The Hydrologic Footprint of Large-Scale Bioethanol Production: A Comparison of Florida's Alternatives

Matt Cohen, Ph.D. and Jason Evans, Ph.D.
School of Forest Resources and Conservation
University of Florida

SFRC

UNIVERSITY OF FLORIDA
IFAS

L.V. Korhnak

Water Implications of Biofuels Production in the United States (2007)
Water Science and Technology Board (WSTB)

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Water Implications of Biofuels Production in the United States

Committee on Water Implications of Biofuels Production in the United States

Water Science and Technology Board

Division on Earth and Life Studies

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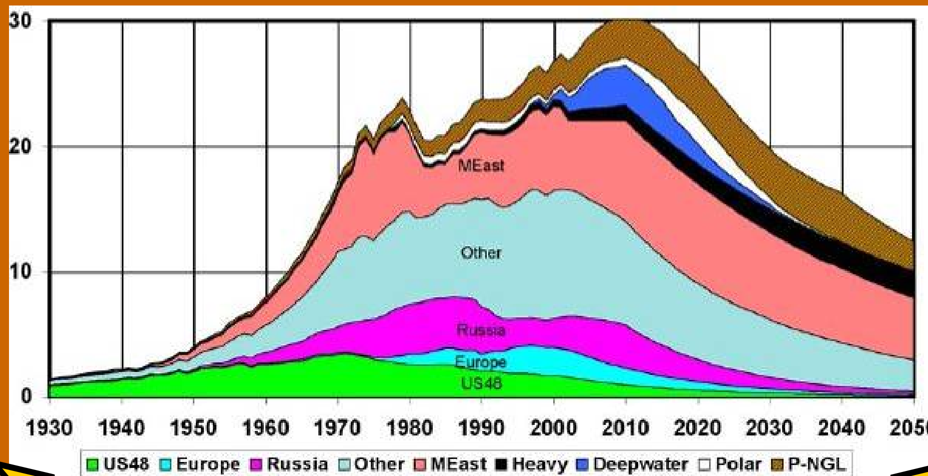
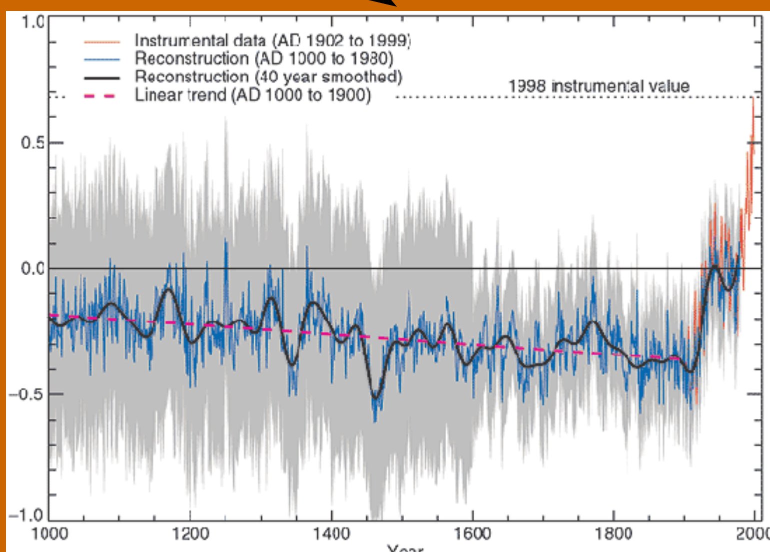
Global Rationale for Alternative Energy



Peak Oil (price$_{2/26/2008}$ = $100.88/bbl)



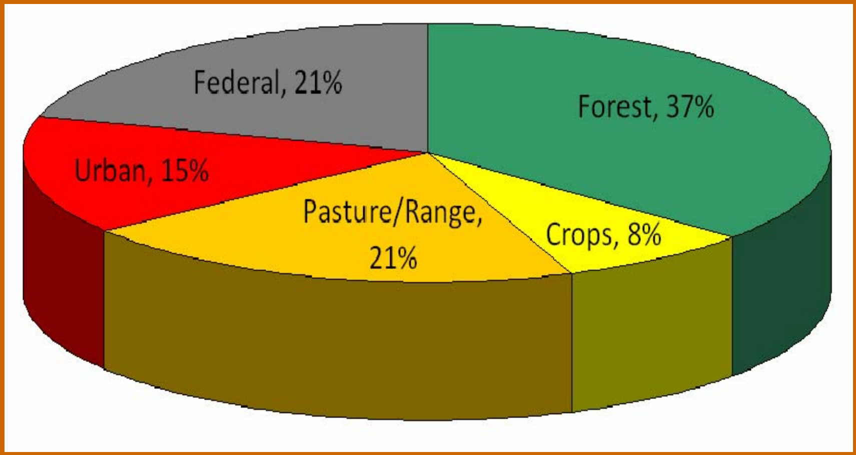
Global Climate Change

Geopolitics

Current Status

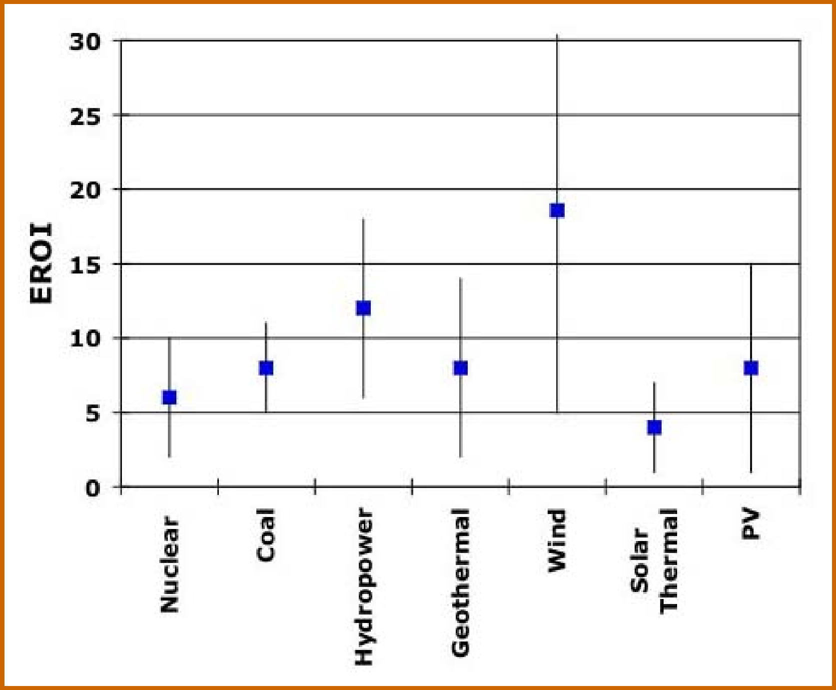
- Current Global Liquid Fuel Consumption
  - 1,200 billion L/yr
  - ~ 2% bioethanol + biodiesel (▲5.3% per yr)
- Principal producers of biofuels
  - USA (corn + soy) – 12.9 billion L/yr [2006]
    - Current liquid fuel use: 500 billion L/yr
  - Brazil (sugarcane) – 15.1 billion L/yr [2006]
    - Current liquid fuel use: 20 billion L/yr

- Liquid Fuel Consumption in Florida
  - Current Use = 1.11E18 J/yr
    - (28.9 billion L/yr)
  - Population ~ 17 million people (+1000/d)
  - Land Area ~ 13.7 million ha
    - Future production constraints



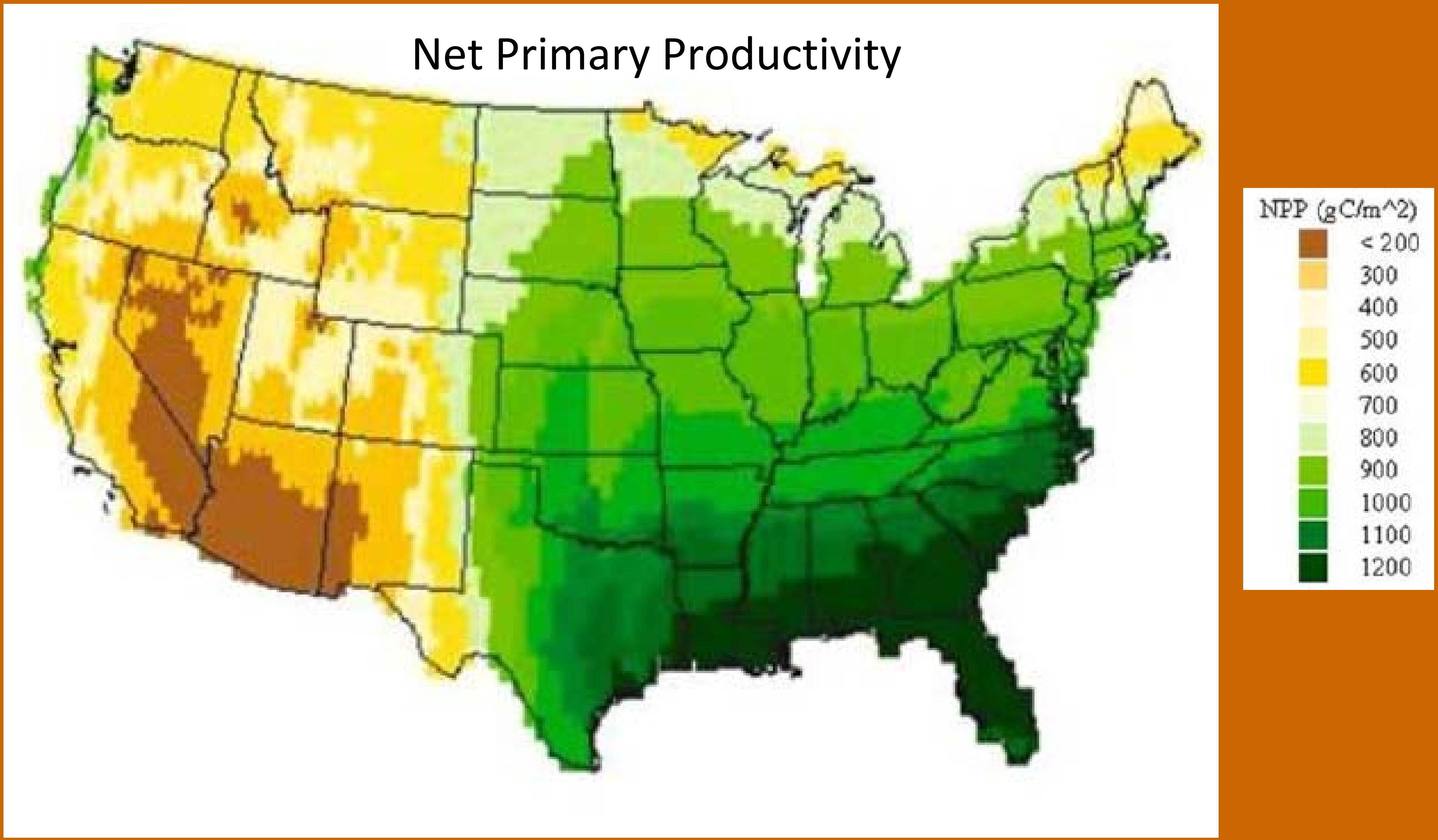
Future Energy

- Transportation sector most constrained
  - Liquid fuel (oil) dependence
  - Massive energy req's.
    - 27.5% of total US energy use
    - 2.65E19 J/yr = 26.5 exajoules/yr
- Electricity sector has more alternatives
  - Wind, Coal, Nuclear, Solar
  - EROI = Energy Delivered/Energy Req'd
- We focus here on <u>liquid fuel</u> replacement
  - Bioethanol/biodiesel



Electric Power Options – Energy Return on Investment
http://www.eoearth.org/image/EROI_electric_power.jpg

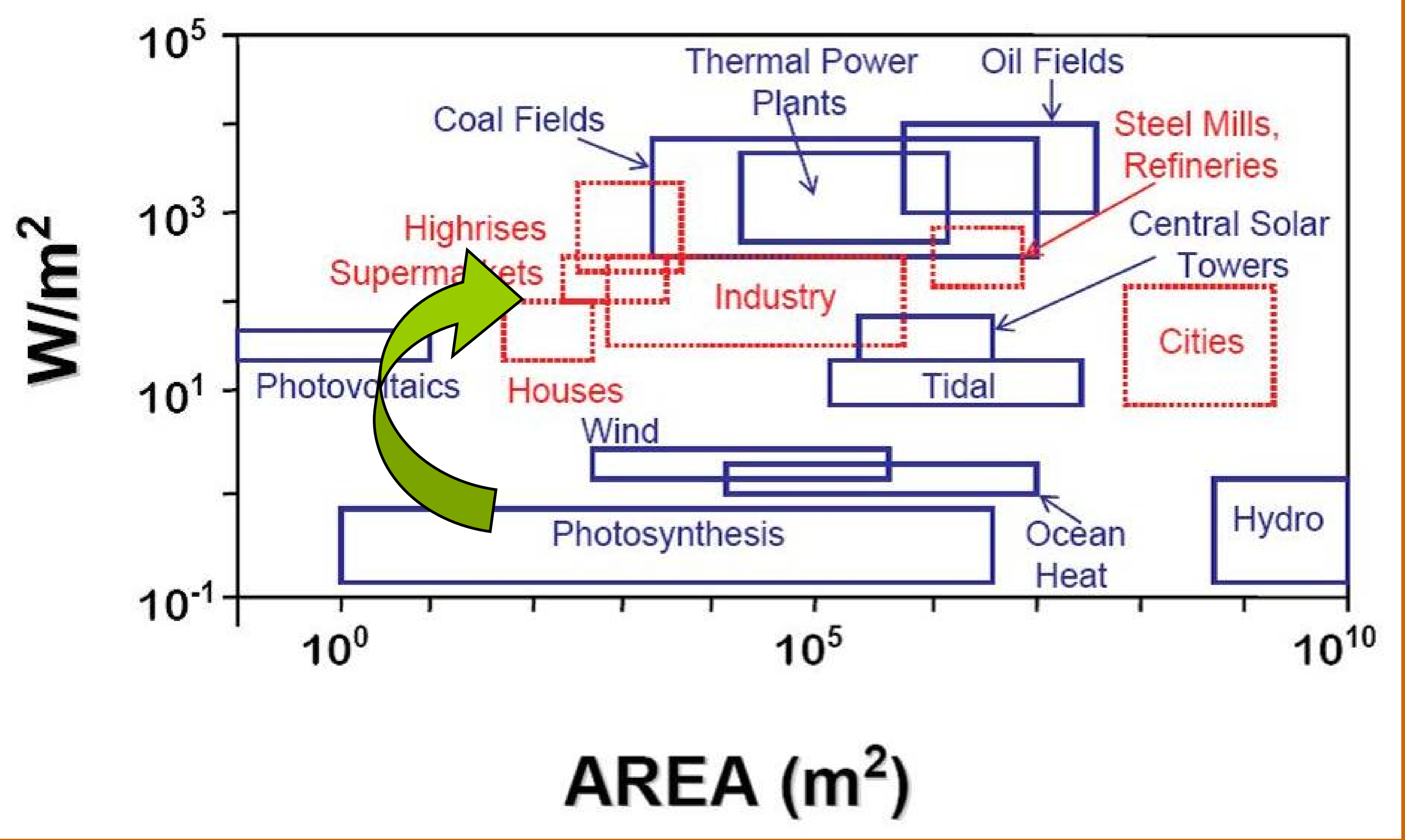
Where to Grow Future Feedstocks?



Izaurralde et al. 2005 (Climatic Change)

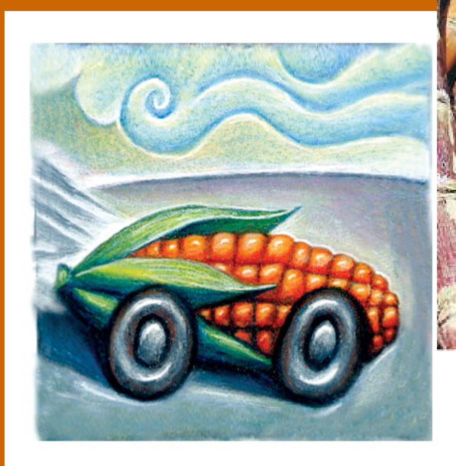
Matching Current and Future Energy Sources to Use

[Power Density for Sources and Uses – Smil 1991]



What Feedstocks to Grow?

- 95% of US bioethanol is derived from corn
- Brazilian ethanol is principally from sugarcane
- Biodiesel from oil crops (soybeans, sunflowers, algae)
- Cellulosic technology
  - Switchgrass, short-rotation woody crops, “waste”






The Future is Now

Savannah Morning News.

Story

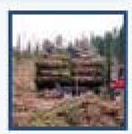
AA + −

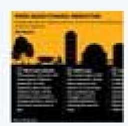
Georgia picks pine over corn

Exchange | Intown

Vicky Eckenrode | Sunday, October 28, 2007 at 12:30 am

Timber companies and researchers are experimenting with the best way to take wood waste during harvesting to plants that can convert the cellulose to ethanol fuel. SPECIAL/GEORGIA FORESTRY COMMISSION (Photo: Savannah Morning News)





State officials have high hopes in converting by-products from forest industry into vehicle fuel

ATLANTA - A plant's groundbreaking next month is expected to usher in a new phase in Georgia's efforts to position itself in front for a new kind of ethanol production.

Officials hope it is just the beginning for converting leftover pine tree odds and ends into vehicle fuel.

Range Fuels is slated to start work Nov. 6 on a facility in Soperton that is projected to eventually produce 40 million gallons of ethanol and 9 million gallons of methanol annually.

"That will be actually a very important event," said Nathan McClure, forest energy and development director for the Georgia Forestry Commission. "This will be the first commercial cellulosic ethanol plant in the country."

The nation's ethanol production reached 6 billion gallons this year - a huge leap from 1 billion gallons in 2000 in part because of a push from federal subsidies. But nearly all that fuel has been derived from corn.

A few facilities in Georgia also have undertaken the fuel production by shipping in corn.

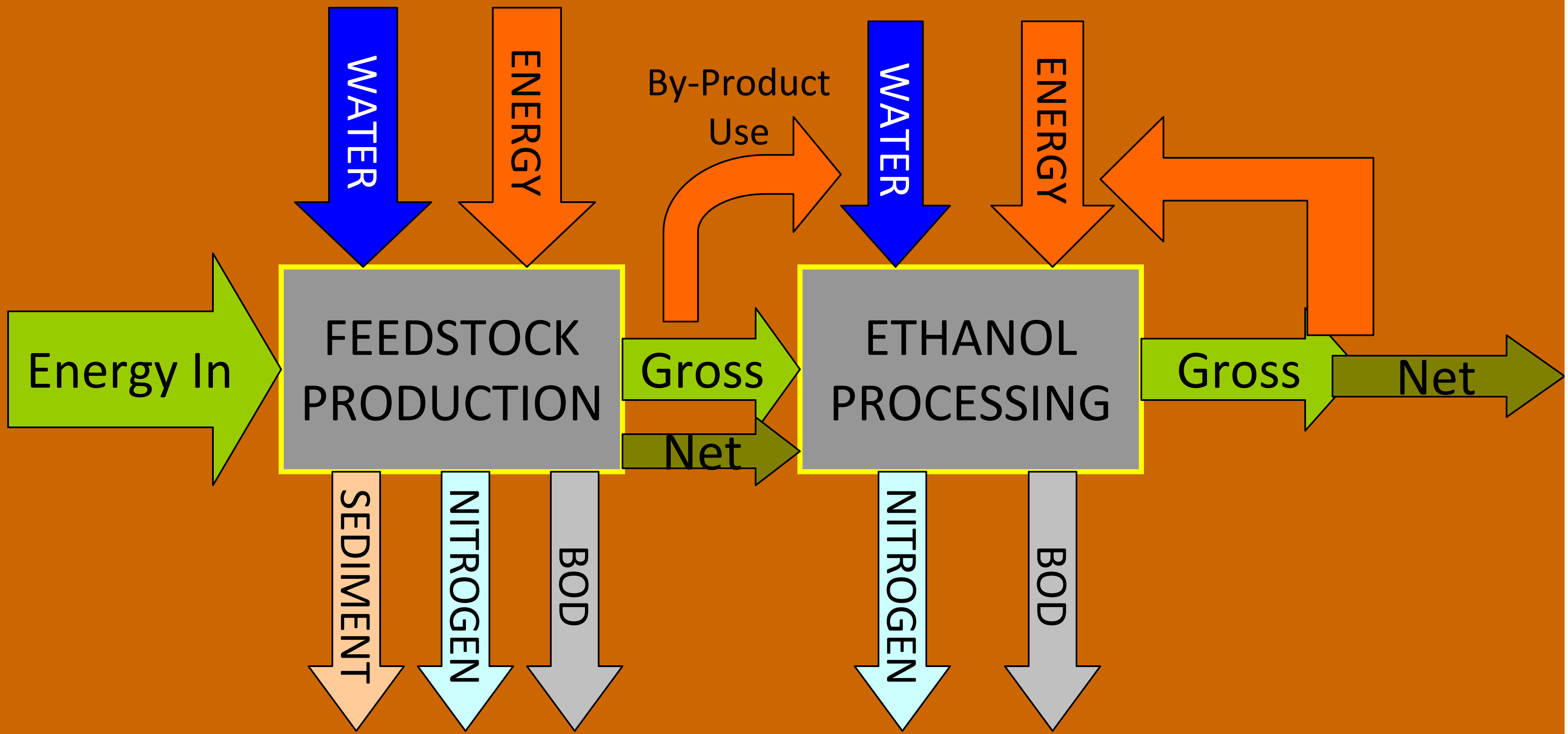
But Georgia forestry officials, university researchers, politicians and investors have high hopes in the cellulosic process, which relies on converting energy from plant fiber rather than the starch in corn.

The cell walls of plants get broken down into sugar molecules and fermented into ethanol.

Evaluating Bioethanol Alternatives

- What scientific basis to compare/recommend?
  - Monetary Cost
  - Carbon
  - Geography
  - Net Energy
  - Environmental Cost
    - Water use, Nutrient pollution, Erosion, BOD load
    - Per net energy

Net Energy Concept – Systems Analysis

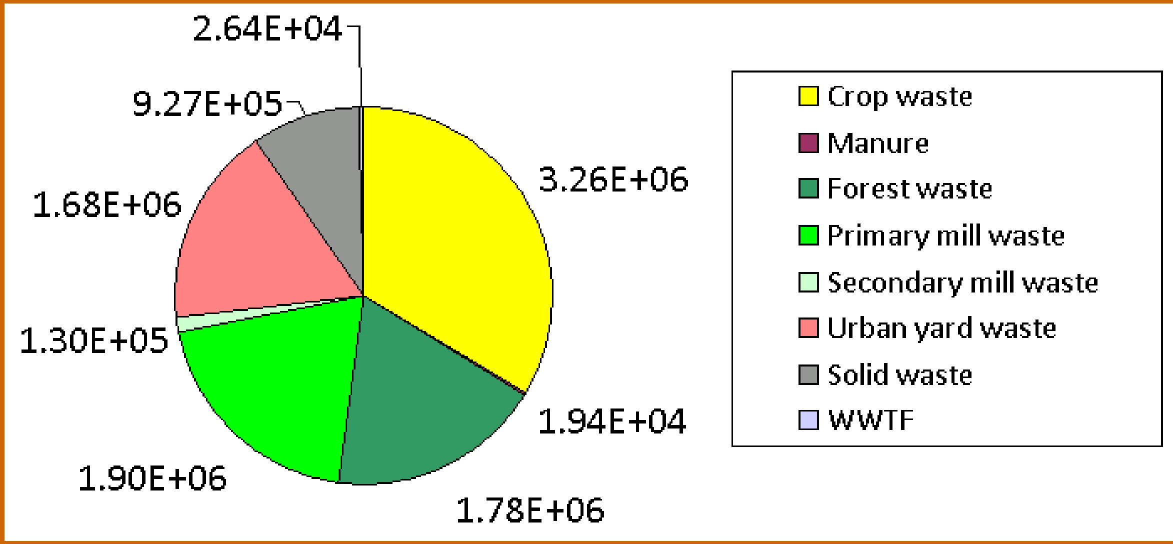


Metrics:

1) Net Energy (GJ_{net} per ha; Energy Return on Energy Invested)
2) Water Use (Mg/GJ_{net})
3) Water Quality (Mg erosion/GJ_{net}; kg N/GJ_{net}; kg BOD/GJ_{net})

Waste vs. Primary Resources

- Waste biomass (forest harvest residues, citrus peels, municipal solid waste) is bio-energy low hanging fruit
  - High net energy as a by-product (also low environmental cost)
  - Limited in magnitude
- Waste biomass for Florida is 9.7 million tons (NREL 2005)
  - At generous gross conversion efficiency (400 L EtOH/dry ton) this can provide 7.5% of Florida's total liquid fuel use



Comparative Net Energy: Corn vs. Wood

CORN	SUGARCANE	WOOD
FEEDSTOCK	FEEDSTOCK	FEEDSTOCK
Gross Yield ~ 200 GJ/ha/yr	Gross Yield ~ 440 GJ/ha/yr	Gross Yield ~ 160 GJ/ha/yr
Input Energy ~ 45 GJ/ha/yr	Input Energy ~ 50 GJ/ha/yr	Input Energy ~ 1.7 GJ/ha/yr
– N, Diesel, Pesticide	– Diesel, Pesticide, N	– Diesel, Labor, N
– Net Energy_{PROD} ~ 4.5:1	– Net Energy_{PROD} ~ 12.5:1	– Net Energy_{PROD} ~ 94.8:1
PROCESSING	PROCESSING	PROCESSING
Input Energy ~ 11.0 MJ/L	Input Energy ~ 1.5 MJ/L	Input Energy ~ 7.9 MJ/L
SYSTEM YIELD	SYSTEM YIELD	SYSTEM YIELD
EROI ~ 1.14:1	EROI ~ 4.33:1	EROI ~ 4.13:1

Beyond Net Energy: Environmental/Resource Costs

- Water
  - Feedstock production requirements
  - Fermentation/distillation requirements
- Pollutants
  - Erosion/Sediment increases
  - Nitrogen enrichment
  - Oxygen consuming wastes
- Wildlife habitat? Diversity?
- "Footprint" evaluations made based on NET ENERGY
  - $\$/GJ_{net}$
  - $g\ N/GJ_{net}$
  - $g\ H2O/GJ_{net}$
  - $Hectares/GJ_{net}$

Feedstock Water Use: Blue vs. Green Water

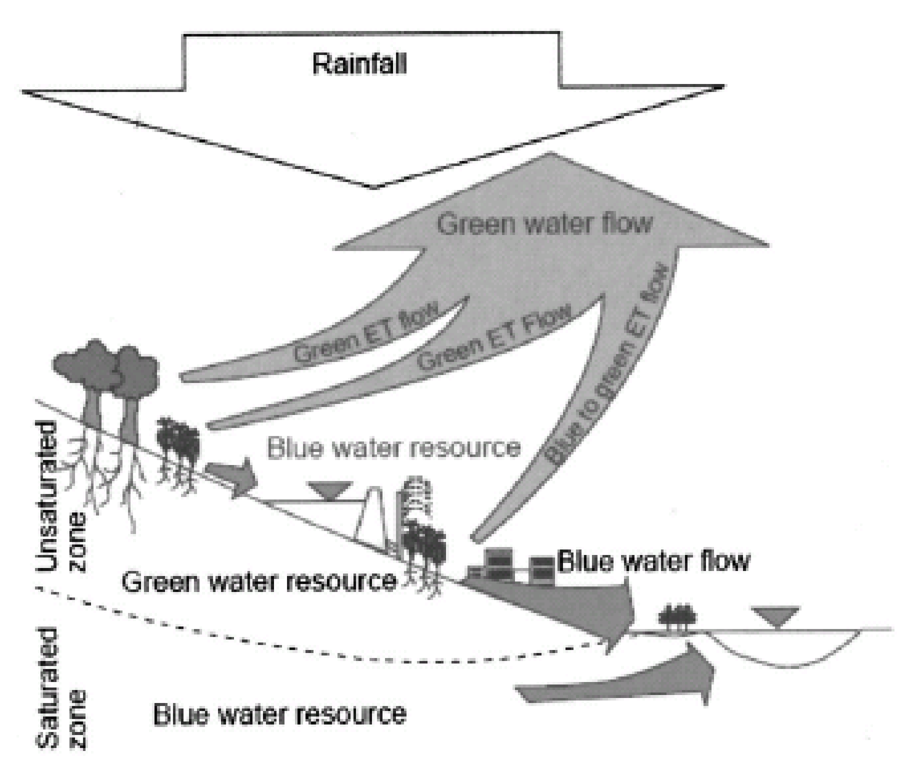
Powell et al. 2005 – Can. J. For. Res.

Runoff/Recharge (Blue Water) = Rainfall – ET

Plantation yields ~ 250 mm less water per year

Green Water = Use

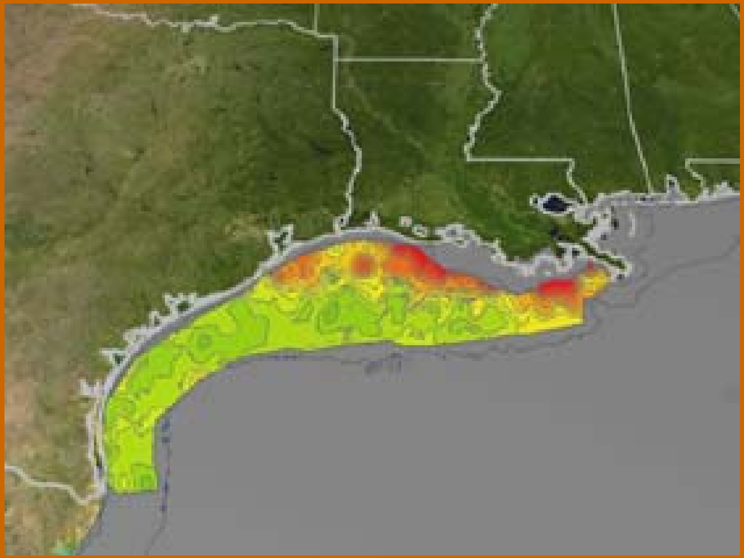
- Corn
  - ET ~ 635 mm over 4 months
    - 200-300 mm of irrigation
  - ET_{ref} ~ 300 mm over 4 months
  - 335 mm/yr
- Sugarcane
  - ET ~ 1240 mm per year
    - Irrigation is negligible for most Florida sugarcane
  - ET_{ref} ~ 750 mm per year
  - 490 mm/yr
- Wood (life cycle)
  - ET ~ 1000 mm per year
  - ET_{ref} ~ 750 mm per year
  - 250 mm/yr



Falkenmark and Rockstrom 2006
(J Water Resources Planning and Management)

Water Quality Concerns

- Nitrogen pollution
  - Gulf of Mexico hypoxia
  - St. Johns River
- Erosion/sediment production
  - Significant concern in the Piedmont
- Loads of O_2 consuming wastes
  - BOD ~ 1000 mg/L
  - Low dissolved oxygen is among the most common water quality problems in Florida



Environmental Costs: Corn vs. Wood

CORN

FEEDSTOCK

- Water – 110 Mg/GJ_{net}
- Nitrogen – 11.2 kg/GJ_{net}
- Erosion – 0.11 Mg/GJ_{net}

PROCESSING

- Water – 12.3 Mg/GJ_{net}
- BOD – 6.1 kg/GJ_{net}

LAND

- Land ~ 330 m^2/GJ_{net}

SUGARCANE

FEEDSTOCK

- Water – 52 Mg/GJ_{net}
- Nitrogen – 1.9 kg/GJ_{net}
- Erosion – 0.05 Mg/GJ_{net}

PROCESSING

- Water – 6.0 Mg/GJ_{net}
- BOD – 0.8 kg/GJ_{net}

LAND

- Land ~ 96 m^2/GJ_{net}

WOOD

FEEDSTOCK

- Water – 43 Mg/GJ_{net}
- Nitrogen – 0.16 kg/GJ_{net}
- Erosion – 0.01 Mg/GJ_{net}

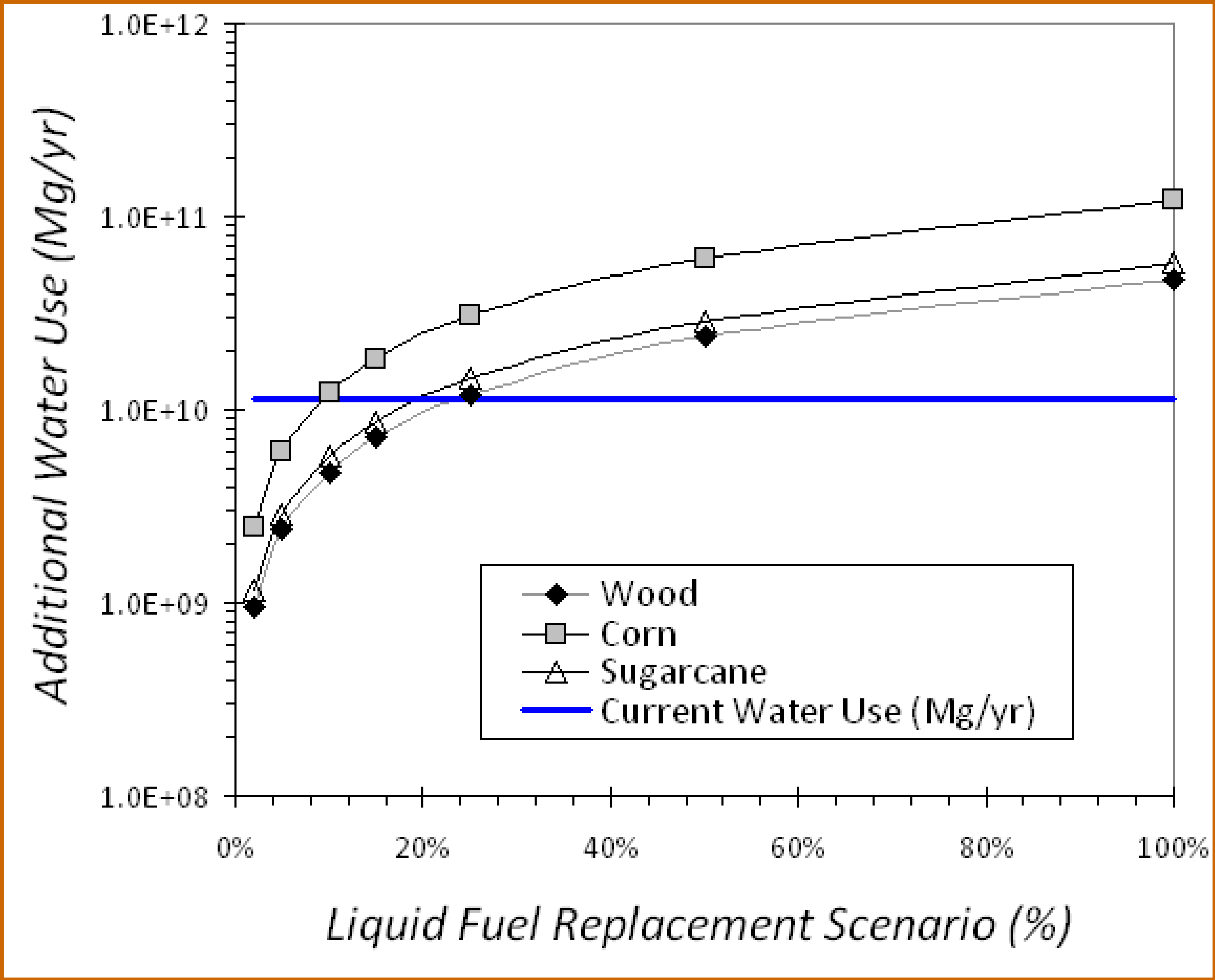
PROCESSING

- Water – 6.2 Mg/GJ_{net}
- BOD – 0.9 kg/GJ_{net}

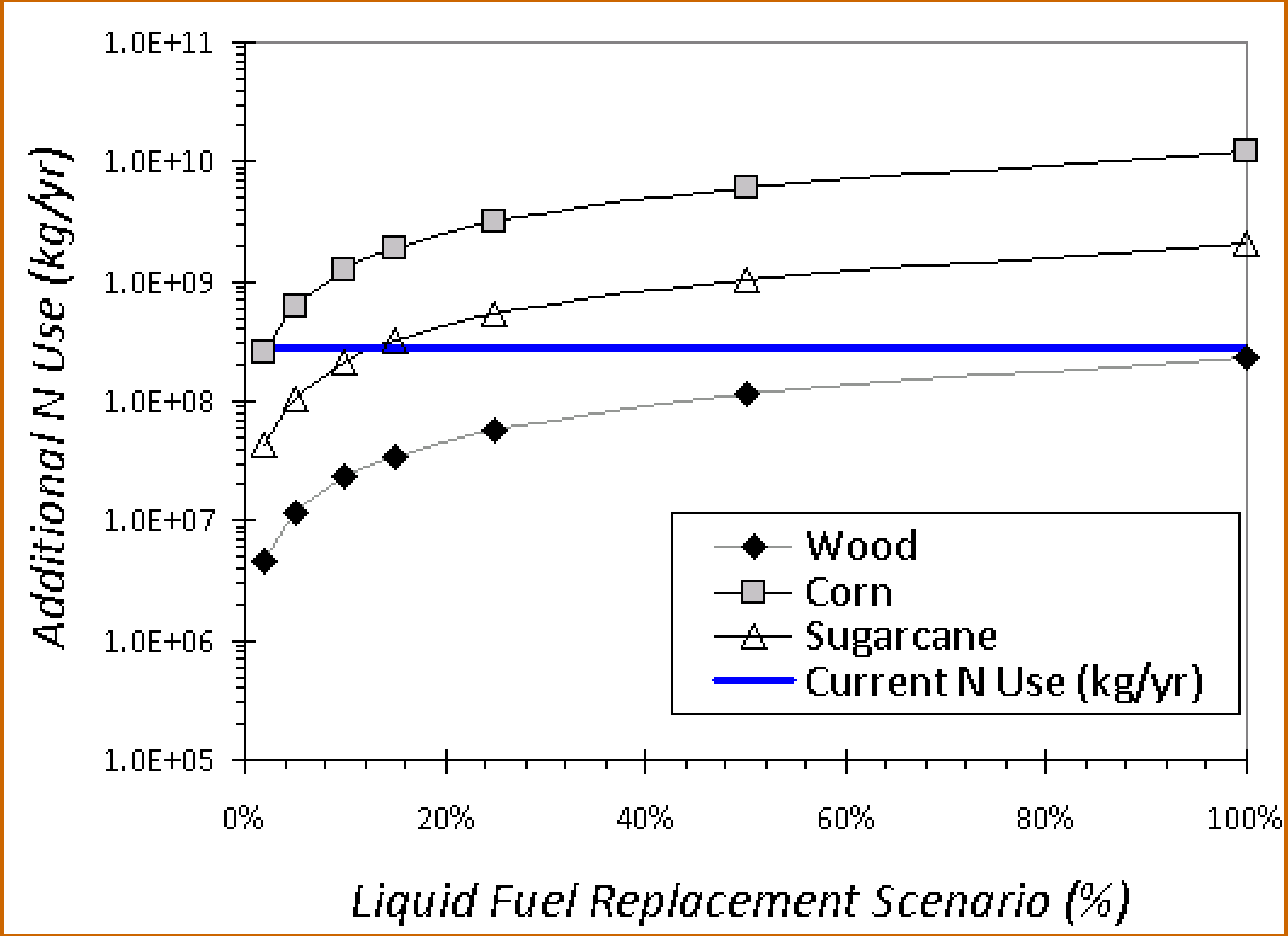
LAND

- Land ~ 168 m^2/GJ_{net}

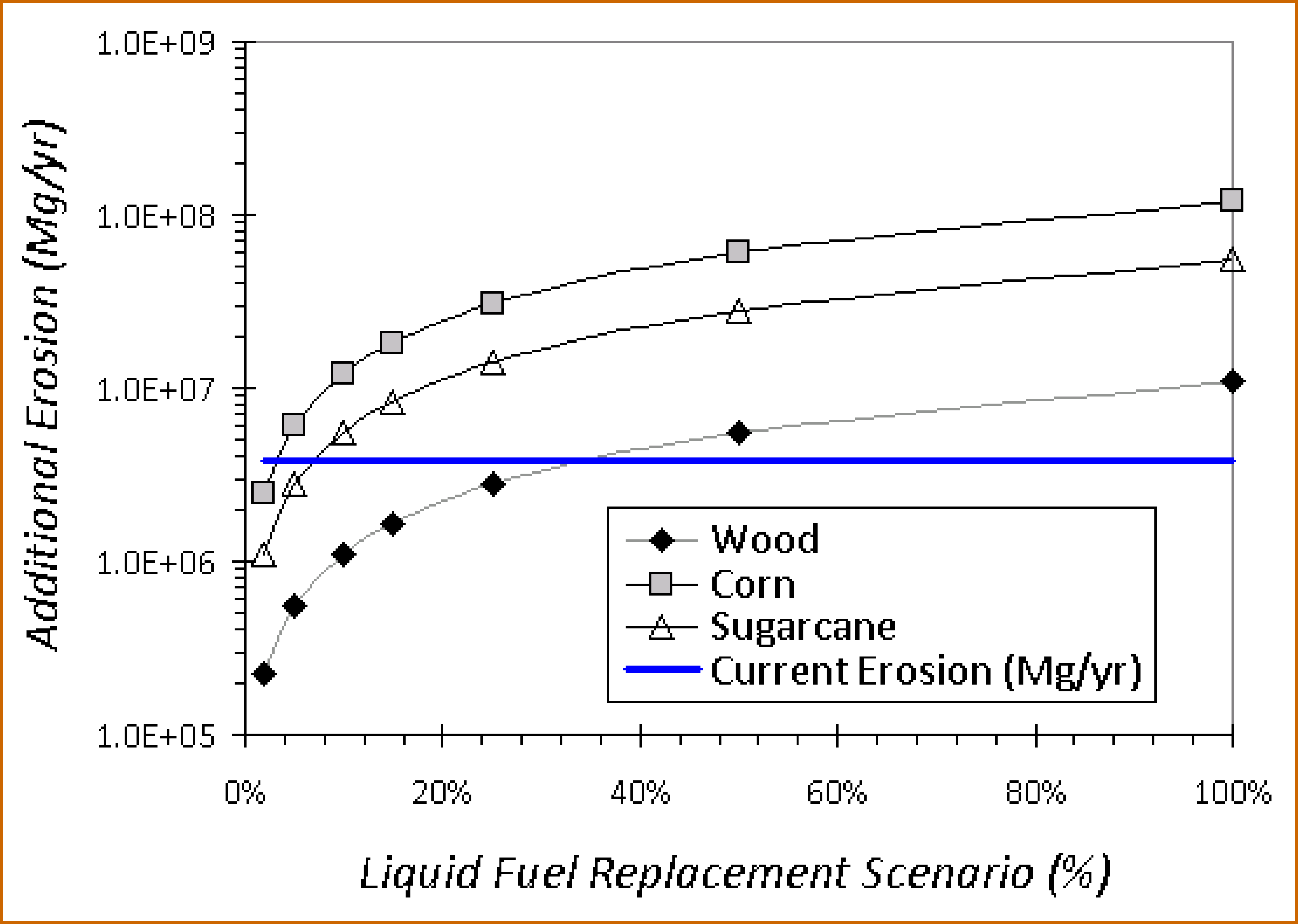
Fuel Replacement Scenarios: Water



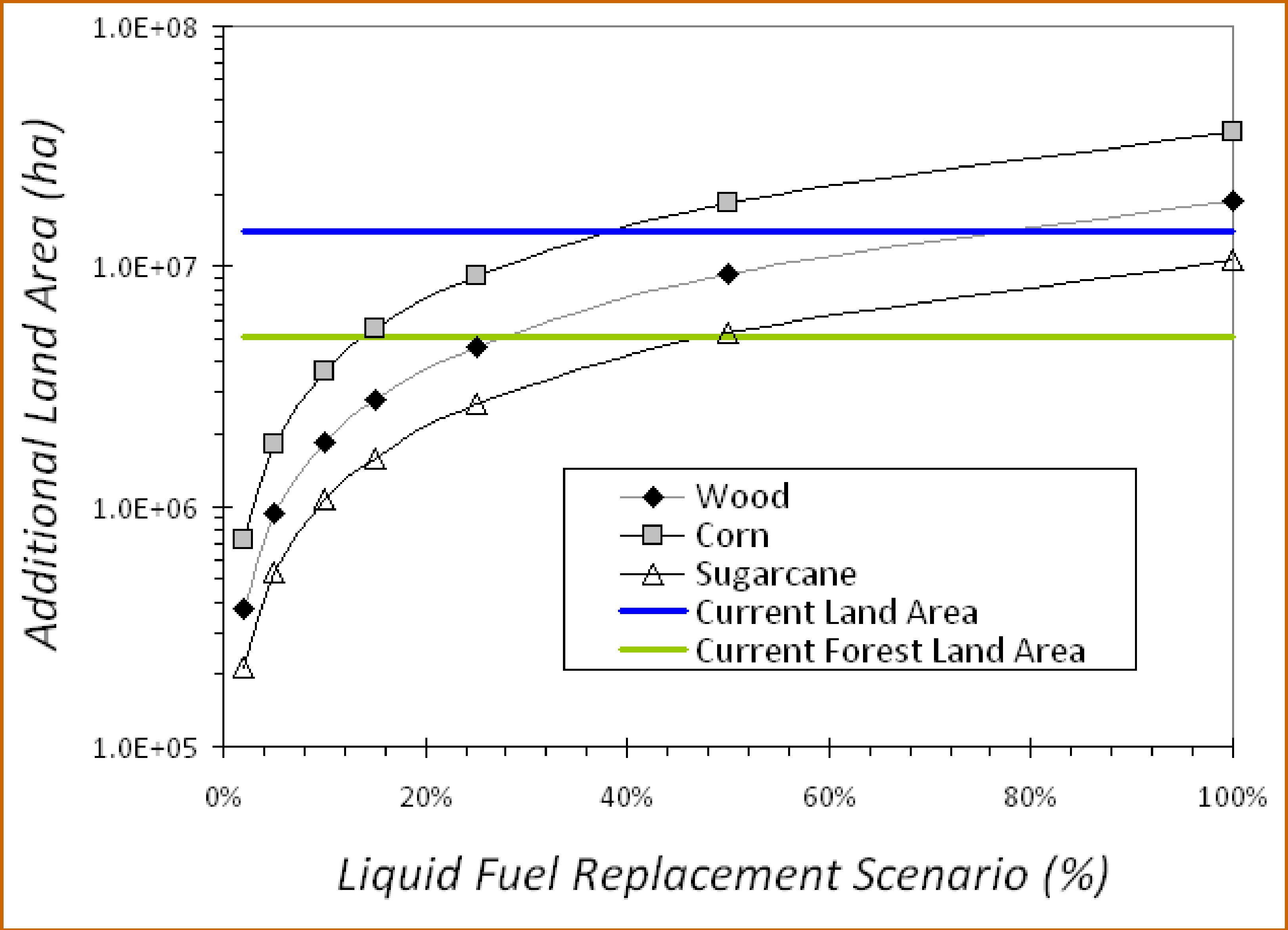
Fuel Replacement Scenarios: Nitrogen



Fuel Replacement Scenarios: Erosion



Fuel Replacement Scenarios: Land



Summary/Synthesis

- Three southeastern feedstocks provide <u>net energy</u>
- Forests and cane are FAR preferable to corn
  - Ancillary benefits of forests are substantially higher
- Hydrologic costs are potentially high and may force competing priorities (e.g., MFLs, TMDLs)
  - When using forest feedstocks, double Florida's current:
    - Water Use at 25% liquid fuel replacement
    - Erosion at 40% liquid fuel replacement
    - Nitrogen loading at 100% liquid fuel replacement
  - Using **<u>all</u>** forest land in the state at 25% replacement
- Liquid biofuels are likely only part of the solution
  - Cannot be expected to reasonably replace gasoline
  - Maximum national benefit in Southeastern USA


Questions? Comments?
mjc@ufl.edu
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L.V. Korhnak