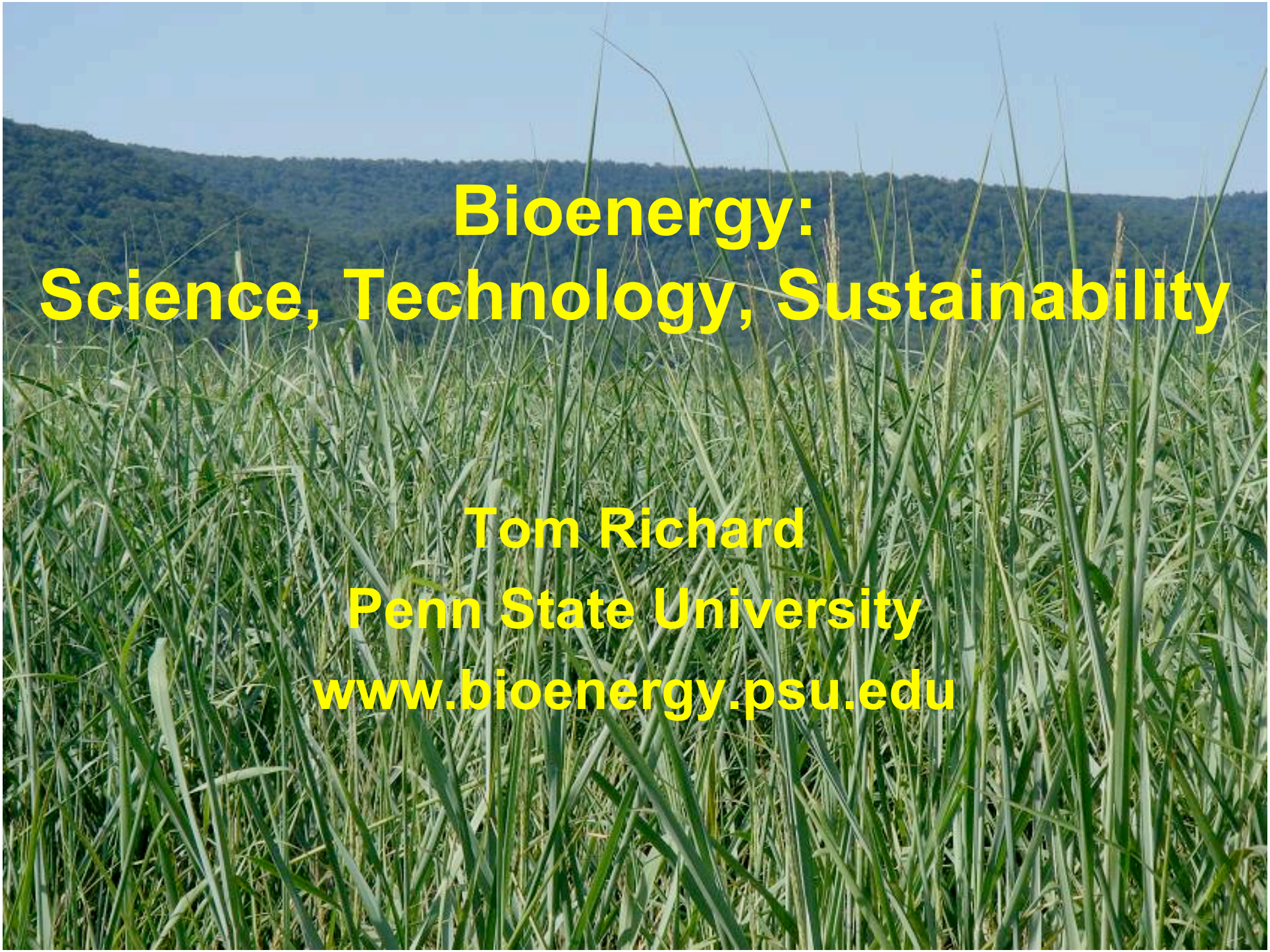
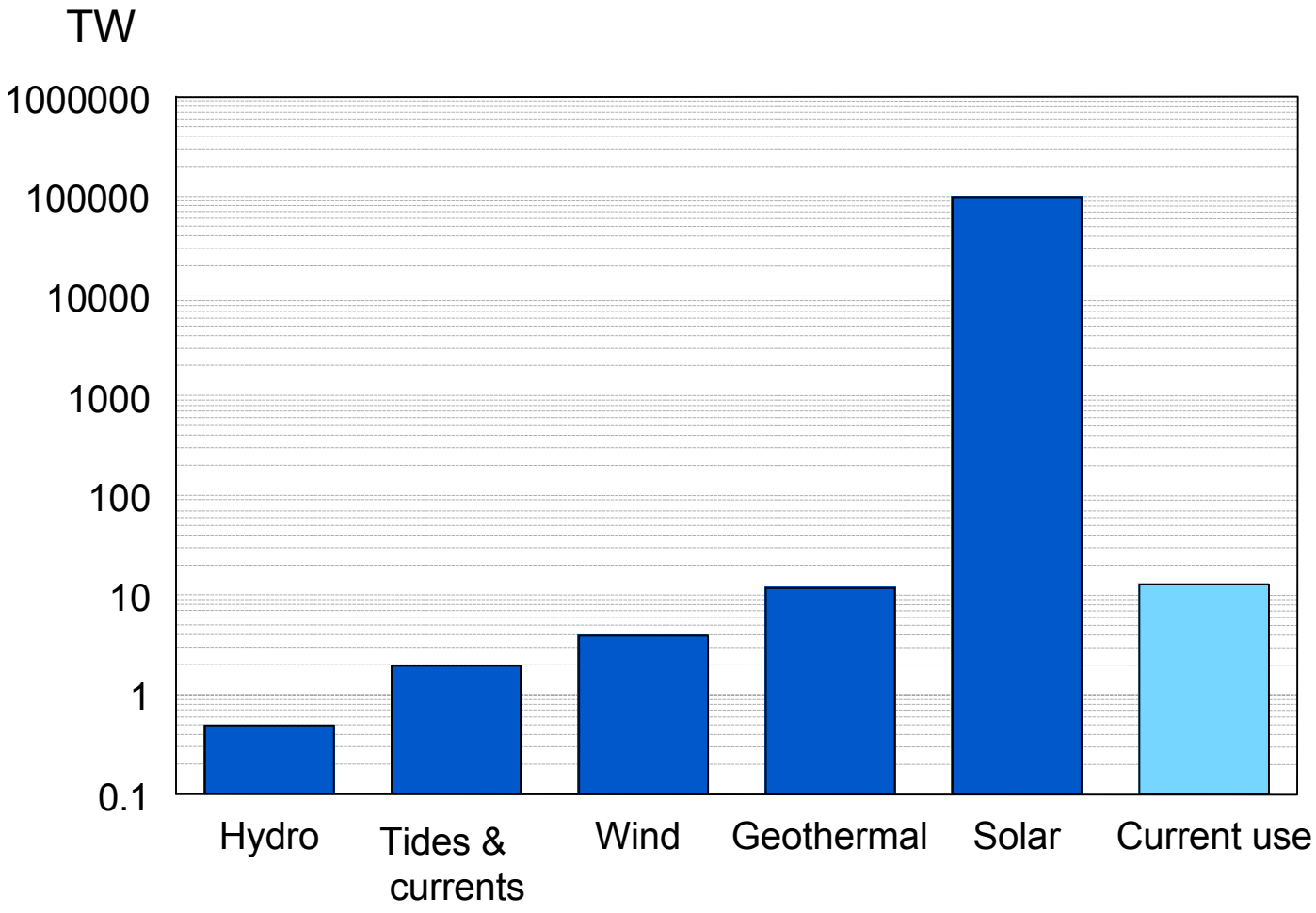
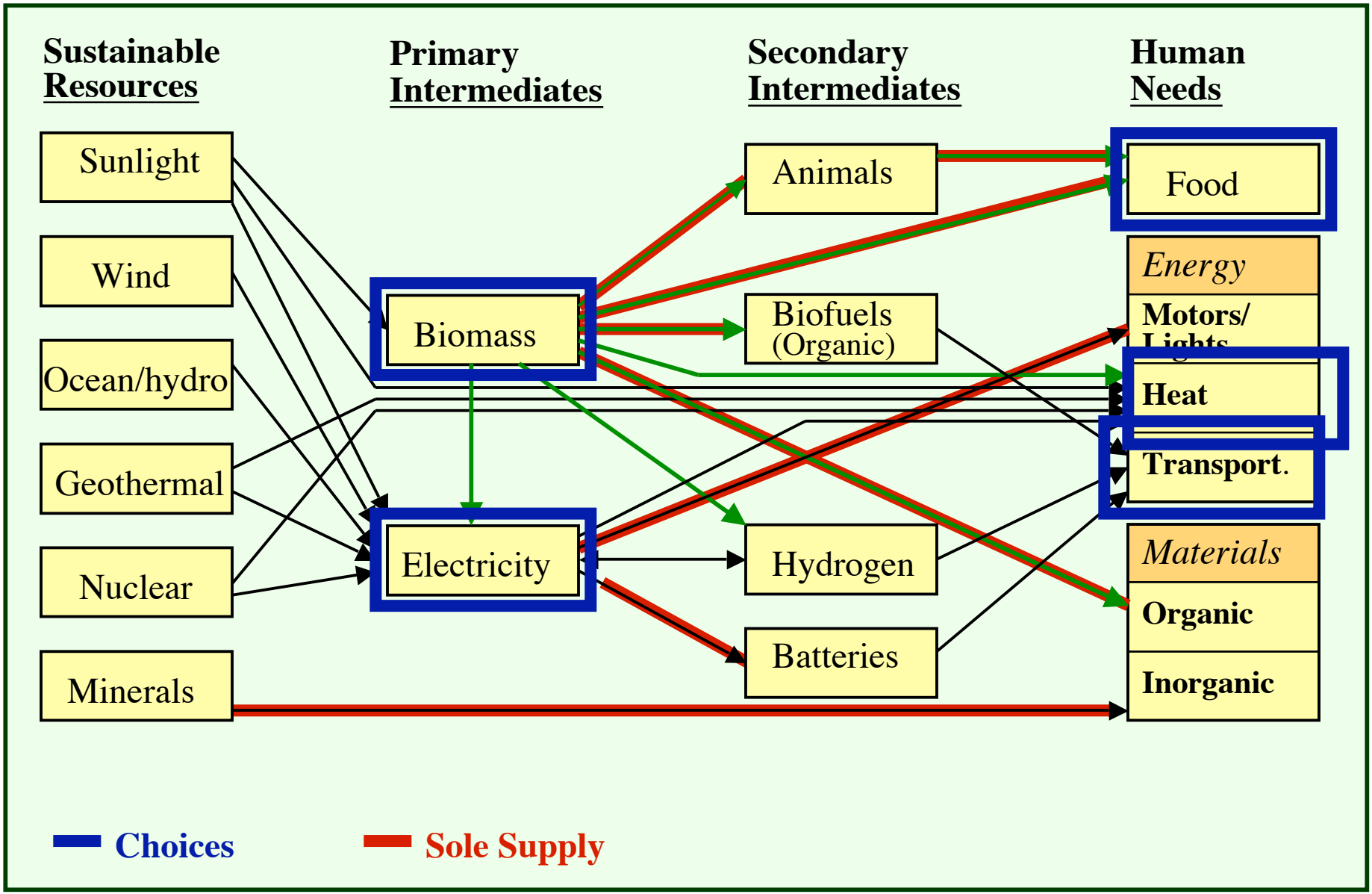

Bioenergy:
Science, Technology, Sustainability
Tom Richard
Penn State University
www.bioenergy.psu.edu

Potential of underused renewable energy sources



From: Basic Research Needs for Solar Energy Utilization, DOE 2005

Imagining a Sustainable World



Lee Lynd, Dartmouth College

Principal Biomass Conversion Pathways

- Production
- Collection
- Processing
- Storage
- Transportation

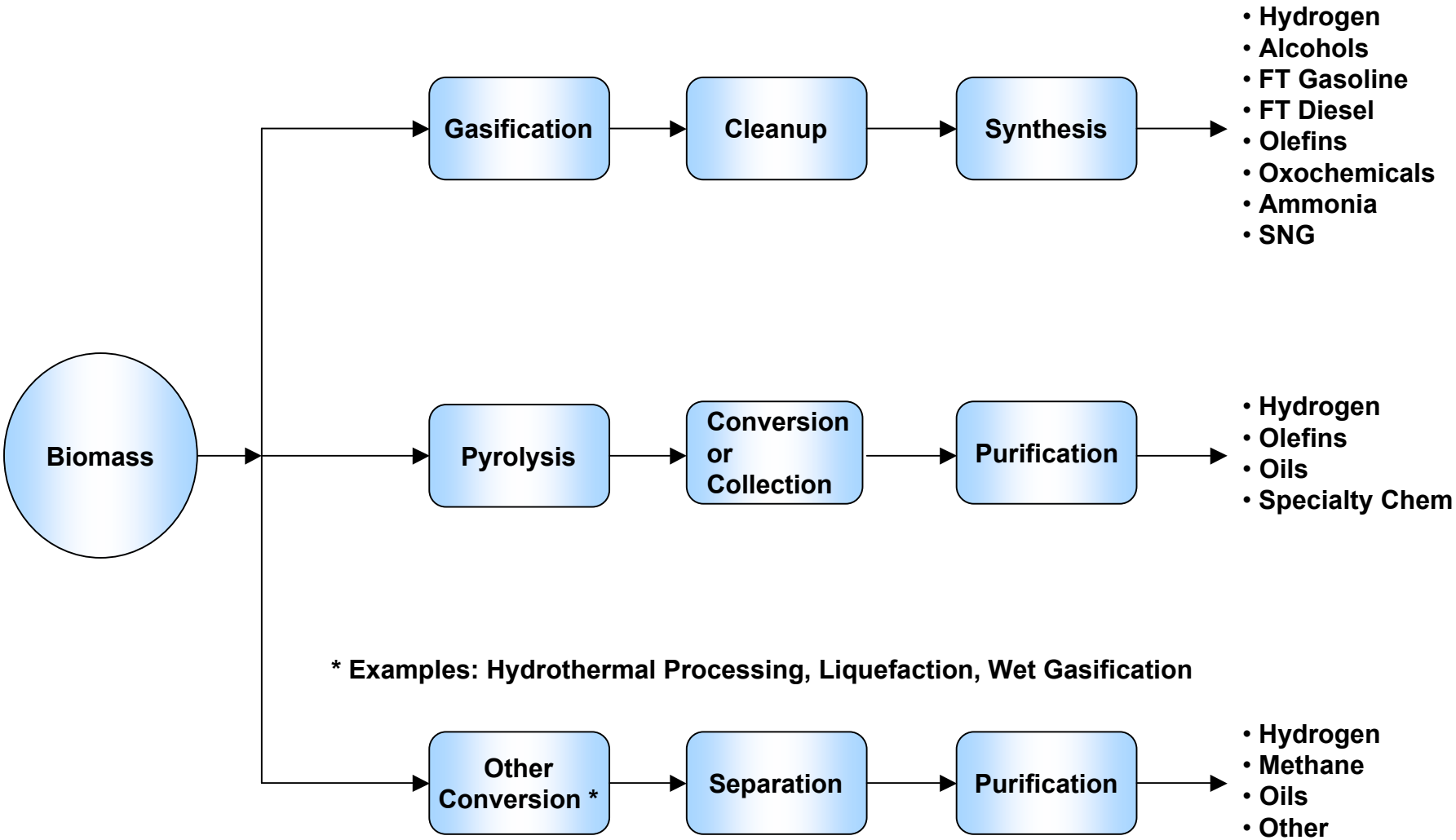
- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
  - Refining
- Biochemical Conversion
  - Anaerobic/Fermentation
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Esters
  - Alkanes

- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

Biomass Feedstock → **Integrated Biorefinery** → **Value added products**

Bryan Jenkins, UC Davis

Thermochemical Technologies



Bryan Jenkins, UC Davis

Ethanol Production Today

BRAZIL

sugarcane

(sucrose)

extract → Sugars → ferment → **ethanol**

USA

corn

(starch)

Hydrolyze (enzymes) → Sugars → ferment → **ethanol**

Brazil and the US are the leaders in ethanol fuel production
They use the “easy way” to make ethanol.

Dan Cosgrove, Penn State

Cell walls → fuel

Slow & expensive step

"recalcitrance"

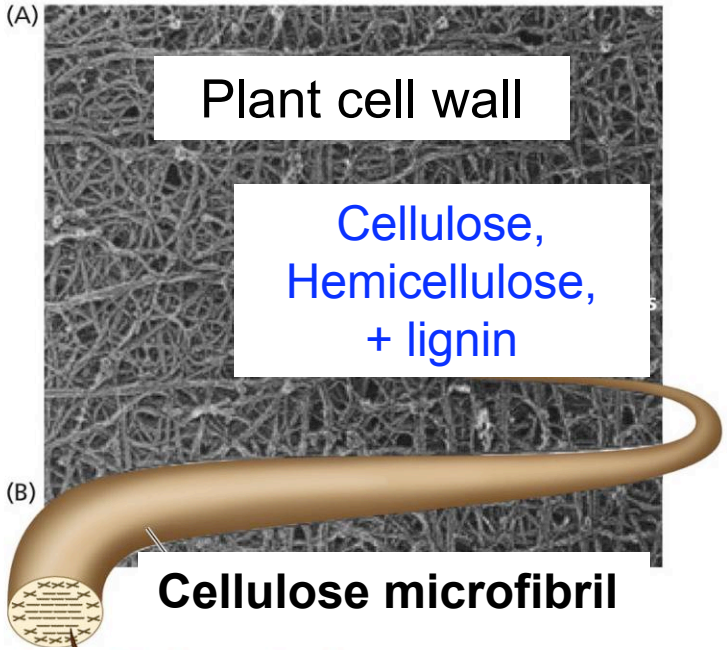
enzyme digestion

chemical pretreatments

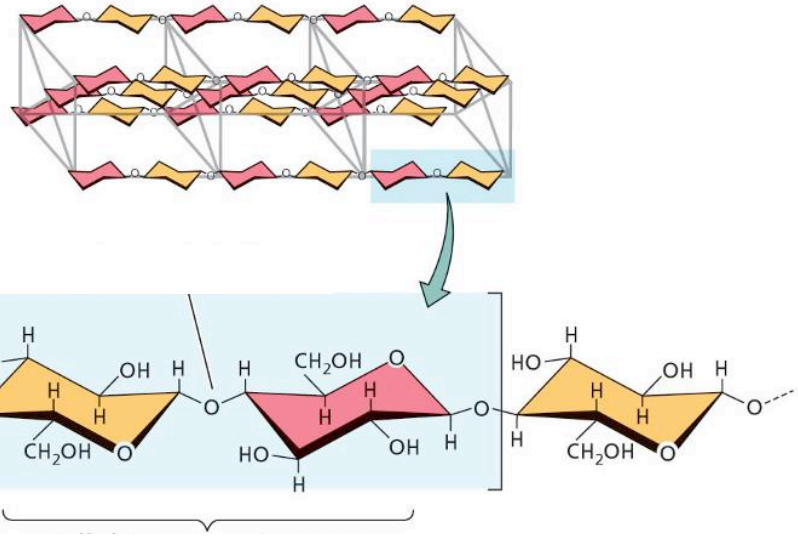
sugars

Fermentation

ethanol



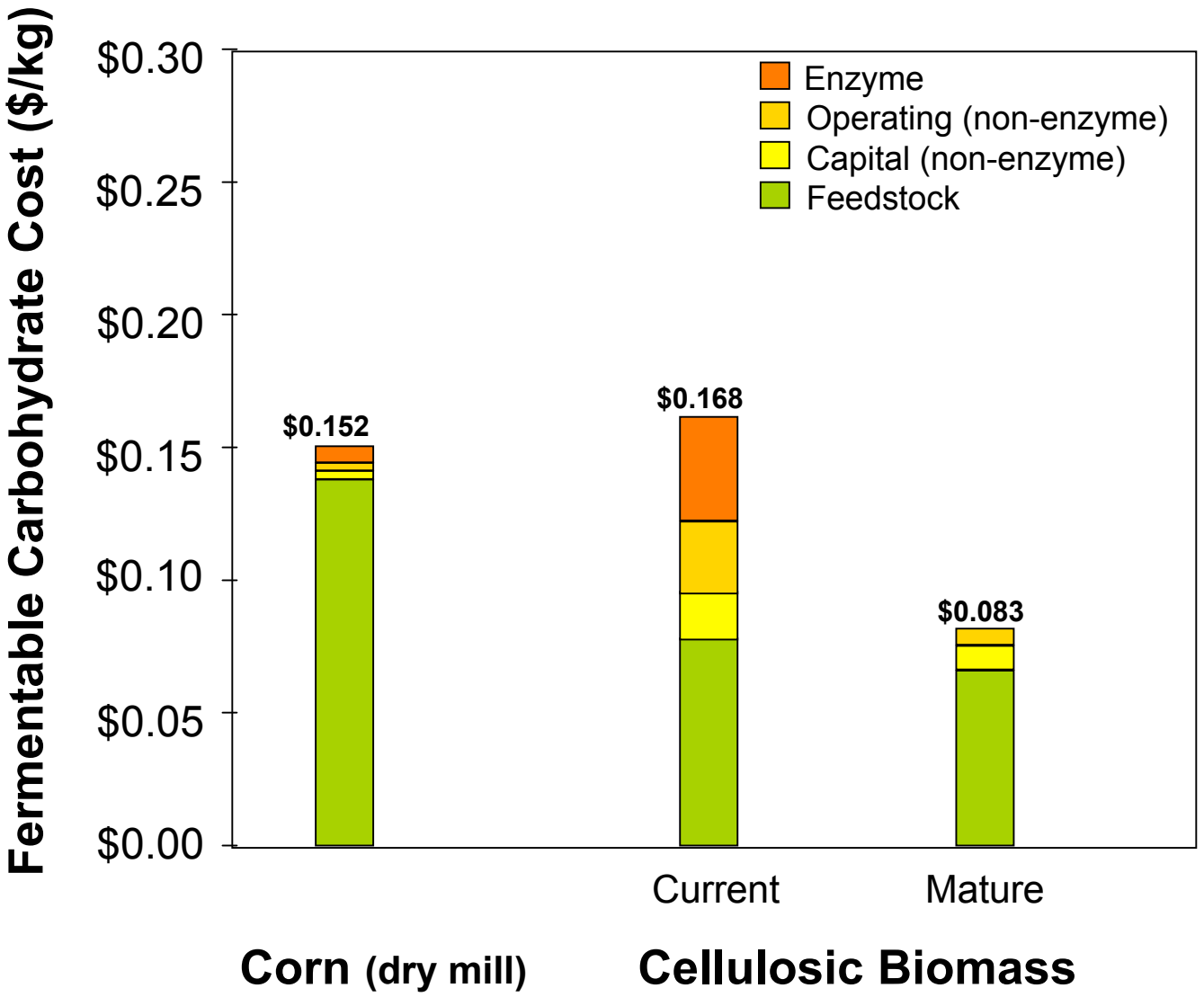
Cellulose microfibril



Parallel strands of glucose polymers

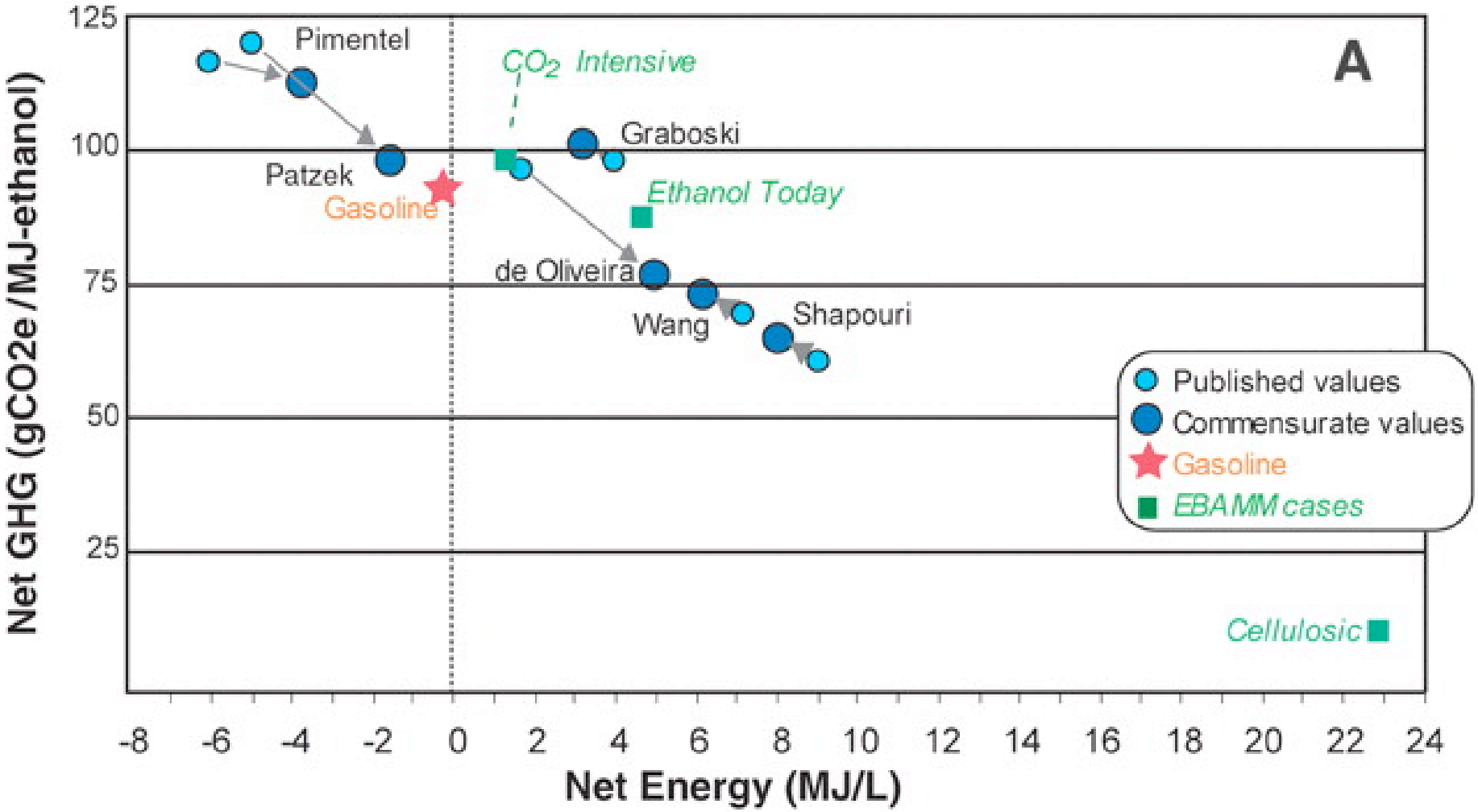
Dan Cosgrove, Penn State

Economic Drivers: Biological Processing of Lignocellulose



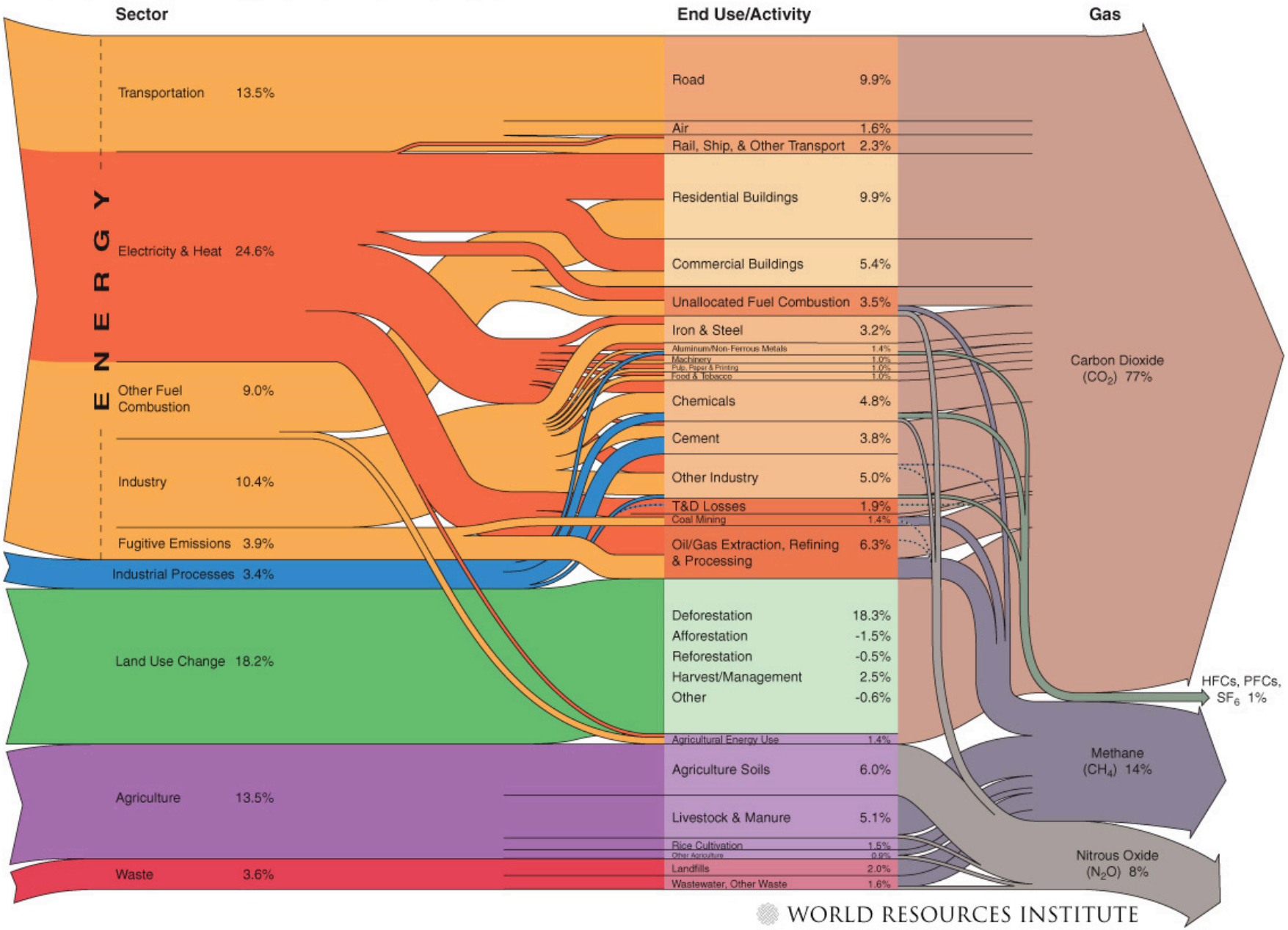
Laser and Lynd, 2007

Net energy and net greenhouse gases for gasoline, six studies, and three cases



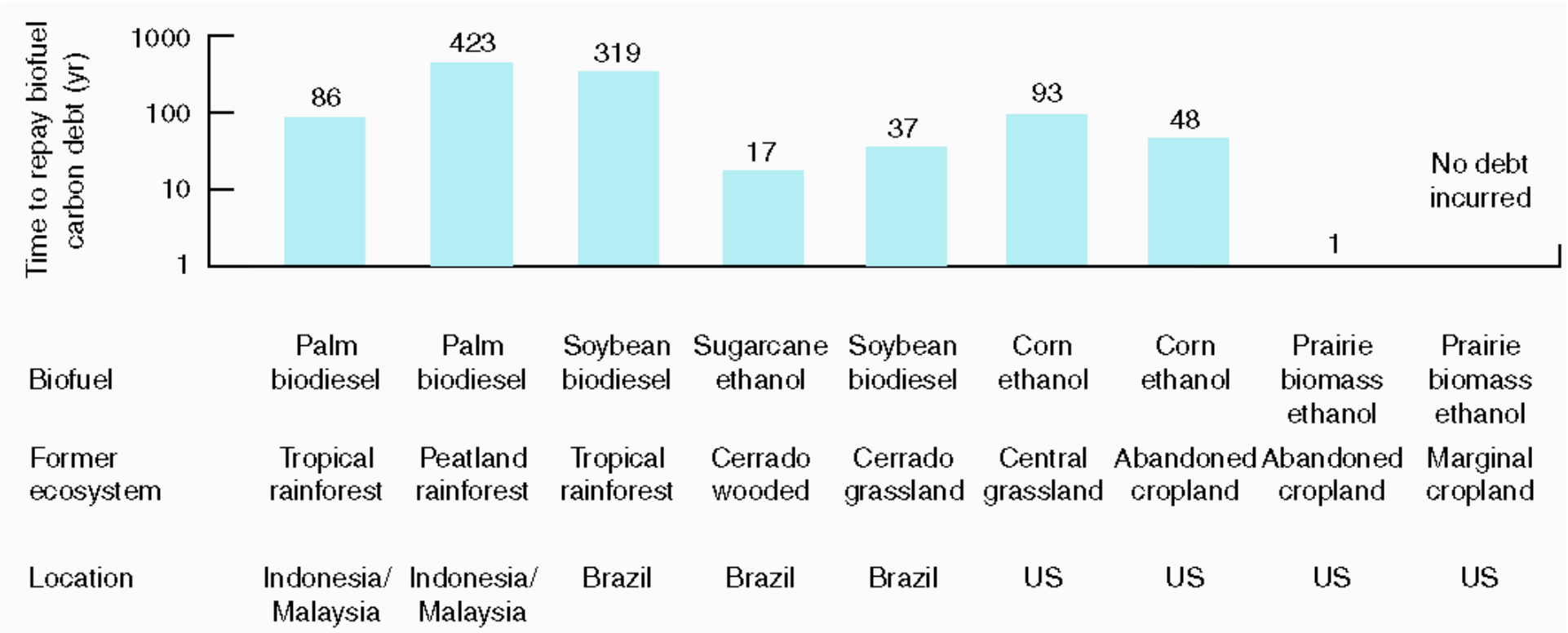
A. E. Farrell et al., Science 311, 506 -508 (2006)

World GHG Emissions Flow Chart



WORLD RESOURCES INSTITUTE

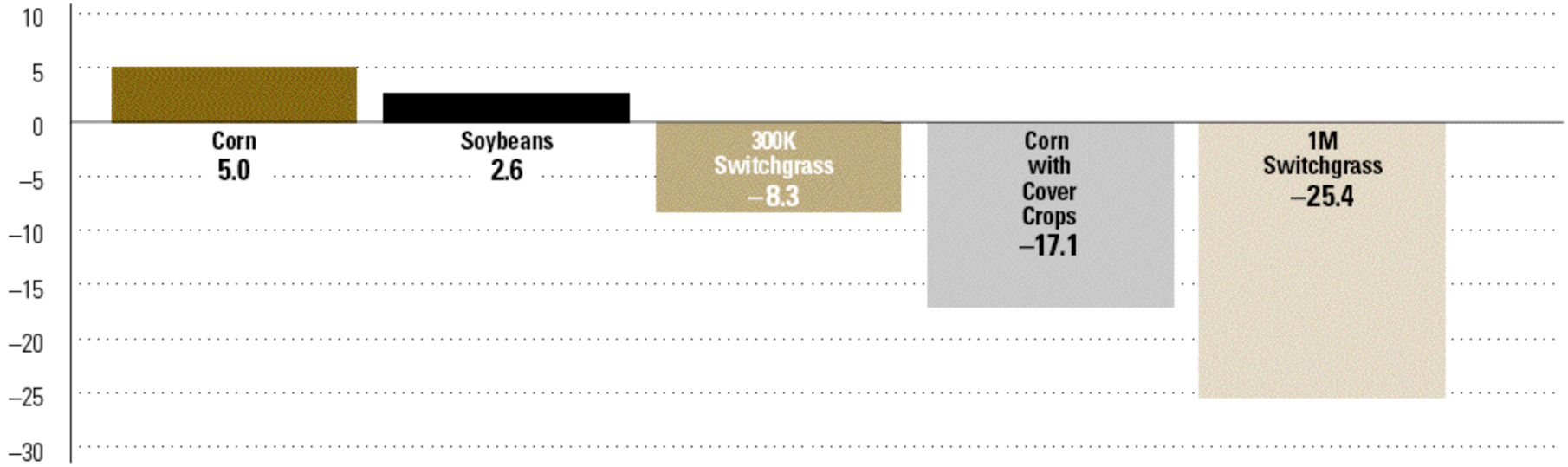
The Carbon Debt Mortgage from Land Use Change



Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne, 2008, "Land Cleaning and Biofuel Carbon Debt," *Sciencexpress*, available at www.sciencexpress.org, Feb. 7.

Maximum Nitrogen Load Changes for Biofuels

Millions of pounds per year of nitrogen delivered from the Chesapeake Bay watershed to the Bay under five modeling scenarios.



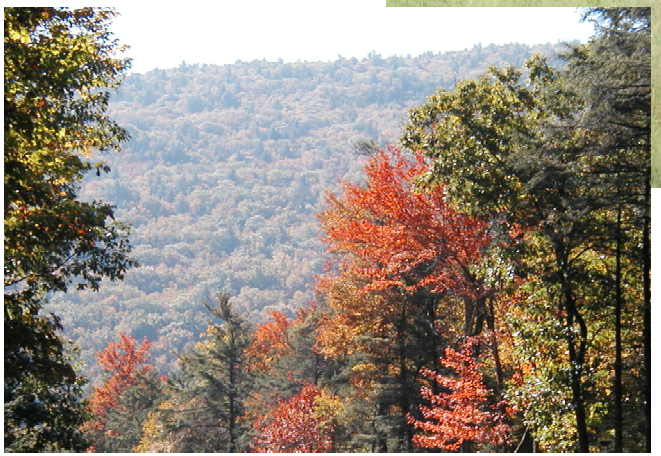
Assumptions for Alternative Scenarios:

- **Corn:** 300,000 additional acres of corn with typical levels of management practices
- **Soybeans:** 300,000 additional acres of soybeans with typical levels of management practices
- **300K Switchgrass:** 300,000 acres of switchgrass, converted primarily from hay and pastureland, with no fertilization
- **Corn with Cover Crops:** Cover crops on all existing and new (additional 300,000) corn acres and one quarter of all other row crops, watershed-wide.
- **1M Switchgrass:** 1 million acres of switchgrass, converted primarily from hay and pastureland, with no fertilization

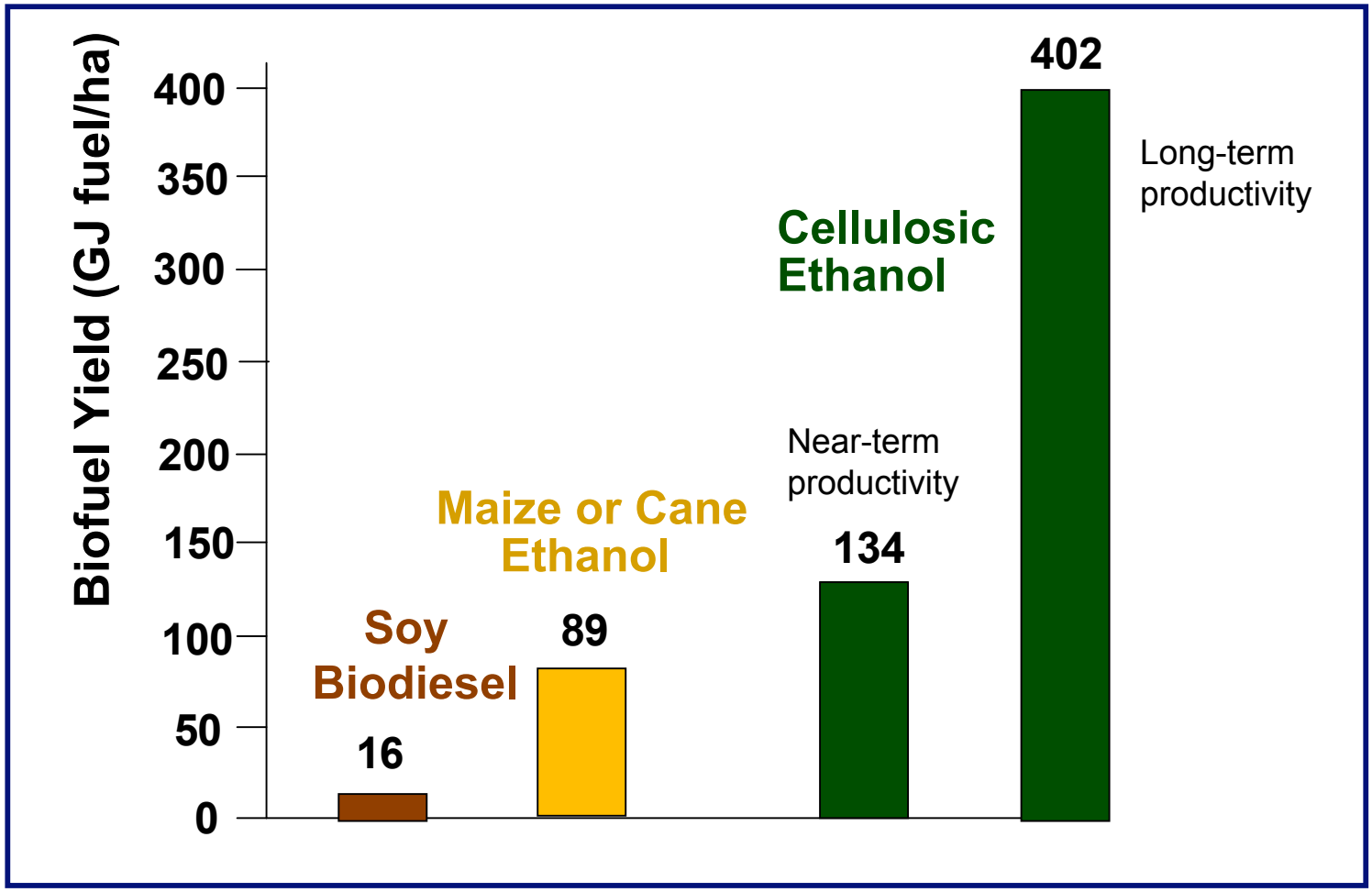
SOURCE: U.S. EPA CHESAPEAKE BAY PROGRAM OFFICE

Five Sustainable Sources

- Organic Wastes
- Algae (?)
- Perennial Crops
- 21st Century Forestry
- **Multi-functional Agriculture**

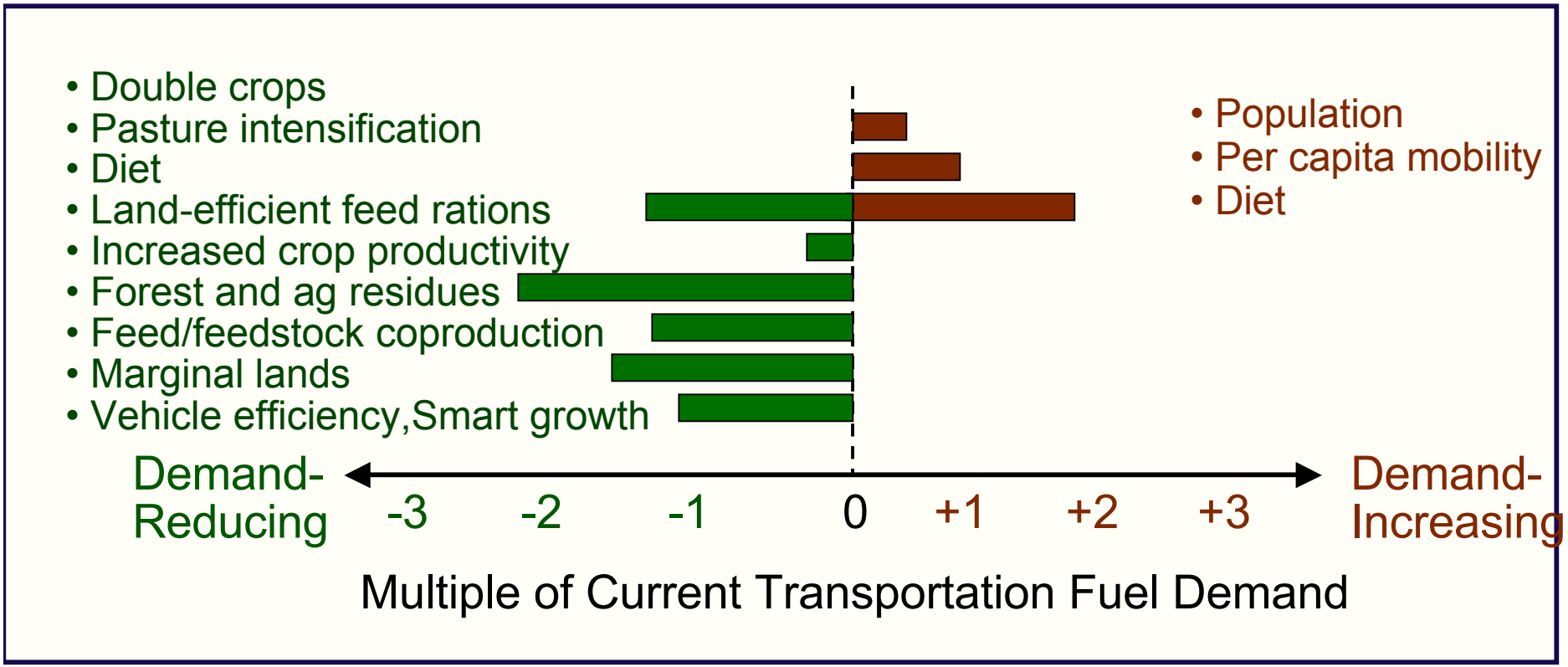


Comparative Land Productivity of Biofuel Options



Crop Yields (U.S. except Cane)	Fuel Yields
Near-term cellulosic: 5 dry ton/acre	Cellulosic ethanol 91 gal gasoline eq./ton (RBAEF)
Long-term cellulosic: 15 dton/acre	Corn ethanol: 2.8 gal/bushel
Corn: 160 bushel/acre	Soy oil: 18% of bean (dry basis)
Cane: 3 tons sugar (dry)/acre	0.47 kg ethanol/kg sugar
Soy: 42 bushel/acre	Biodiesel yield: 0.95 kg/kg soy oil

Quantitative evaluation of land use impacts (global)

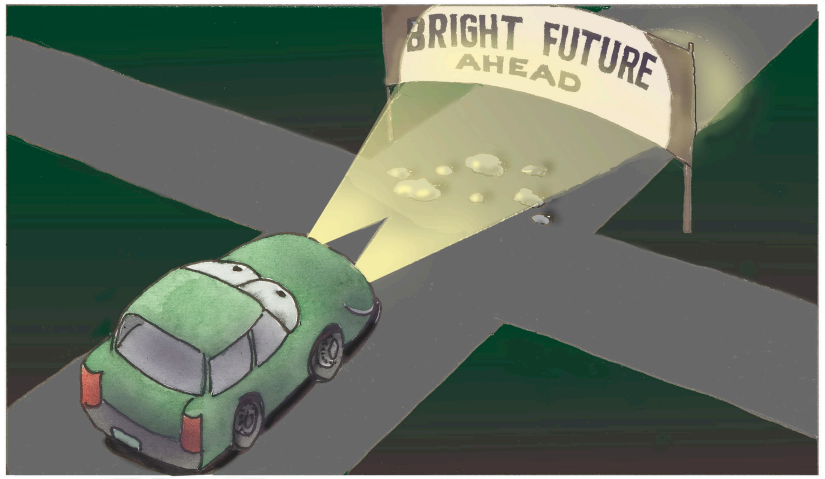


Global Sustainable Bioenergy: Feasibility & Implementation Paths - "GSB Project"

Project initiated (June, 2009)

- International Organizing Committee formed
- Joint statement in *Issues in Science and Technology*
- Web site launched

Key Question: *Is it physically possible for bioenergy to meet a substantial fraction of future world mobility and/or electricity demand while our global society also meets other important needs.*



"High Beams" Approach

Staged structure

1. Meetings, assemble international team, scope project, get support
2. Address key question posed above unconstrained by current realities
3. Work back to the present considering policy, economic, transition, and development issues

GSB Project: Stage 1 Meetings & Organizing Committee

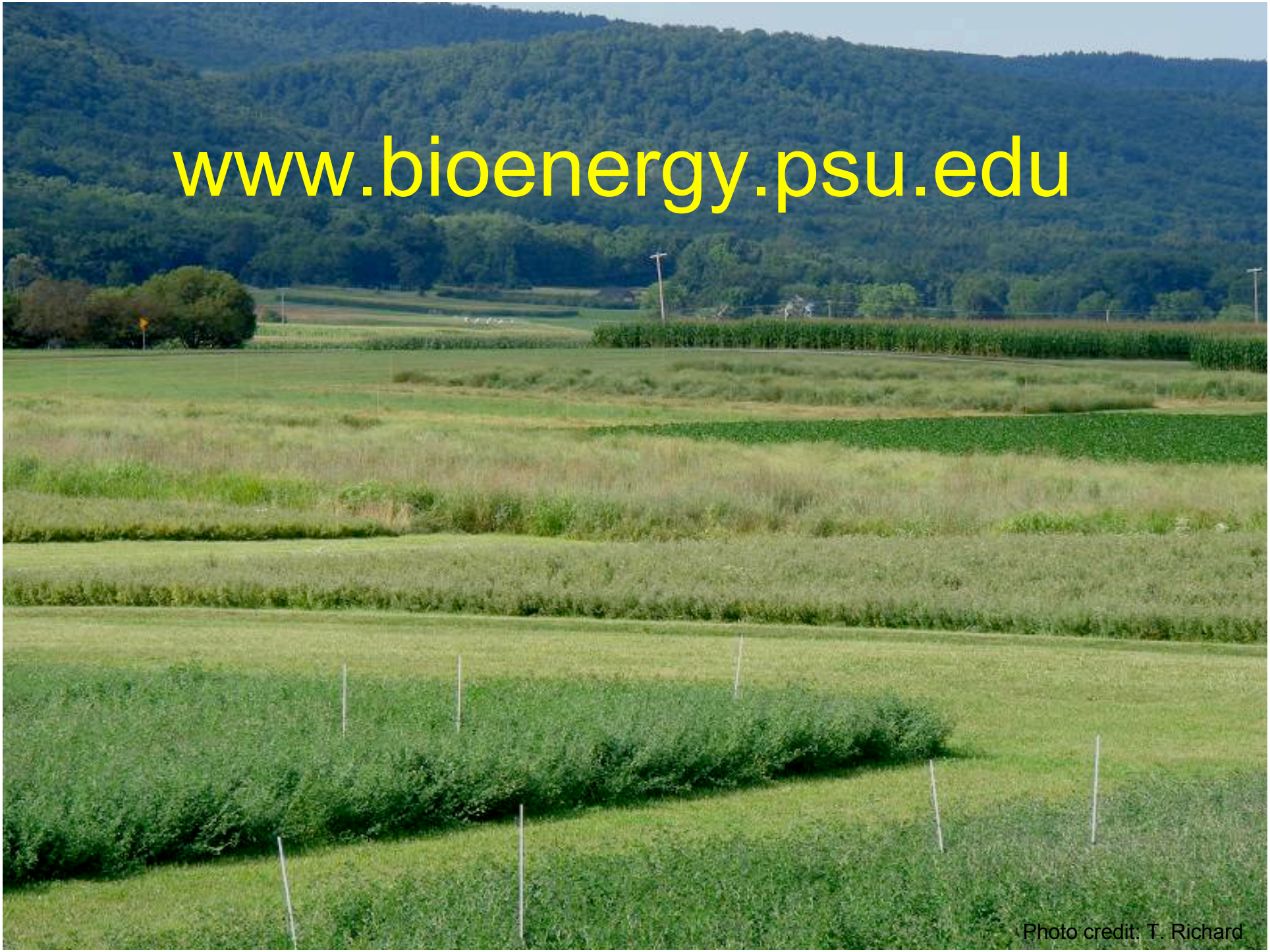
Representation	Host Institutions, Location	Meeting Chairs/ Organizing Committee Members	Dates
European Union	Kluyver Center for Genomics of Industrial Fermentations, Delft, The Netherlands	• Andre Faaij, Utrecht University • Patricia Osseweijer, Delft University of Technology	February, 24-26, 2010
Africa	University of Sellenbosch, Stellenbosch, South Africa	• Emile van Zyl, University of Stellenbosch • August Temu, World Agroforestry Centre, Nairobi	March, 17-19, 2010
South America	University of São Paulo, São Paulo, Brazil	▪José Goldemberg, University of São Paulo ▪Carlos Henrique de Brito Cruz, FAPESP, São Paulo	March, 22-24, 2010
North America	▪ University of Minnesota, Minneapolis/St. Paul, USA	• John Foley, University of Minnesota	May, 2010
Asia, Oceania	TBD	Reinhold Mann, Battelle Science and Technology, Malaysia	June 2010?

Steering Committee: Nathanael Greene, Natural Resources Defense Council

Lee Lynd (Chair), Dartmouth, Mascoma Corp.

Tom Richard, Pensylvania State University

- *Sustainable forests and agricultural systems are a prerequisite for sustainable biomass energy systems*


www.bioenergy.psu.edu
Photo credit: T. Richard