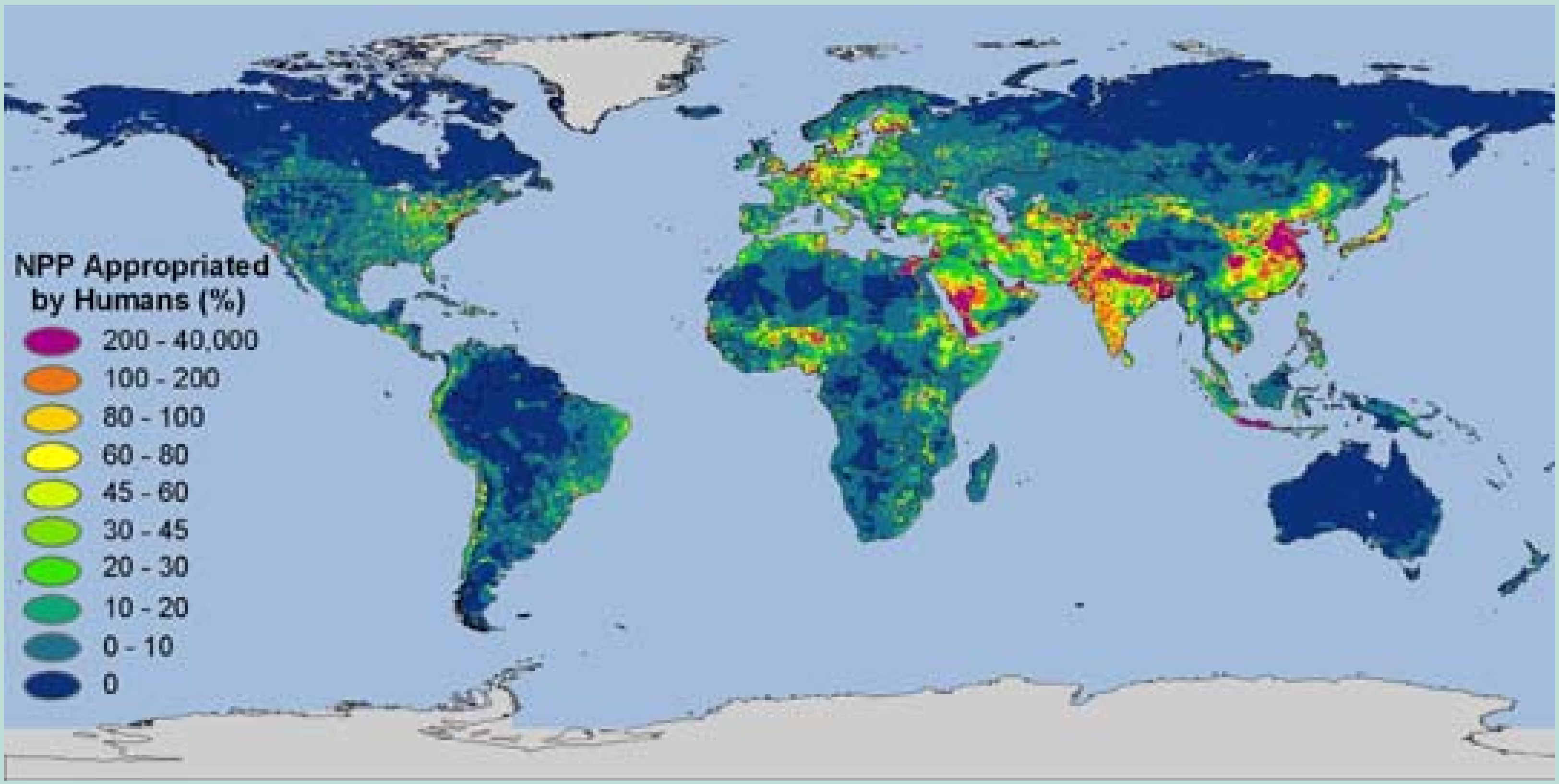


http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html

Humans appropriate large amounts of global net primary production



http://nasadaacs.eos.nasa.gov/articles/2007/2007_plants.html

The solution: optimized feedstocks, & use of entire plant biomass

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- Optimal feedstock properties:
  - High Yield (>15 tons/acre/year)
    - 20% of 25 mi radius = 300M gal/year
  - Low Input (fertilizer, water, tillage, pesticides)
  - High conversion efficiency
  - Sustainable
  - Stable quality from year to year

- Perennial crops are ideal feedstock crops

Benefits of perennials

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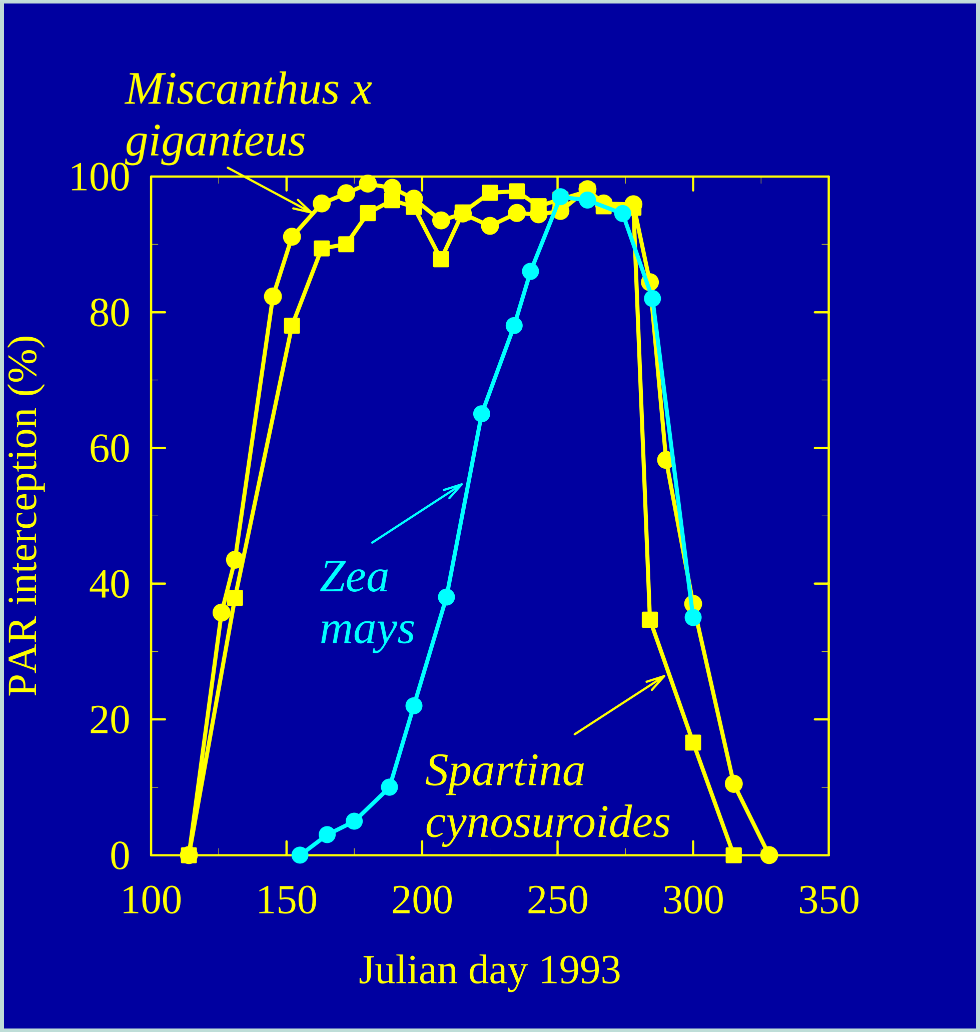
- For efficient use of land (see later), useful biomass production from received light energy must be maximized
- Minimizing environmental impact and maximizing environmental benefit suggests perennial crops, particularly rapid cycling trees and fast-growing grasses, as dominant crops for the cellulosic biofuel economy
- Includes:
  - Leading candidate grasses include switchgrass and Miscanthus
  - Leading candidate trees include eucalyptus, poplar and willow

Perennials maximize light and heat capture



Courtesy of Steve Long, University of Illinois

US 2nd generation grass alternatives

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Crop	Product Attributes	Yield (t/acre)	Region
Forage Sorghum	Photoperiod sensitive tall, thick stem and/or short, small stem, BMR	10 -- SE 8 -- SP/MW	MW marginal/ SP/SE
Sweet sorghum	Non-cellulosic, combine with grain process	25 wet	Upper gulf coast
Miscanthus	Seed propagated high biomass	10-15 (SE)	MW/SE
Miscane	Mis/sugar cane cross, cold tolerant, 4-6 m height	10-15, seed propagated	Upper SE
Energy Cane	Biomass, low sugar	Same, costly propagation	SE/S. TX
Switchgrass	Perennial, seed propagated,	5 - 8	MW/SE

Leading crop candidates largely "undeveloped"

- Key lessons of first decade:
  - ~ Biotechnology/genomics provides a platform for:
    - ~ improved core genetics through use of dense marker maps;
    - ~ biotech traits for enhanced value
  - ~ Best demonstrated for corn yield improvement

- Improvement of perennial crops for cellulosic biofuel economy requires rapid adoption and application of these same tools:
  - ~ Efficient development of dense genetic maps
  - ~ Efficient, cost-effective development of informative markers for key traits
  - ~ Deployment of biotech traits used in today's crops in tomorrow's biofuel crops

Tools to impact rapid domestication of new energy crops

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- High efficiency sequencing
  - ~ Lumina, 454, ABI
  - ~ Marker ID
  - ~ Dramatically reduces time to develop dense marker maps to accelerate marker-assisted breeding
- Efficient transfer of developed traits
  - ~ Inherent yield (e.g., photosynthetic capacity)
  - ~ Water use efficiency
  - ~ Nutrient use efficiency
  - ~ Drought tolerance
  - ~ Disease resistance

Yield Stability

Mendel is pioneering rapid adoption of Miscanthus

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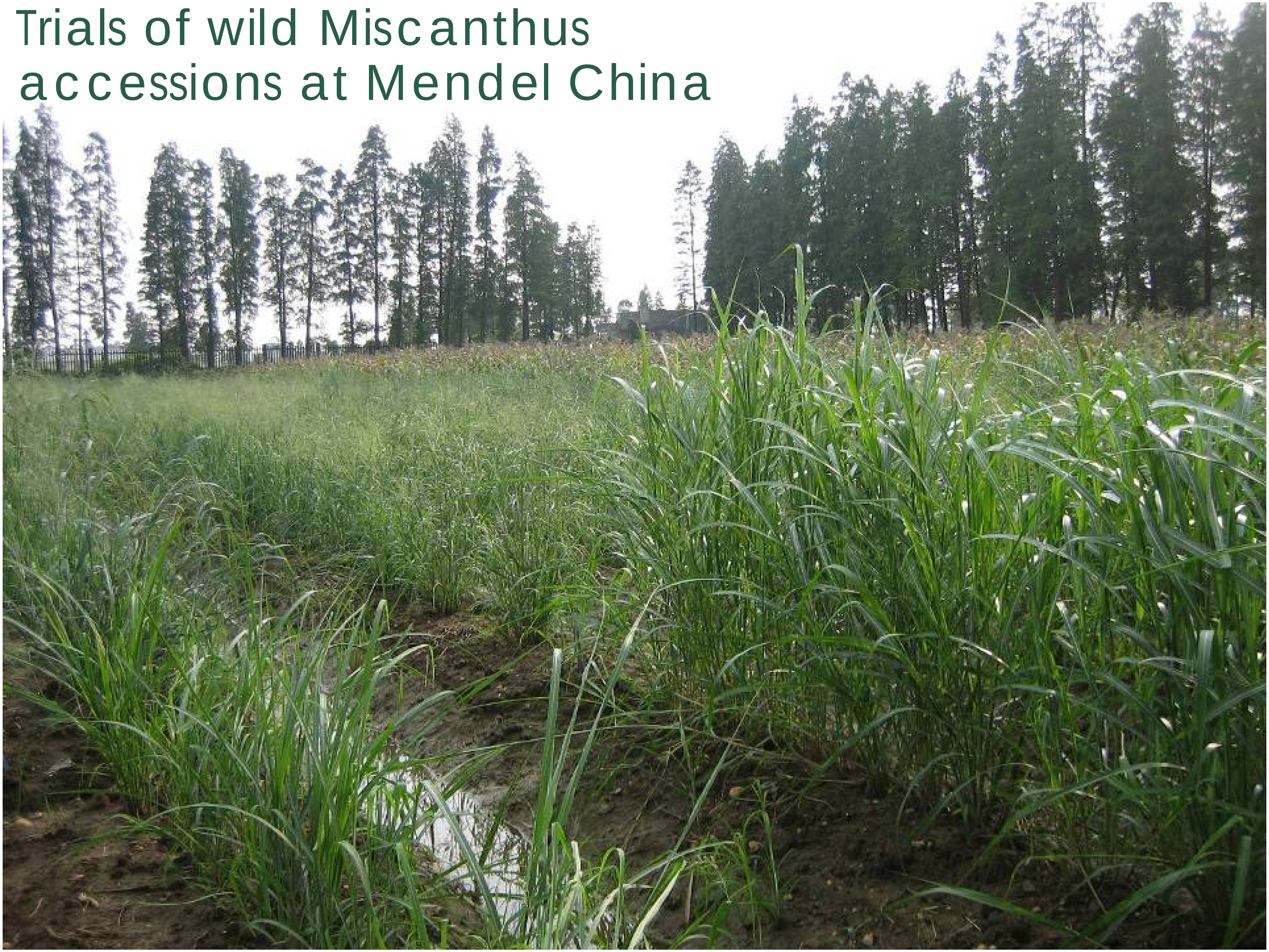
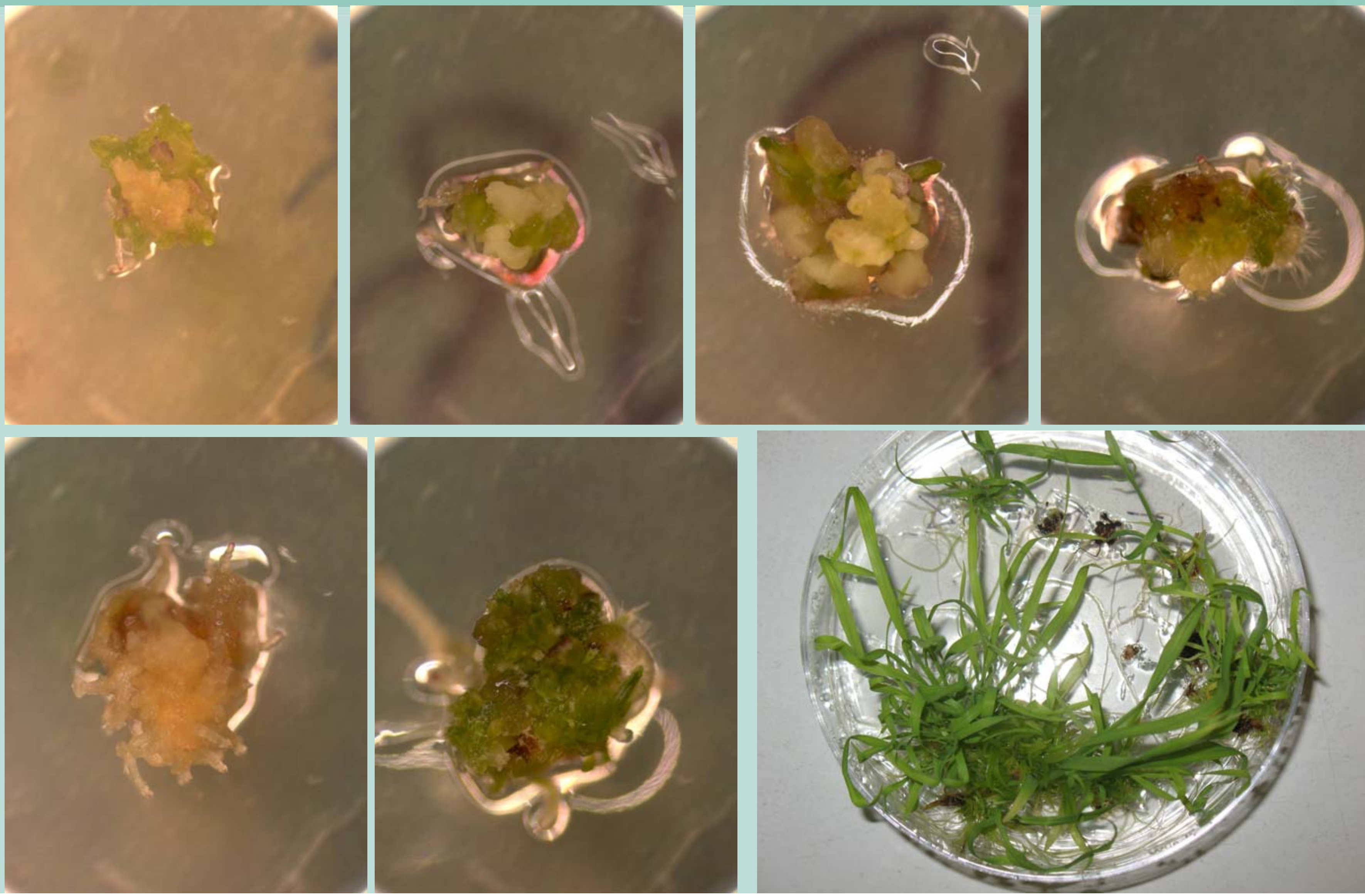
- Assembling the world's leading germplasm collection
  - ~ Establishing a world-class, advanced breeding program
- Deploying biotech traits created through an extensive R&D program during our first decade
  - ~ Corn is a good "model crop" for the energy grasses
  - ~ Soybean is more closely related to the tree species

Mendel Miscanthus initial germplasm collection

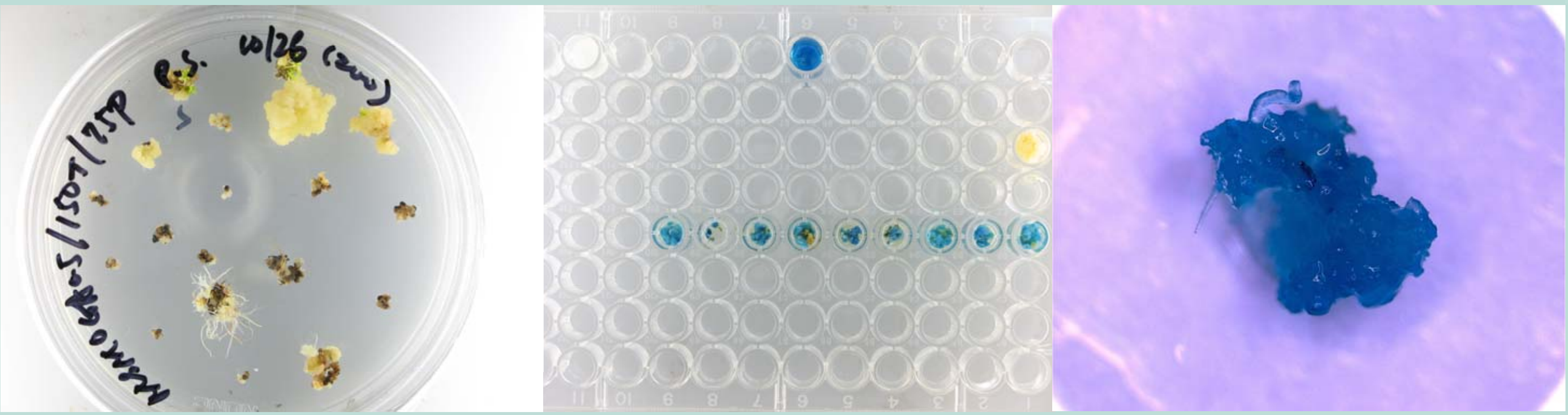
Trials of wild Miscanthus accessions at Mendel China



Miscanthus embryogenic regeneration



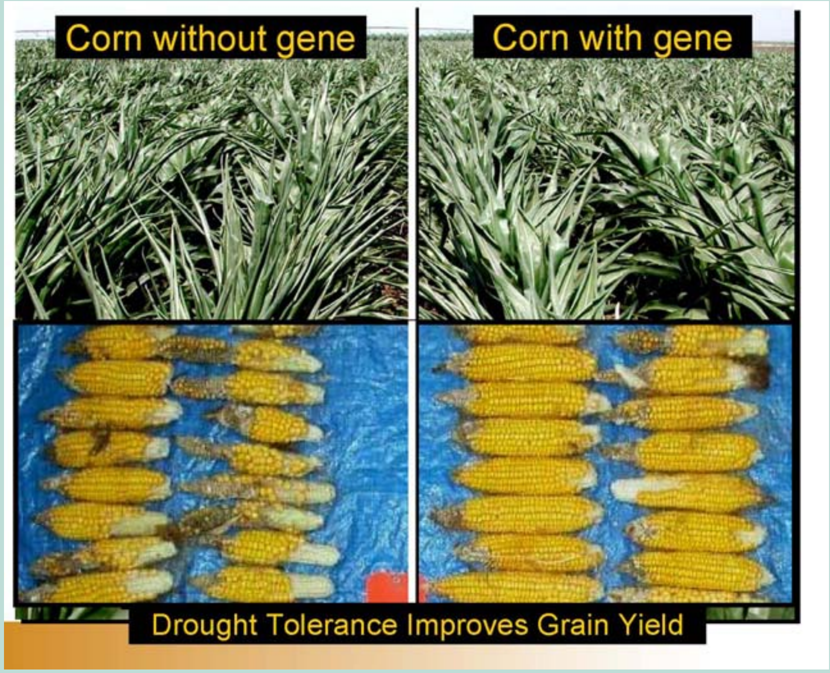
Miscanthus transformed e-callus



High value biotech traits from corn

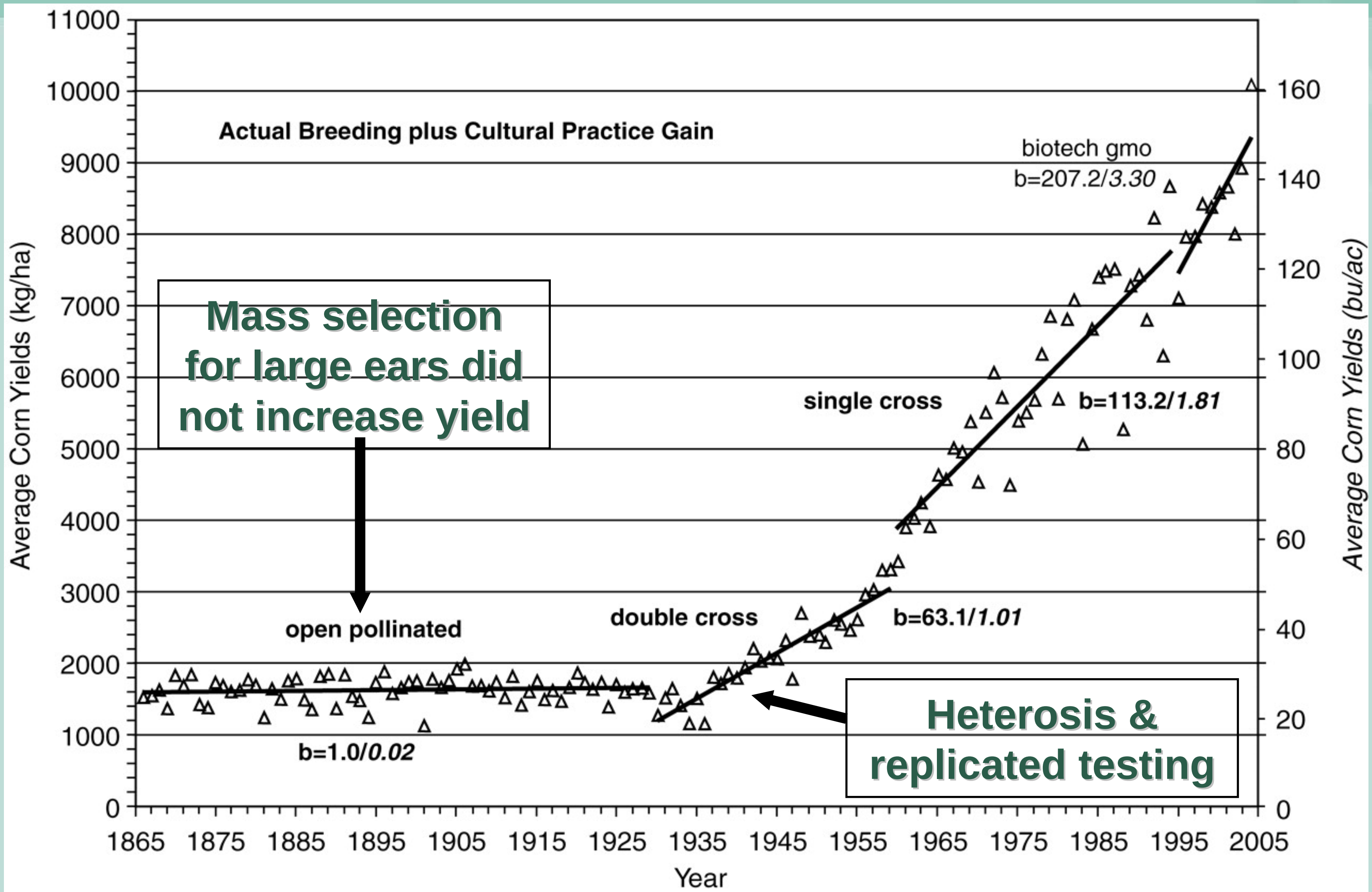
- Intrinsic yield (enhanced photosynthetic efficiency)

- Drought tolerance and water use efficiency

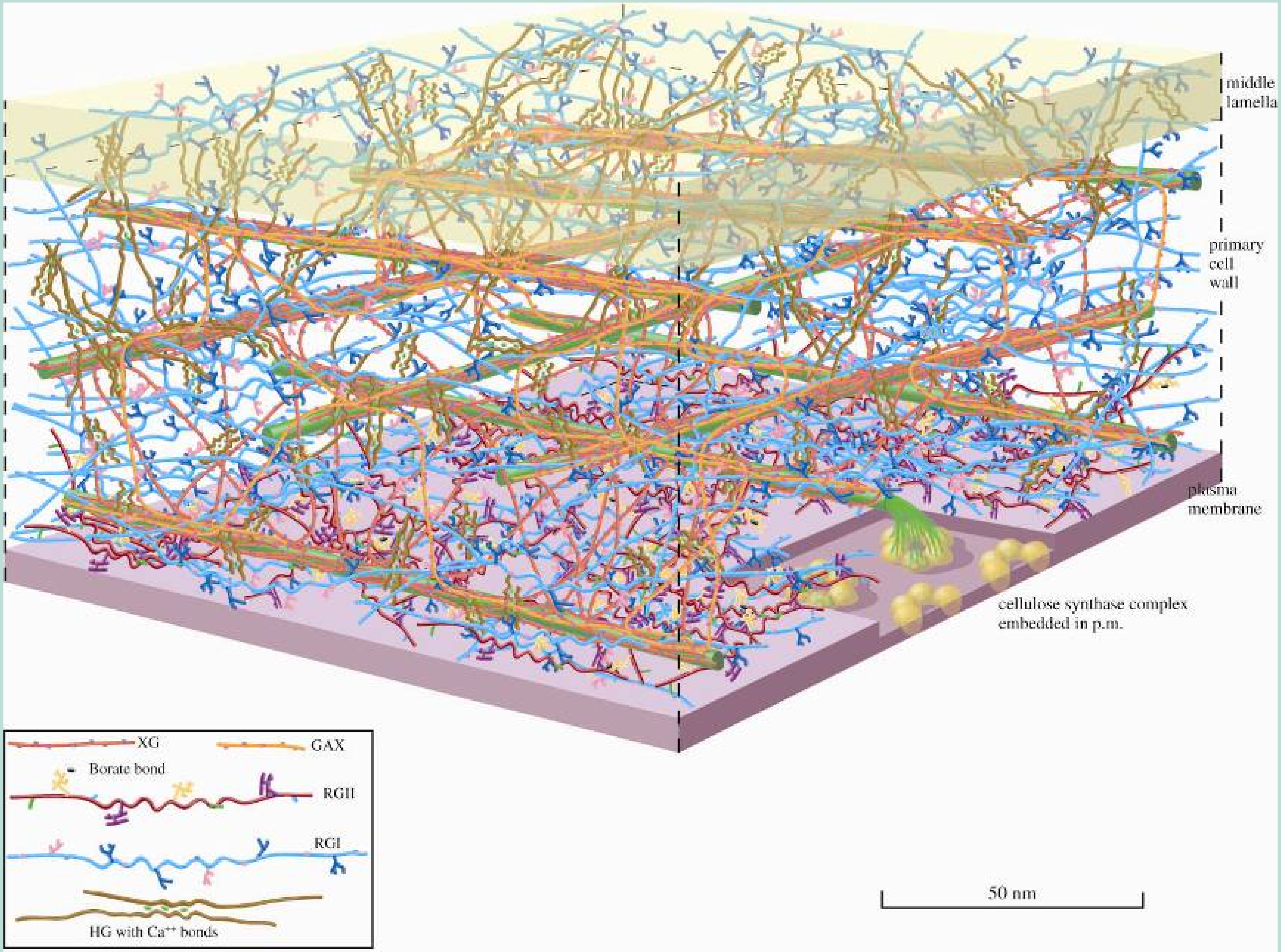


Monsanto presentation 9/15/2004

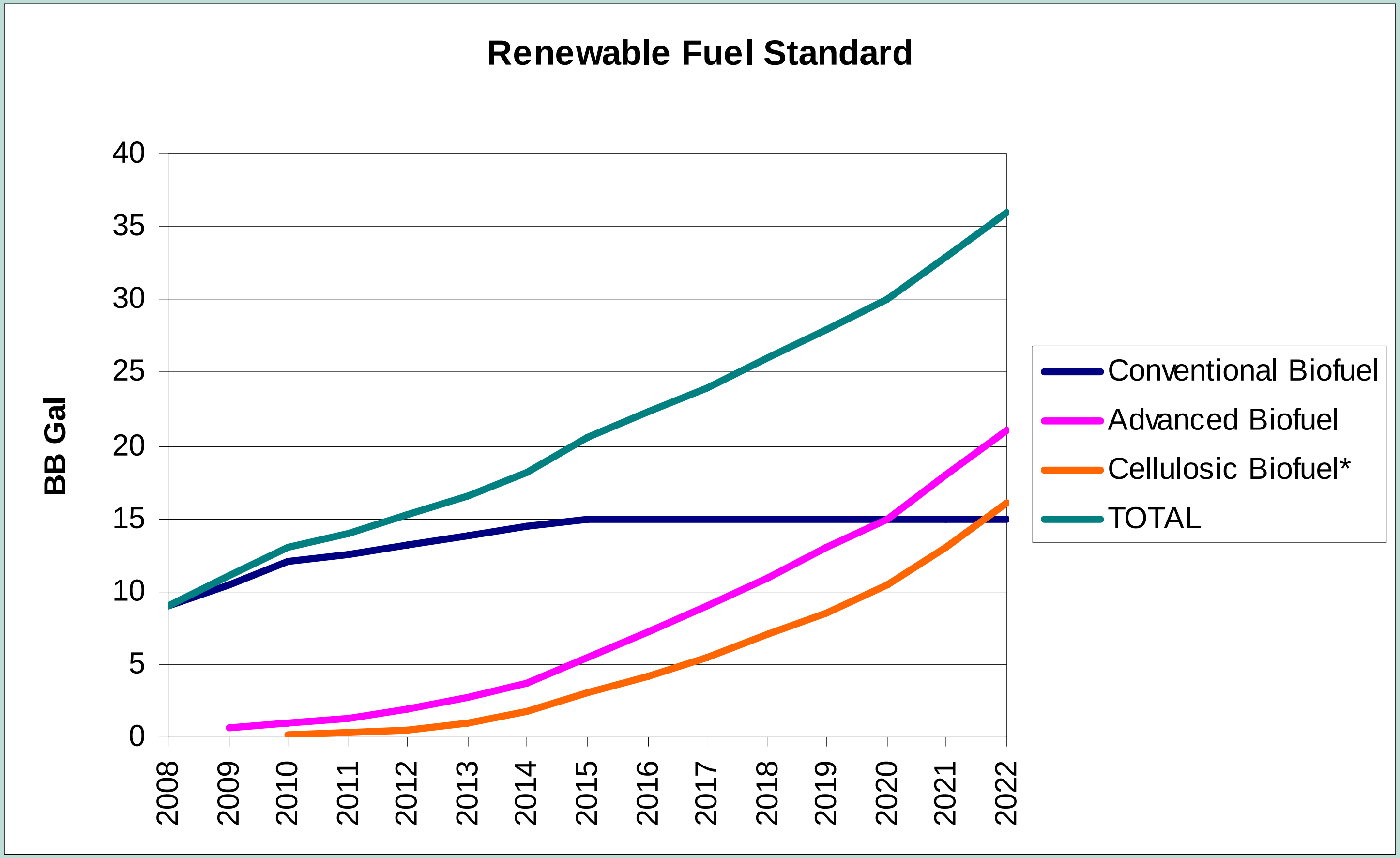
Yields of 2nd generation cellulosic crops can be improved substantially



Enhancing cell wall breakdown



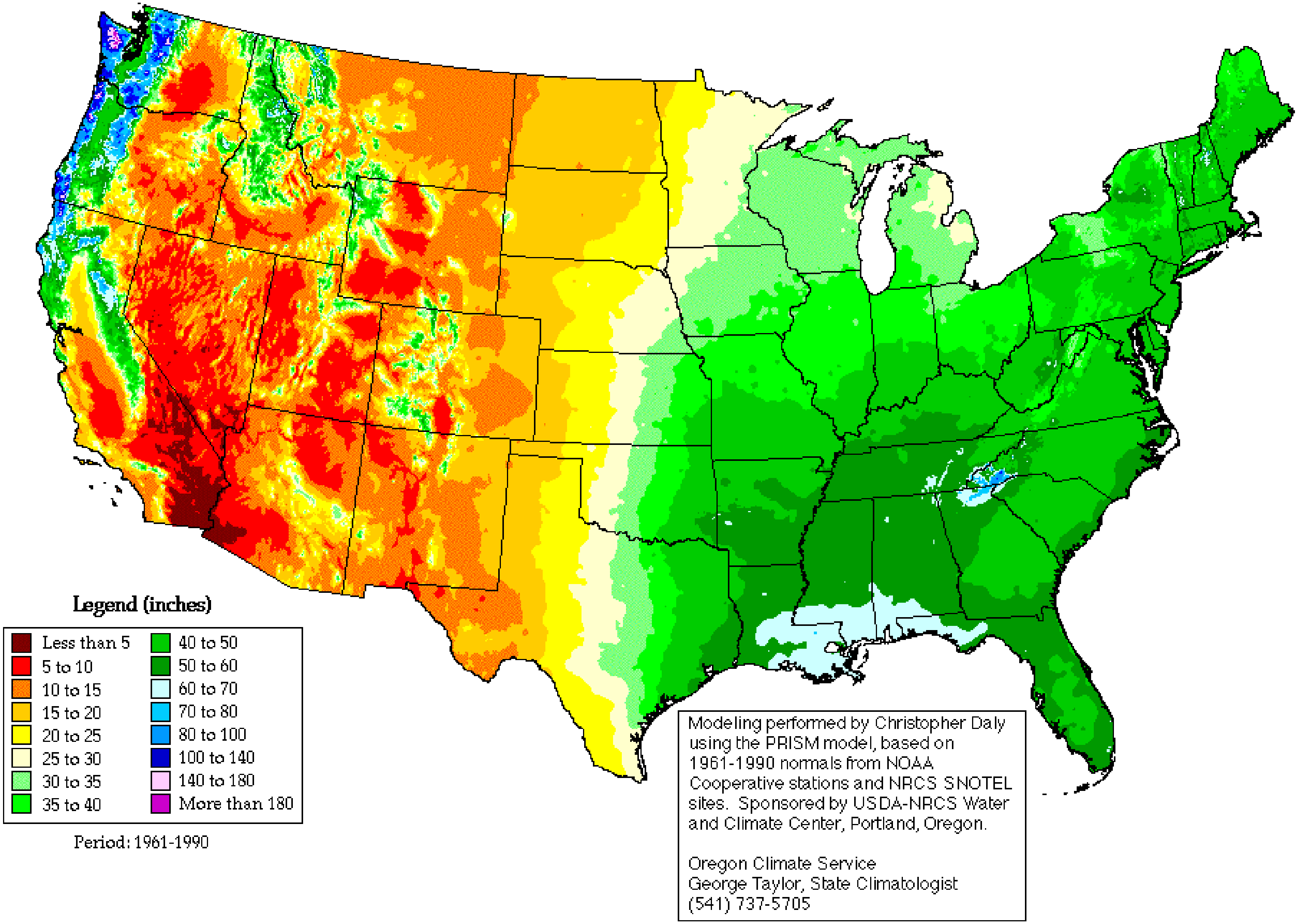
Federal mandates for biofuels were increased late 2007



Note: Cellulosic is a sub-category of advanced biofuel.

Annual Average Precipitation

United States of America



Perennial grass production, bioenergy: long-term projection

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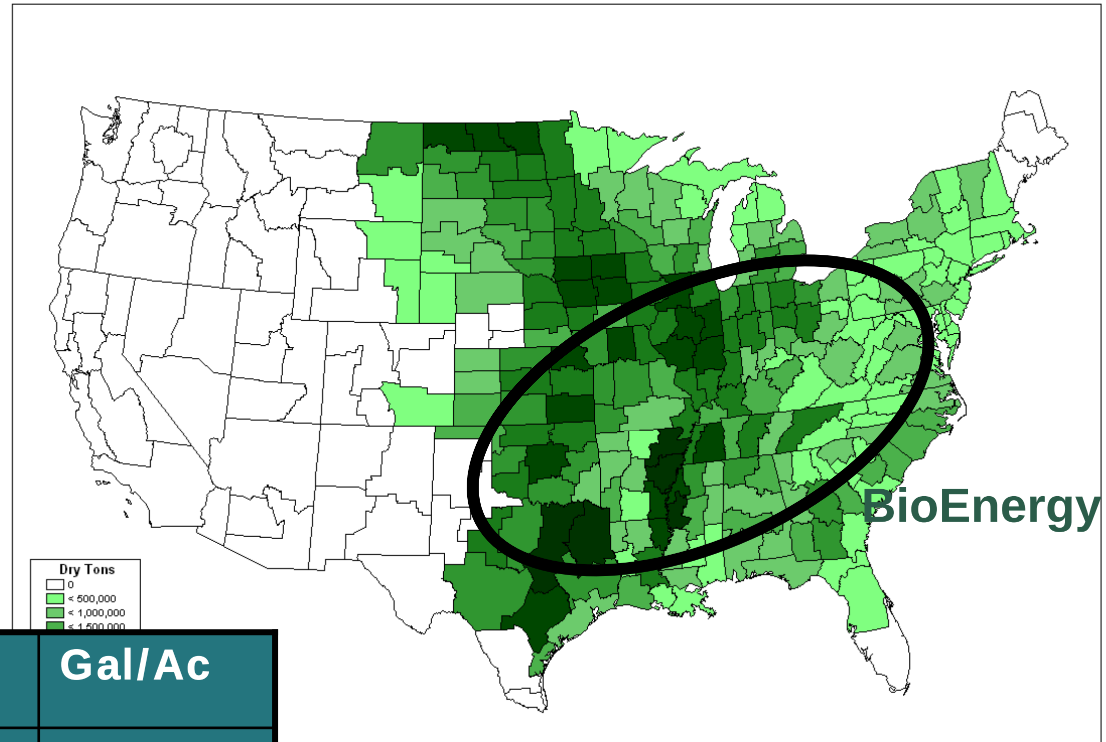

Crop	Acres	Region	Gal/Ac
Corn	10 mm	Heartland	~415
Corn (projected)	30-35 mm	Heartland + NGP	~760
Grasses (projected)	50 mm	MP + EU + parts of SS	1,500
Eucalyptus	10-20 mm	Parts of SS	1,200

By the end of the third decade we will see....

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- .... dedicated energy crops grown on over 50 mm acres in the U.S. alone (nearly 15% of arable land)
- ... over 250 mm acres globally (more than 10% of arable land)
- ... providing greater than 50% of liquid transportation fuels, and adequate food to feed 8 billion people

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Genomics tools for advanced breeding and biotech traits will enable the rapid improvement of undeveloped grasses as feedstocks for future cellulosic industry