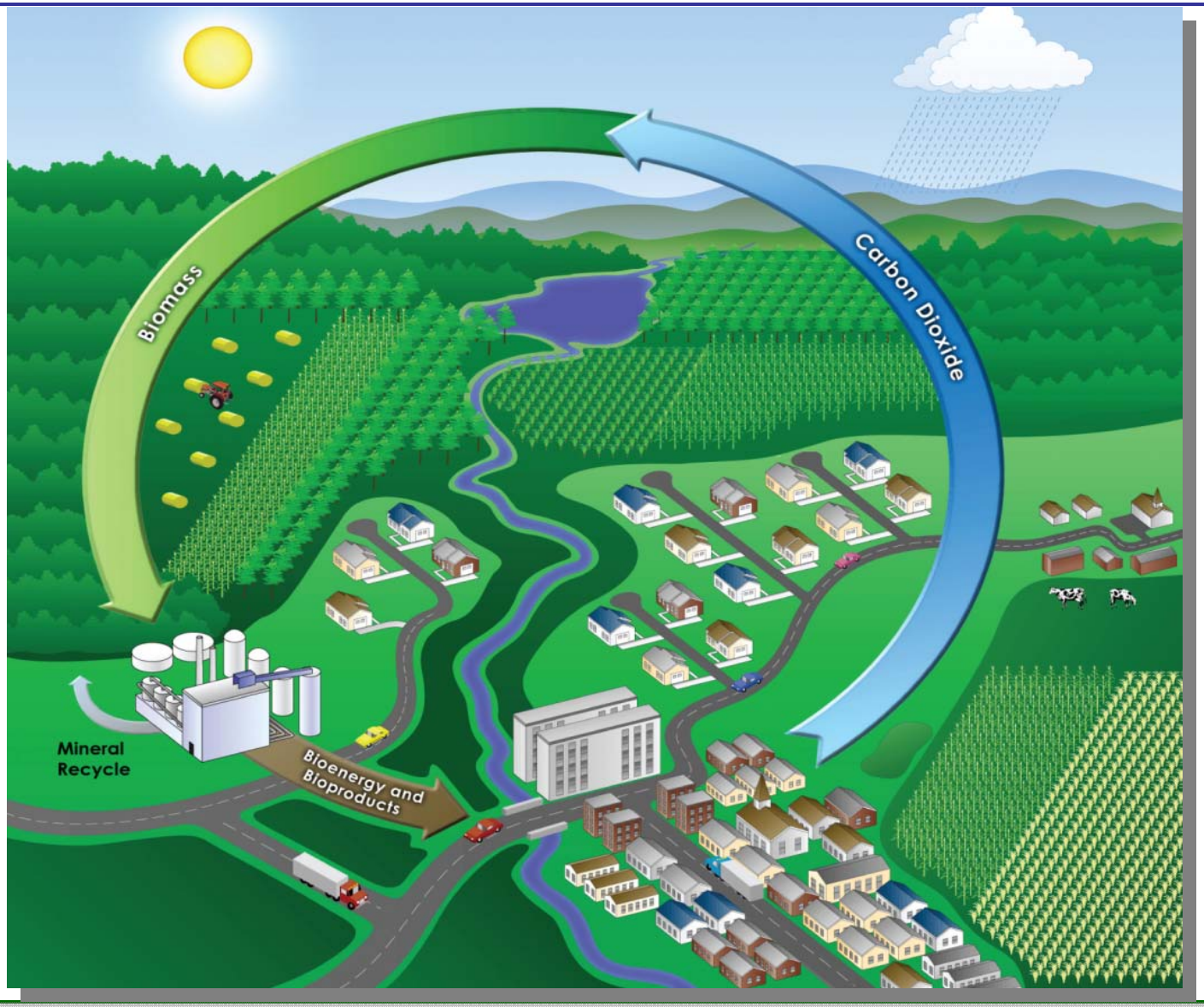
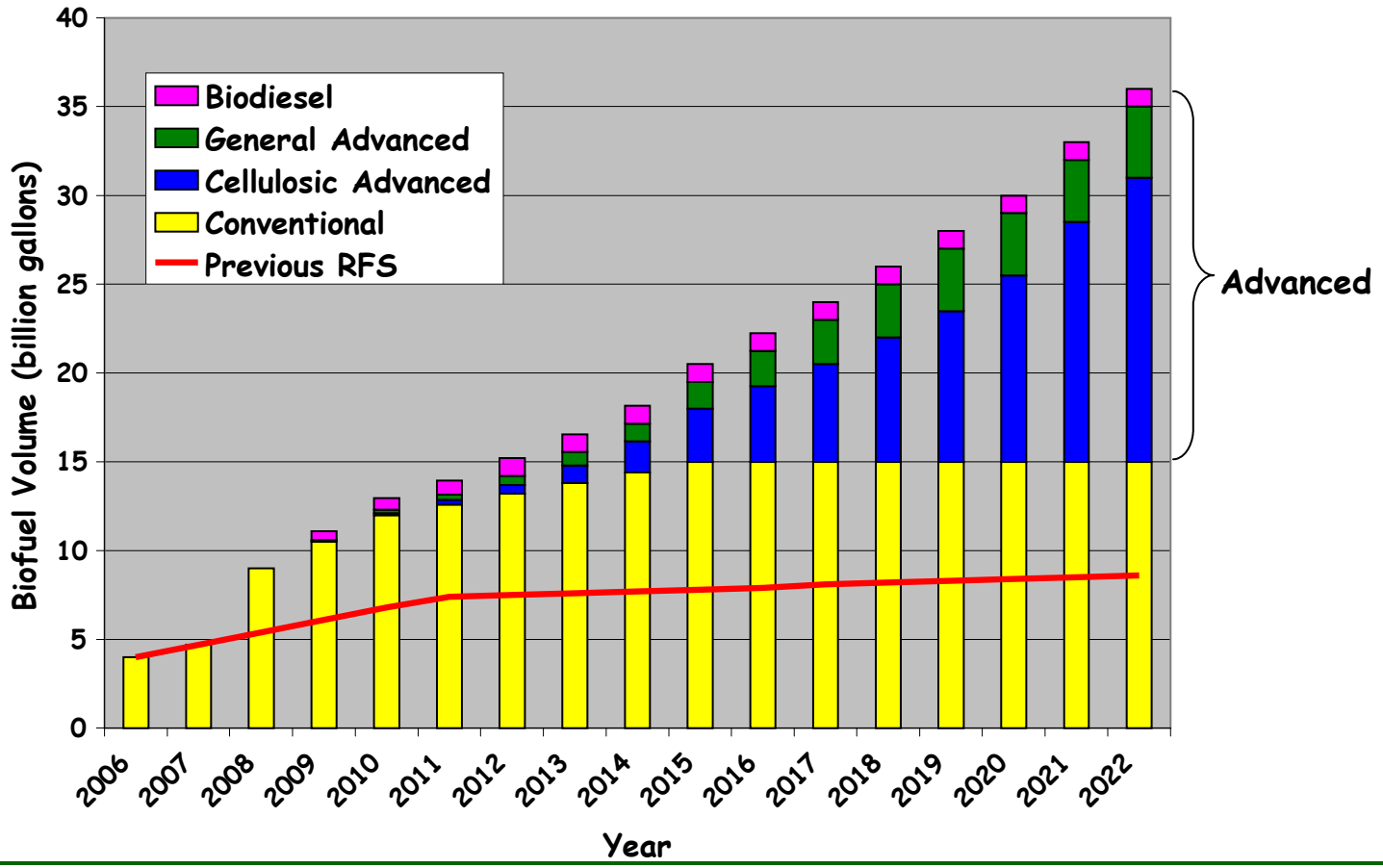
Developing cellulosic biofuels in Kentucky
Biotechnology for biofuels



Seth DeBolt, College of Agriculture, University of Kentucky

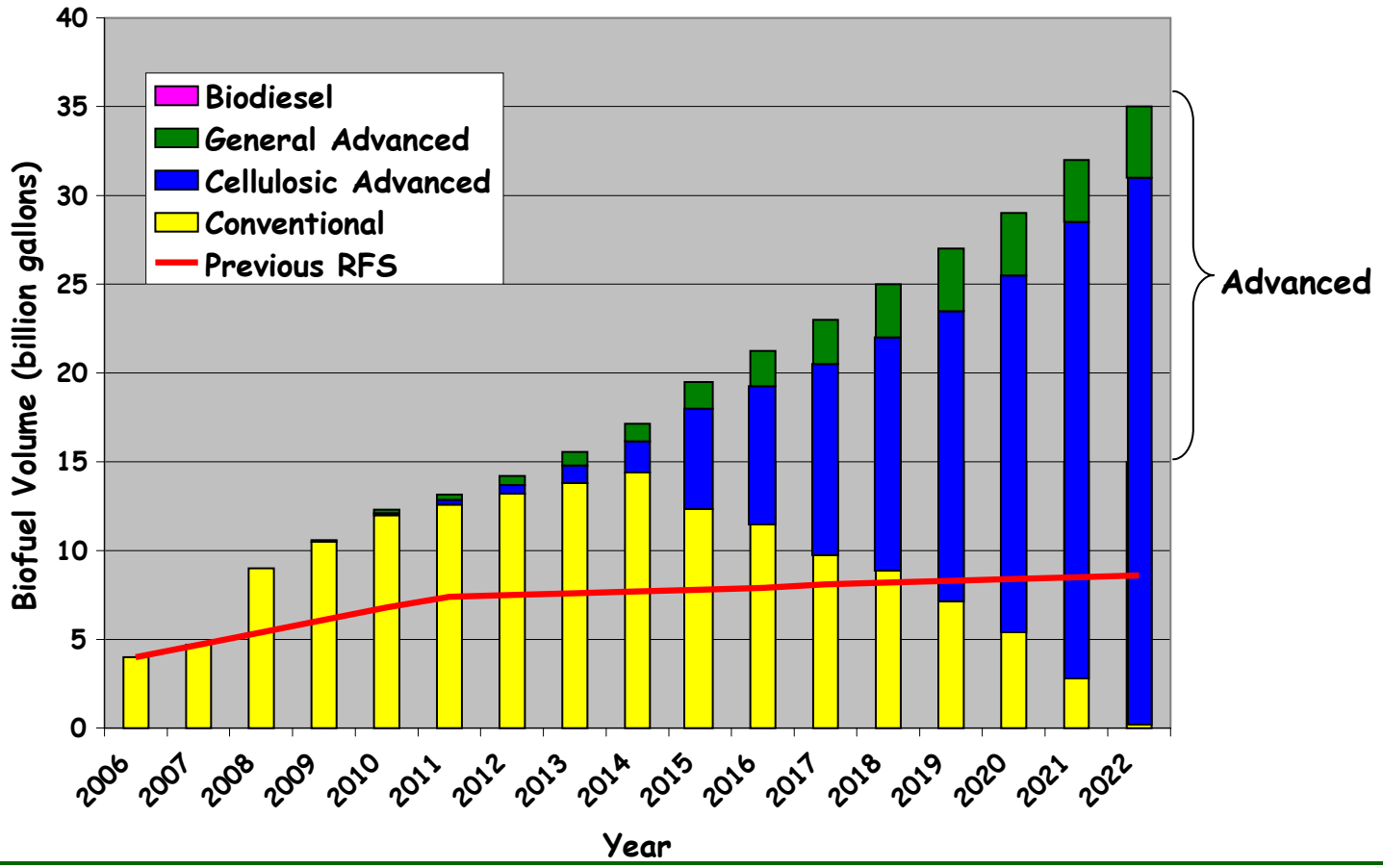
Why cellulosic biofuels?

Renewable Fuel Standard
(Energy Independence and Security Act of 2007)

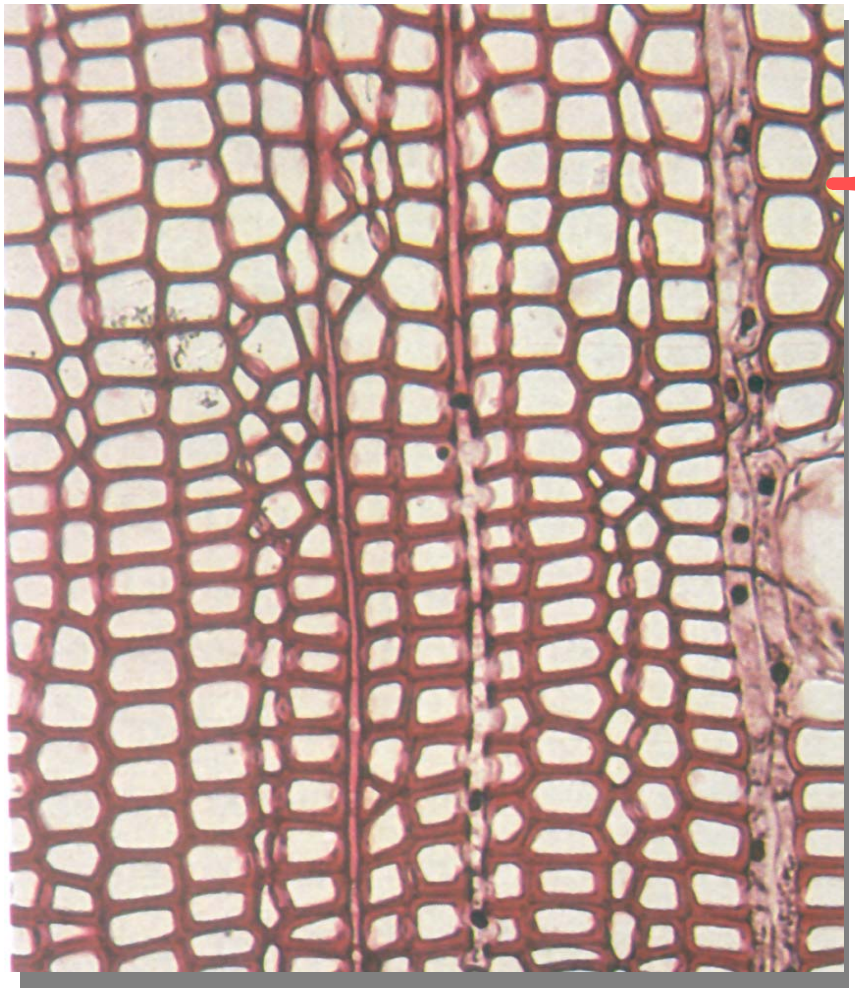


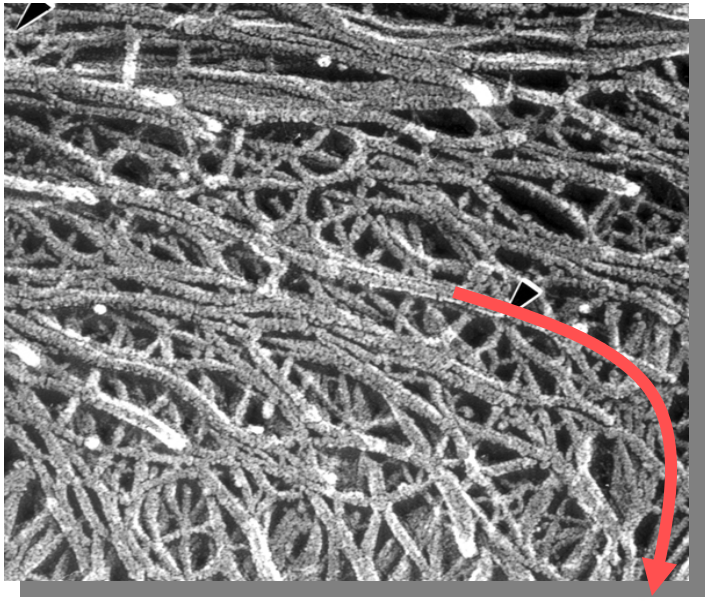
Why cellulosic biofuels?

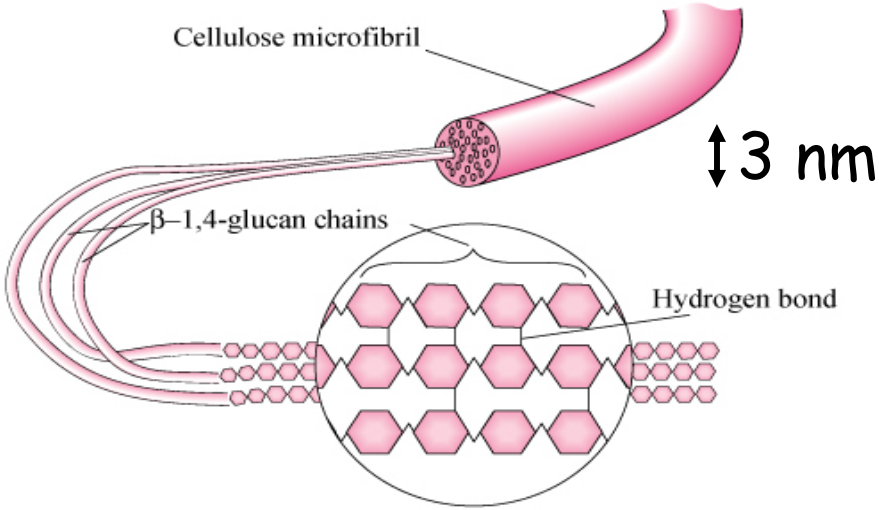
Further optimized renewable fuel standard



What is cellulose?
Plants are mostly composed of sugars



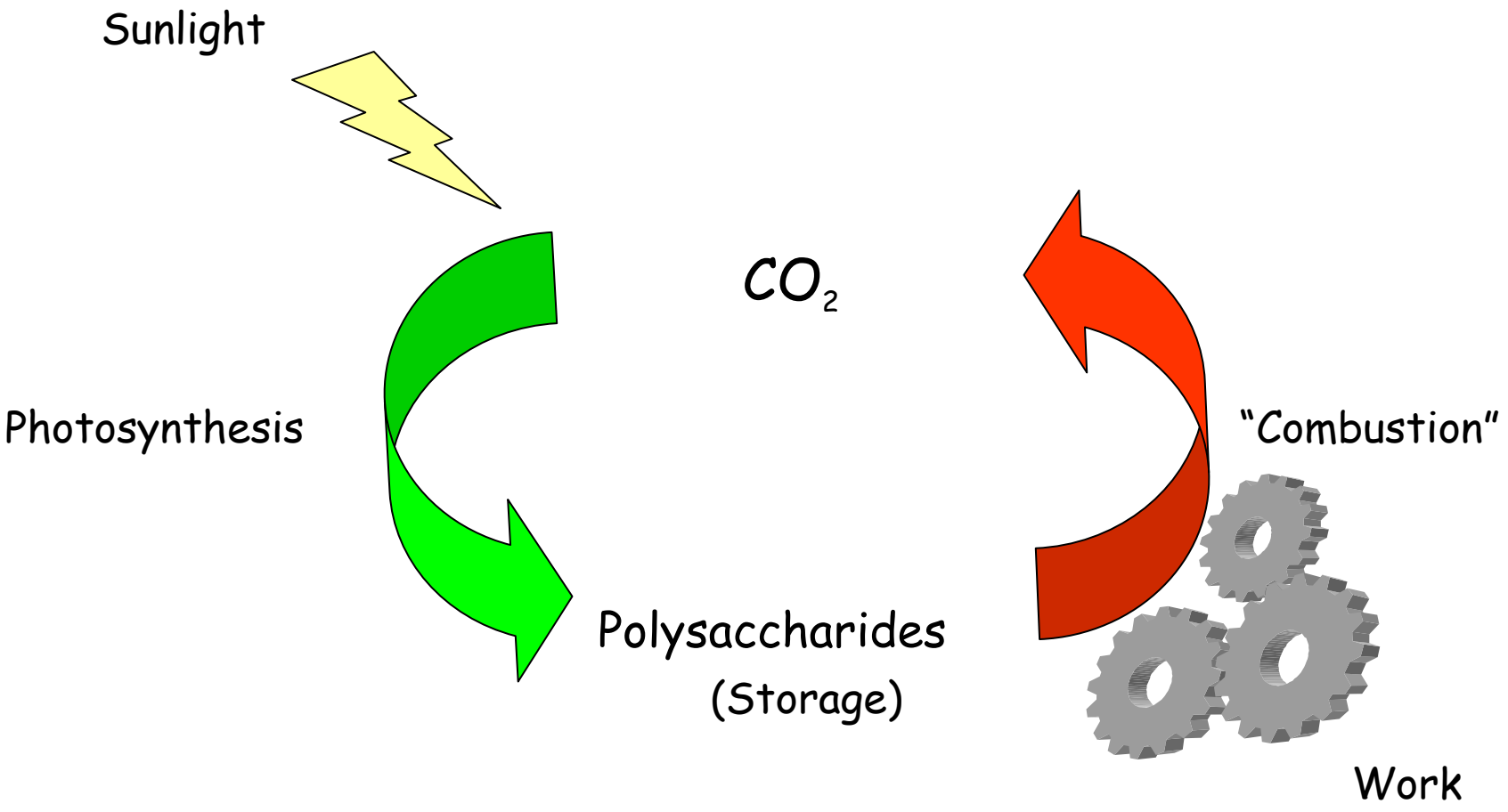




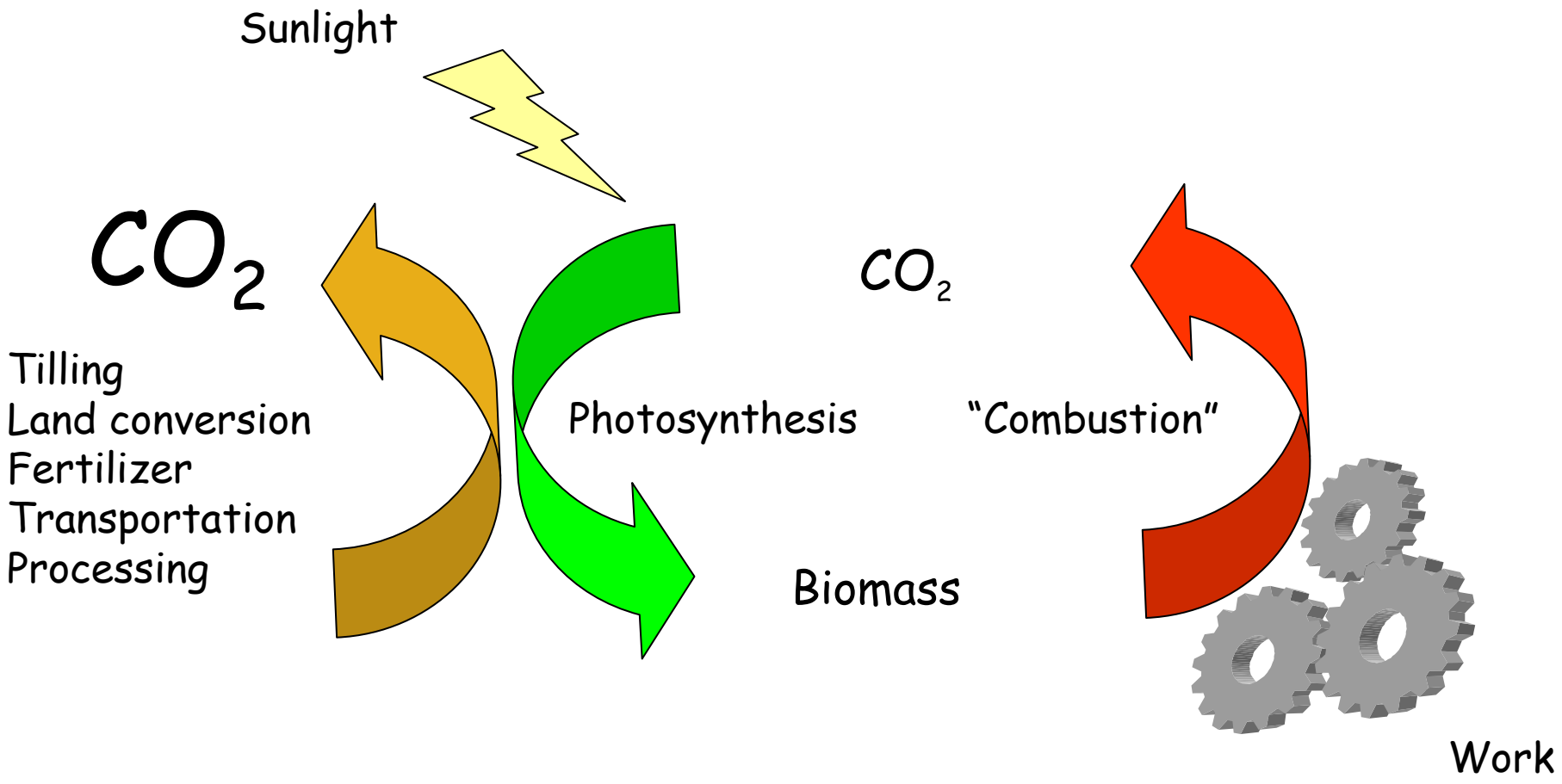
Section of a pine board

Polymerized glucose

Combustion of biomass *can* provide carbon neutral energy



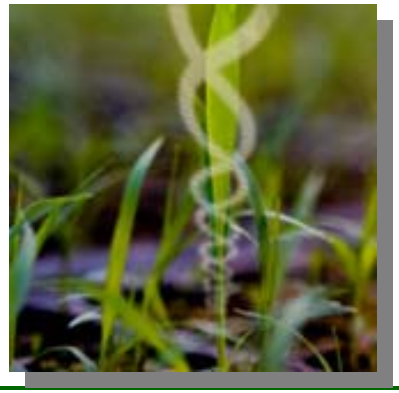
Combustion of biomass *can* provide carbon neutral energy



But it depends on how the biomass is produced and processed

Responsible biofuel

- No conversion of undeveloped land
- No erosion, runoff, nitrous oxide emissions
- Net GHG benefits based on full lifecycle accounting
- No effect on food production
- Make profit



Mission of biotechnology

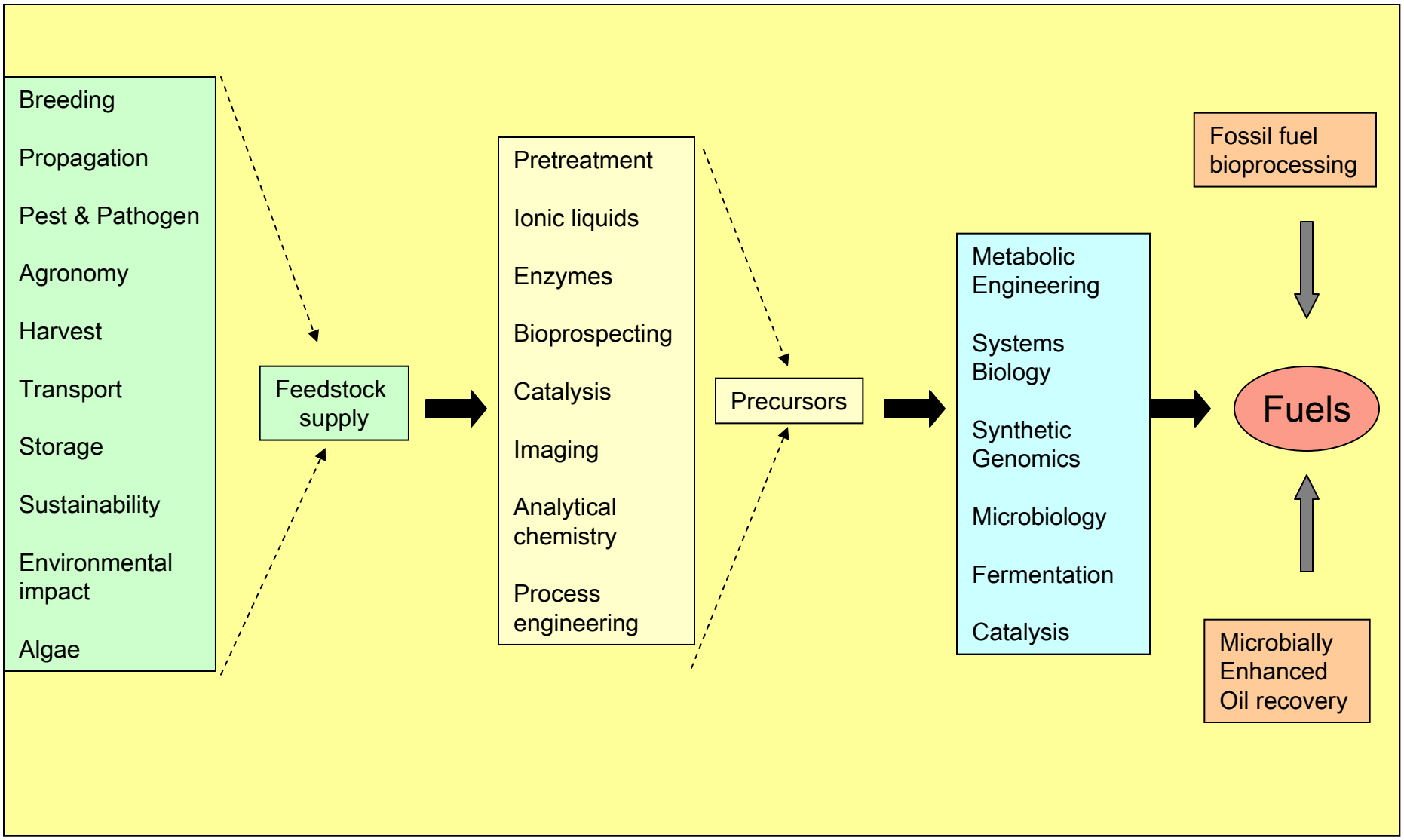
Explore the application of modern biological knowledge to the energy sector

- Fuel production — Primary economy
- **Production of value added bioproducts** — *Ancillary economy*
  - *Biochemicals*
  - *Biosolvents*
  - *Bioplastics*
  - *Smart biocomposites for manufacturing*
  - *Biolubricants*
  - *Biosurfactants*
  - *Biocatalysts*
  - *Biosensors*

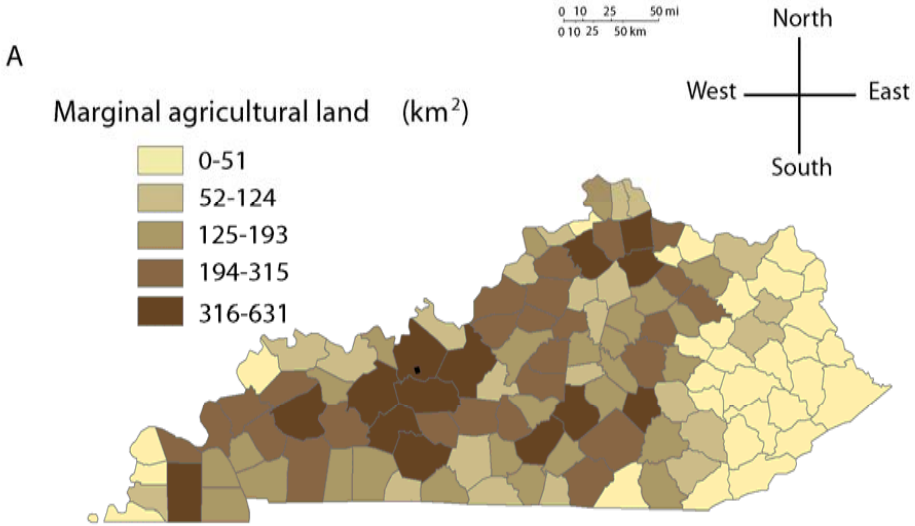
Vision of biotechnology

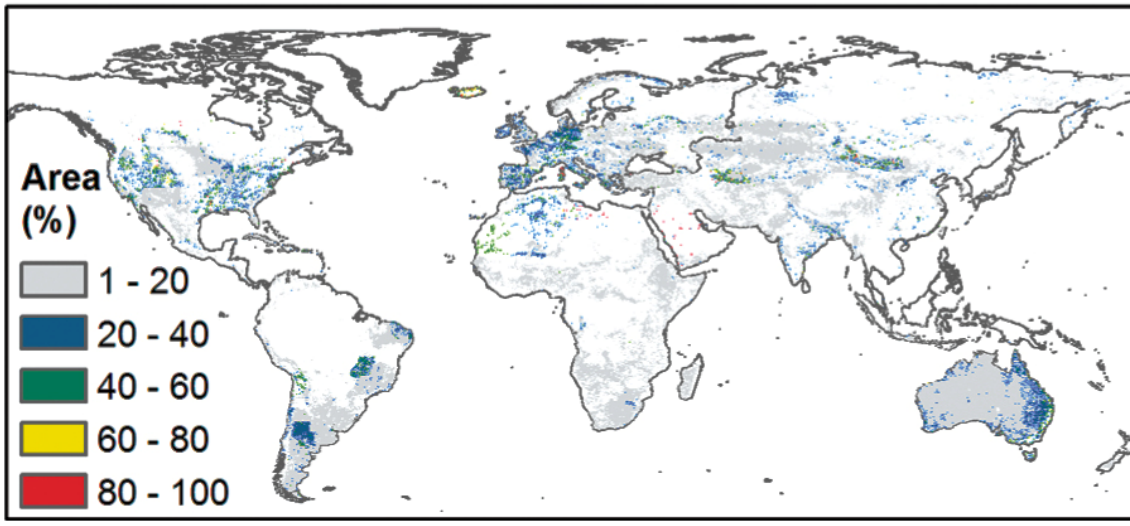
- Create and disseminate *comprehensive* and *coherent* knowledge of the field – facilitate innovation
  - Structured
  - Allows timely & efficient investment
  - Compatible with strengths of Universities in the state
  - Discoveries will happen in many places, including UKY
  - Interdisciplinary research can change paradigms
  - **This problem is global** so solutions will have global consequences

Technical reach of biotechnology



Responsible biofuels concept-
A billion acres of abandoned land worldwide





Marginal land in Kentucky- ground zero for biofuels

- Challenges
  - Yield
  - Ecological maintenance
  - Pathogen pressure

Campbell (2008) Env Sci Technol. Campbell et al., 2009 Science. DeBolt, Campbell et al., (2009) GCBB

Near term goals

Create a laundry list of energy crops

Grasses (C4 due to their capacity to convert sunlight and CO2 into biomass)

a. Miscanthus ssp. – non native, remarkable photosynthetic system

b. Switchgrass (*Panicum virgatum*), eastern gamagrass (*Tripsicum dactyloides*)- native, very efficient

c. *Arundo donax, Saccharum, Phragmites* etc

Woody- high density and short rotation

a. Willow (*Salix ssp.*)

b. Populus, Sycamore, Black Locust

Mixed species energy systems

a. All of the above with legumes for N fixation – enhances CO2 sequestration into the soil- minimize inputs (costs)

Near term goals

Selection of biomass crop management systems

Establishment and maximum production for warm season C4 grasses

- Previous breeding efforts not for early yield (3-4 yr downtime)
- Variaties now in development that provide maximum yield early after establishment (1-2 yr)
- Noble Foundation in Oklahoma program aims to increase establishment from 50% to over 90% which will enhance production in early establishment years of the industry

Near term goals- Yield

Yield of 26.5 tons/acre observed by Young & colleagues in Illinois, without irrigation = 1 year! Miscanthus

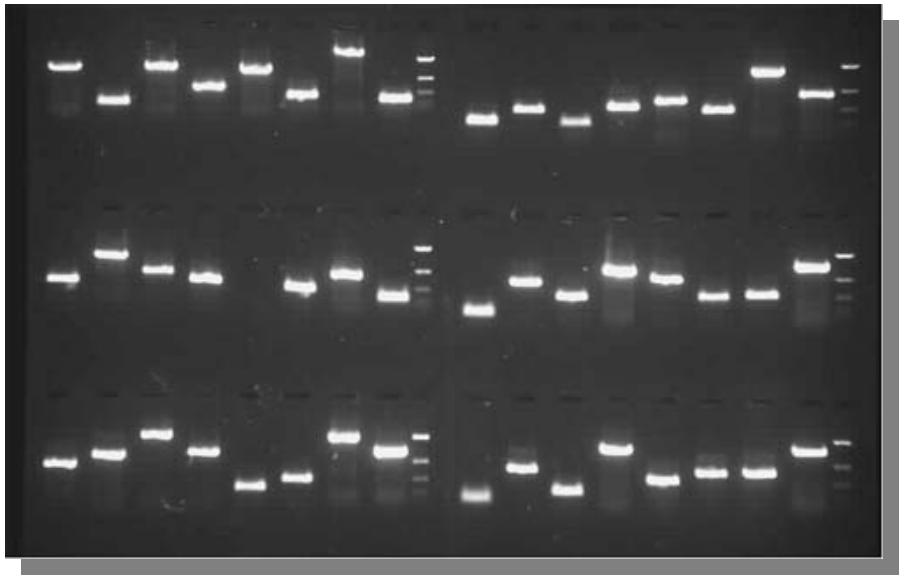
Courtesy of Steve Long et al

Yield of 12 tons/acre observed by Smith and colleagues in Kentucky, without irrigation = a native grass that is well adapted to marginal land conditions = 1 year! Eastern gamagrass. Over 7 years the yield was 4 tons/acre

Stork et al. (2009) Global Change Biology

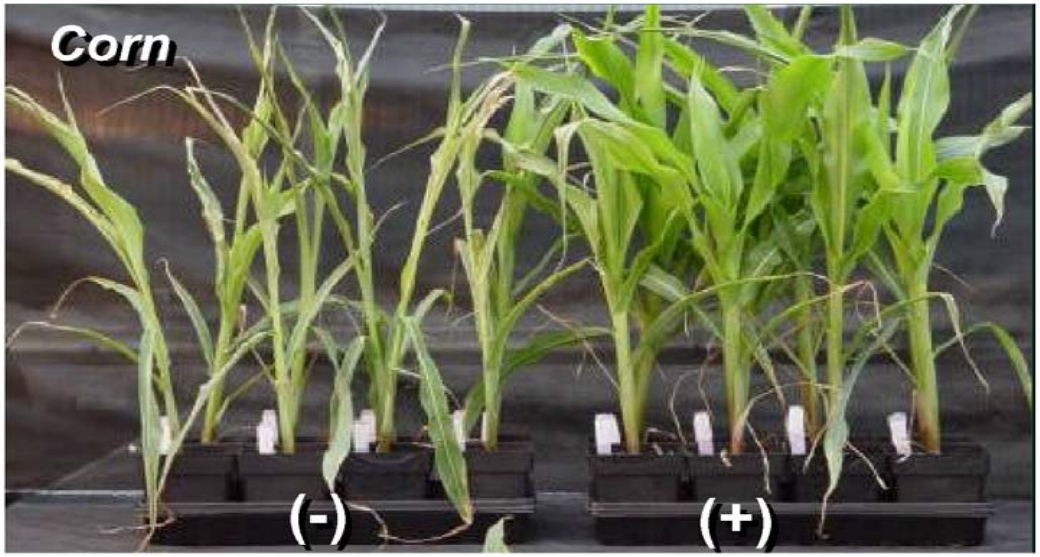
Near term goals- Yield increase

- 20% higher yield recently identified by traditional breeding in switchgrass ‘Alamo’- among the first efforts towards breeding for yield
- Molecular assisted breeding techniques have strong potential to create an additional 50% increase in yield - Goal 10 yrs



Near term goals- advanced biotechnology

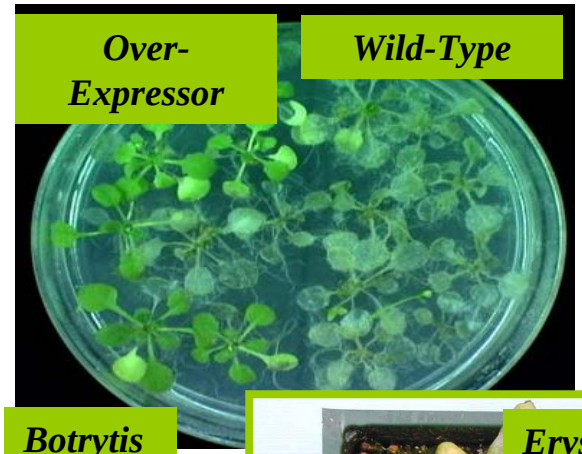
Progress in engineering crops plants for drought resistance



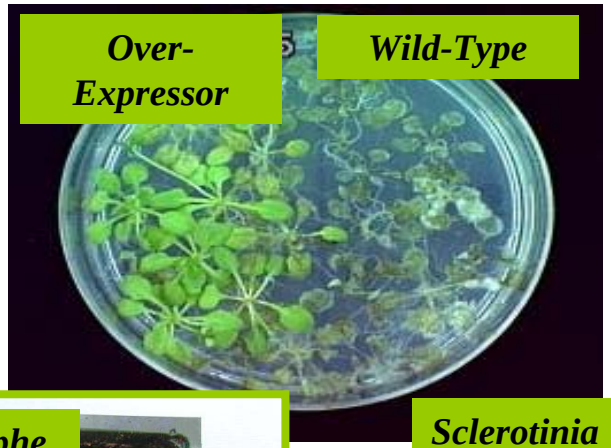
From Monsanto presentation to investors, May 8 2003

Near term goals- advanced biotechnology

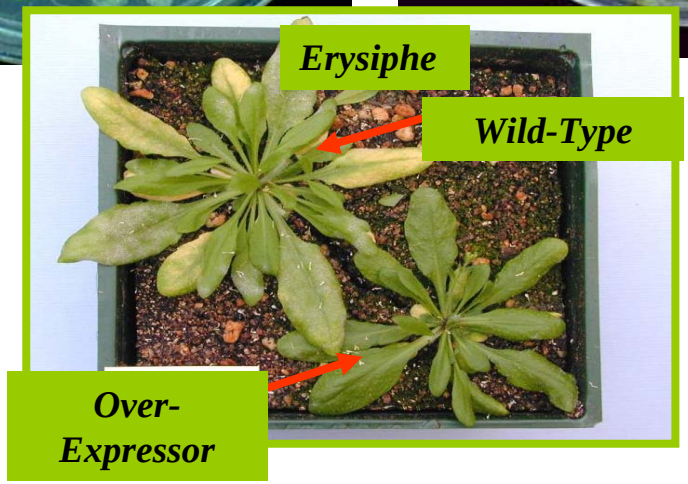
Broad-spectrum disease resistance



Botrytis



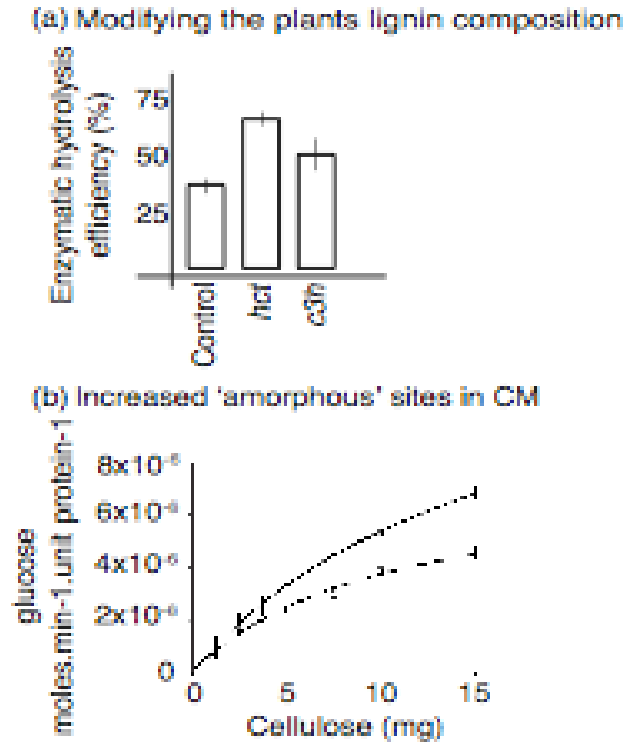
Sclerotinia



Courtesy of Mendel Biotechnology

Near term goals- Enhanced bioconversion

- 50 % increased cellulose conversion efficiency by modifying molecular machine (Harris et al. (2009) GCBB)
- 66 % increased cellulose conversion efficiency by knocking out lignin biosynthesis
- Create a model for energy grasses!
  - What will this look like?
    - Sorghum



UK-RF Patent Pending 1595-(2009), Chen and Dixon, 2007 NBT

Near term goals- Enhanced bioproducts industry

- **Production of value added bioproducts**
  - *Biochemicals*
  - *Biosolvents*
  - *Bioplastics*
  - *Smart biocomposites for manufacturing*
    Ancillary economy
  - *Biolubricants*
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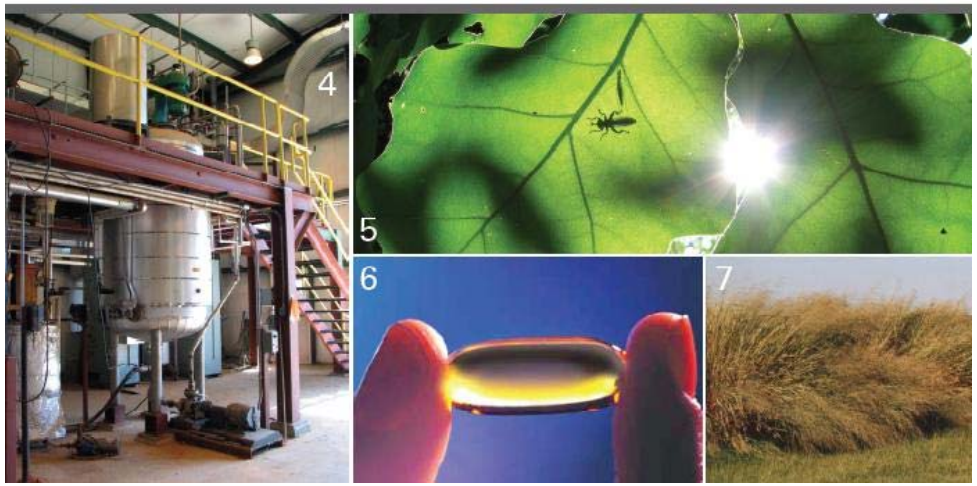
  - *Biocatalysts*
  - *Biosensors*



www.auburn.edu

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Thankyou for your attention

Acknowledgement
UK College of Agriculture
National Science Foundation
Chris Somerville – BP Center
Mendel Biotechnology

Near term goals- advanced biotechnology

Genetic engineering of freezing tolerance in Canola

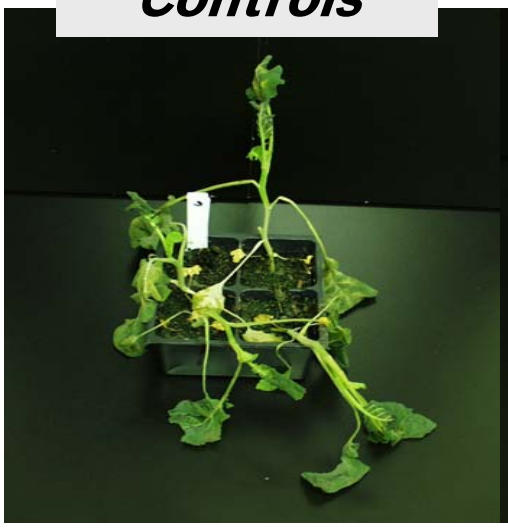
Control and CBF-canola before freezing

Controls

CBF-Canola

Control and CBF-canola after 2 days @ -6°C

Controls



CBF-Canola

Courtesy of Mendel Biotechnology

Challenges-

Target areas for biotechnology and breeding research

1. 2nd generation lignocellulosic biofuels crops
   - C4 grasses- such as miscanthus, switchgrass, eastern gamagrass
   - Short rotation, high density forest crops- willow, poplar, black locust

2. Development of high yielding varieties

3. Adaptation to marginal lands

4. Crops that require fewer agricultural inputs

5. Higher energy density of plant biomass

6. Develop high value bio-products industries driven by biofuel byproducts

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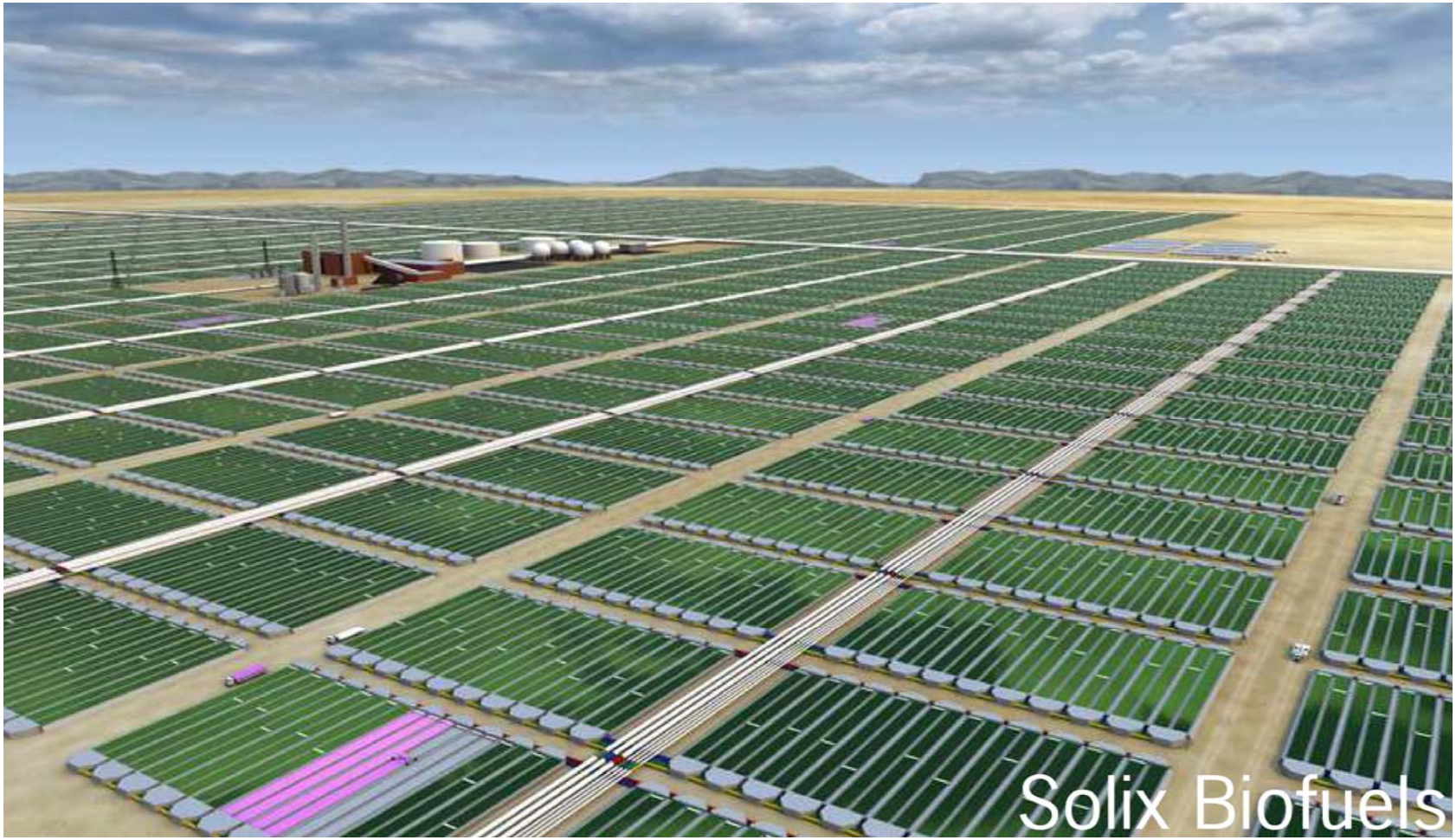
Vision of an algal fuel facility-



http://www.solixbiofuels.com/html/home.html

Challenges- Yield (An energy crop- Miscanthus)

Yield of 26.5 tons/acre observed by Young & colleagues in Illinois, without irrigation

Courtesy of Steve Long et al

Predicted increase in global mean temperature due to CO_2 accumulation

What are advance biofuels going to use?

Responsible Biofuels

- No conversion of undeveloped land
- No erosion, runoff, nitrous oxide emissions
- Net GHG benefits based on full lifecycle accounting
- No impact on food

Where does Kentucky fit in?

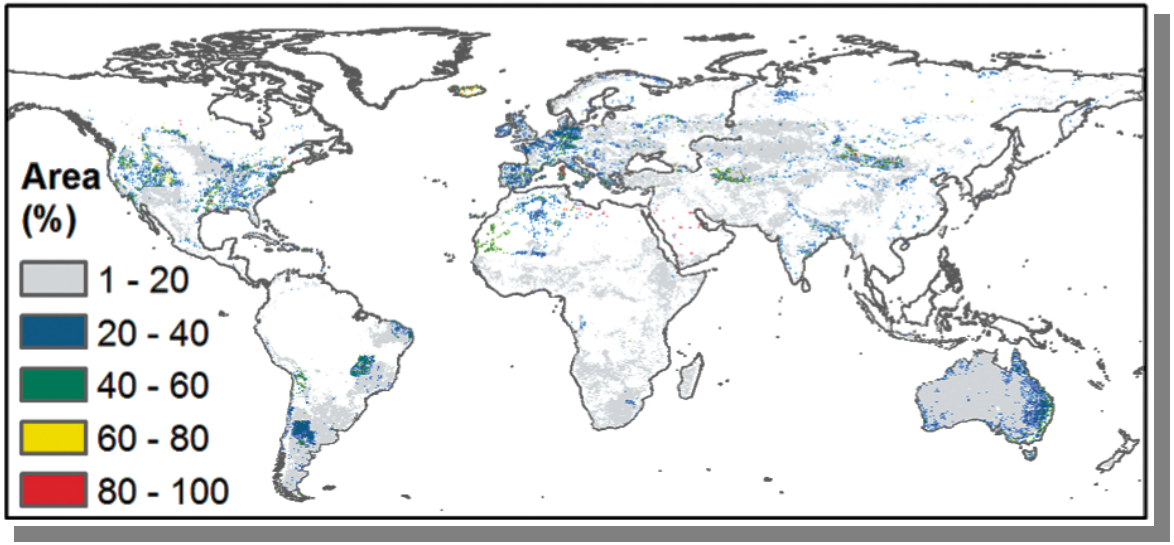
BIOMASS- lignocellulosic fuels

1
- Solid, burned directly
- Lipid to diesel

2
- Sugar to ethanol
- Cellulose to ethanol

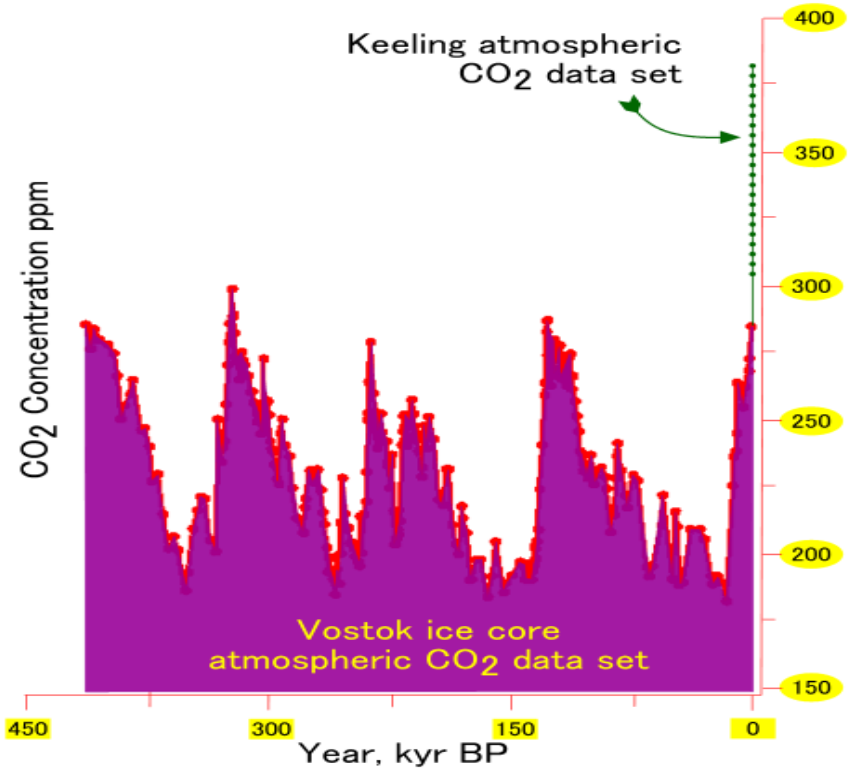
3
- Cellulose to syngas
- Cellulose to diesel or petrol

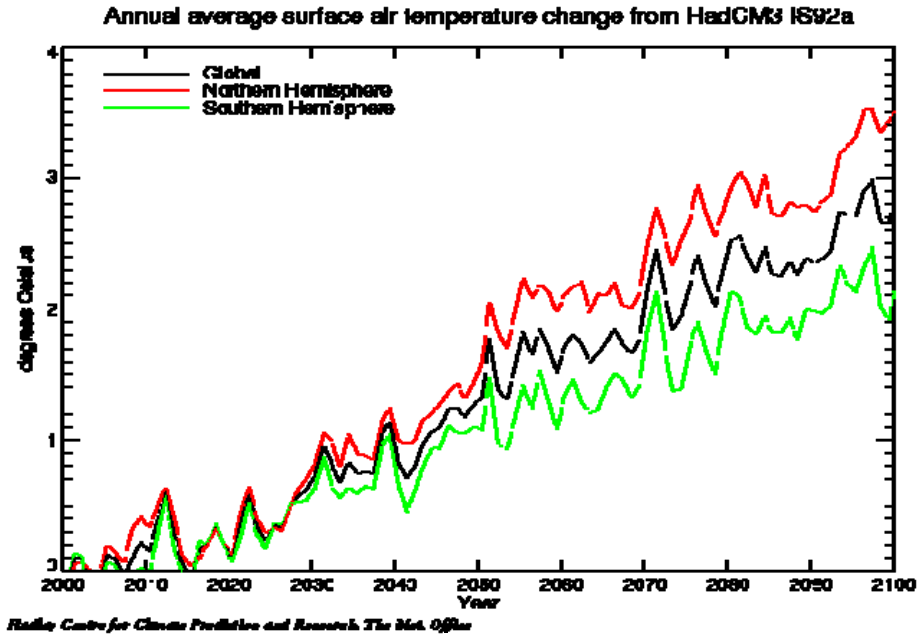
Responsible biofuels concept-
A billion acres of abandoned land worldwide



Campbell (2008) Env Sci Technol. Campbell et al., 2009 Science

2. Atmospheric CO2 is rising rapidly, which influences temperature- - ecological consequences on our way of life





Near term goals- advanced biotechnology

Tolerance to extreme abiotic stress
Plants grown in 300 mM NaCl (sea water is 330 mM)

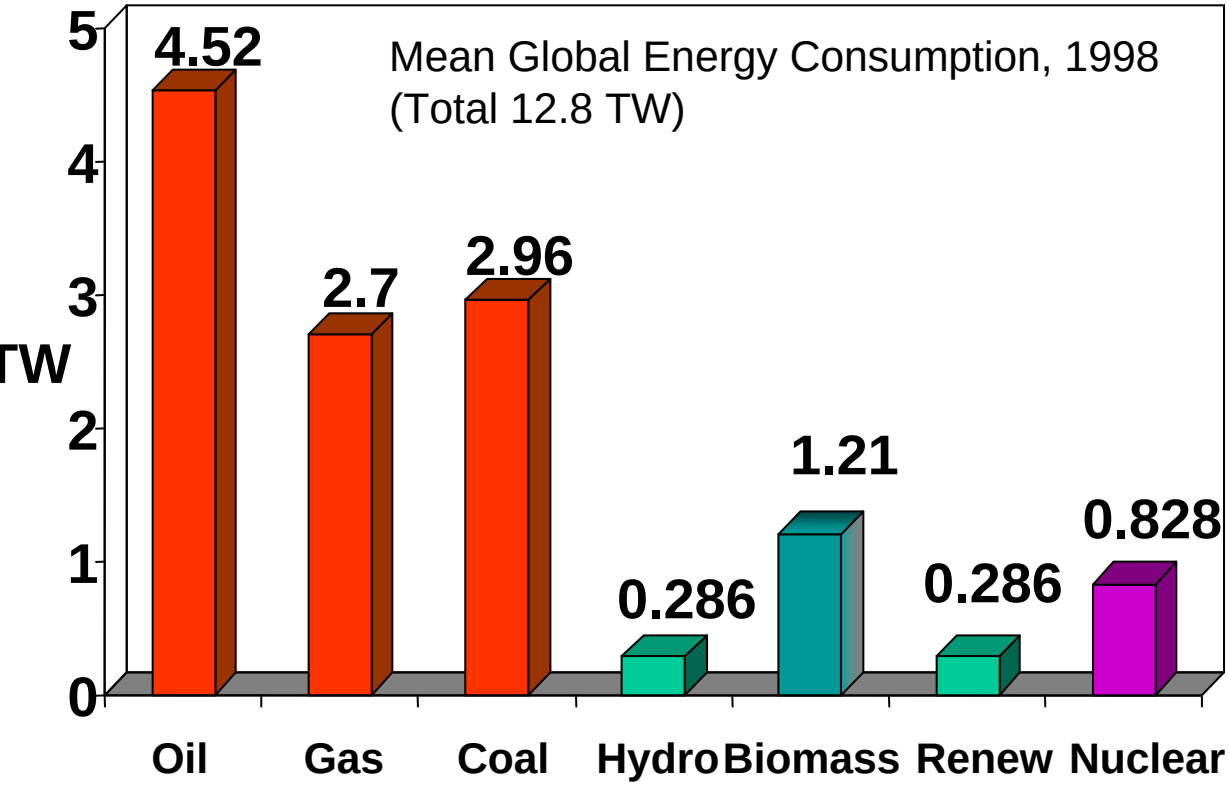
Many reasons for seeking renewable energy:

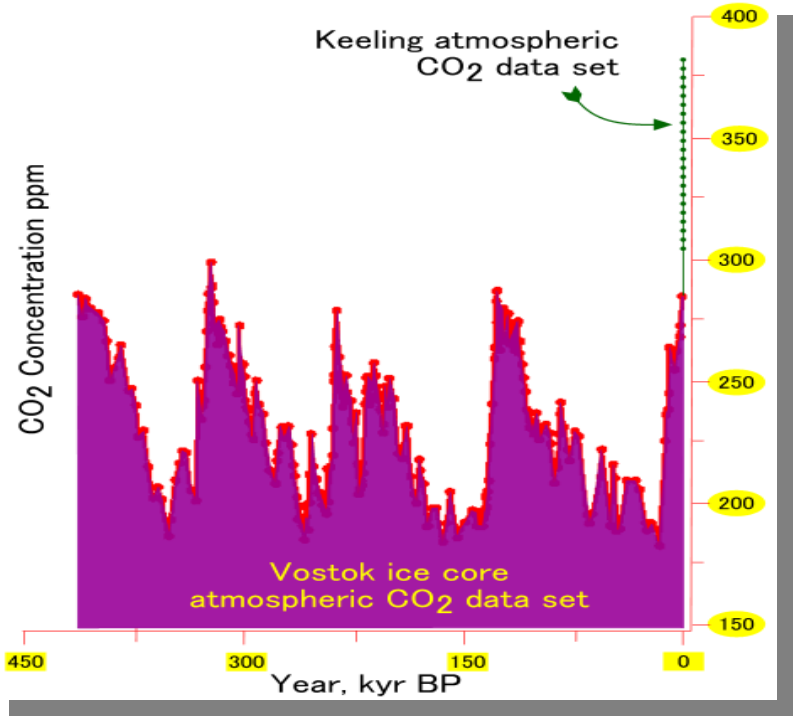
Fossil energy will inevitably runout -

strategic concerns –

create innovative industry –

Atmospheric CO2 is rising rapidly - temperature- - ecological /economical consequences





Potential of carbon-free and renewable energy sources- Think Global!

To meet an estimated consumption 25 TW in 2050

- Nuclear
  - 1 new plant every 2 days for next 45 y
- Wind
  - 4 TW worldwide (~ 2 million windmills)
- Hydro, ocean, thermal
- Photovoltaics
- Biomass

Availability of renewable is regionally constrained