Methods to Simulate Terrestrial Carbon Sequestration Activities: from Process Models to Economics

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4th DOE Conference on Carbon Sequestration
Alexandria, Virginia

May 3-5, 2005

Acknowledgements

- Research supported by
  - U.S. Department of Energy program to enhance Carbon Sequestration in Terrestrial Ecosystems (CSiTE)
  - USDA Consortium for Agricultural Soils Mitigation of Greenhouse Gases (CASMGS)
  - U.S. Environmental Protection Agency

Introduction

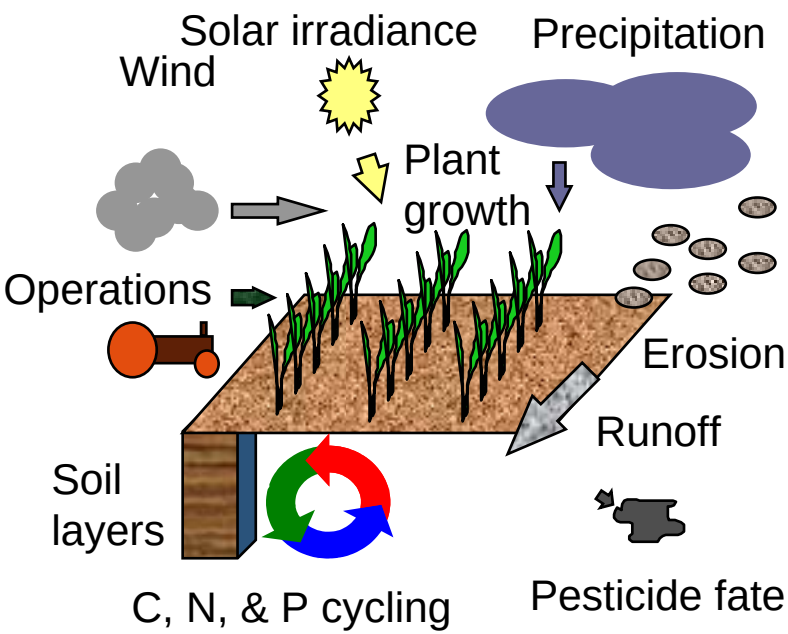
- Can agriculture and forestry provide a short term bridge to a longer term reduced-emissions future?
- How significant a contribution could agriculture and forestry make relative to non-agricultural (e.g., energy and industrial) mitigation possibilities?
- What analysis tools can help us address these questions?

Methodology

- No single model can simulate all the relevant processes and activities
- Three models are used
  - EPIC
    - Crop growth simulation model
    - Validated against long-term agricultural experiments
  - FASOMGHG
    - Economics of land use and production of agriculture and forestry products
    - Simulates terrestrial mitigation options over time as a function of carbon price
  - Second Generation Model
    - Economy-wide simulation of greenhouse gas mitigation opportunities
    - Comparison between types of mitigation opportunities by cost and over time in US
- Changes in crop tillage
  - Used as an example to show information flow between models

Integrating soil and biological processes at landscape scale through simulation modeling

EPIC Model



Representative EPIC modules

Williams (1995)

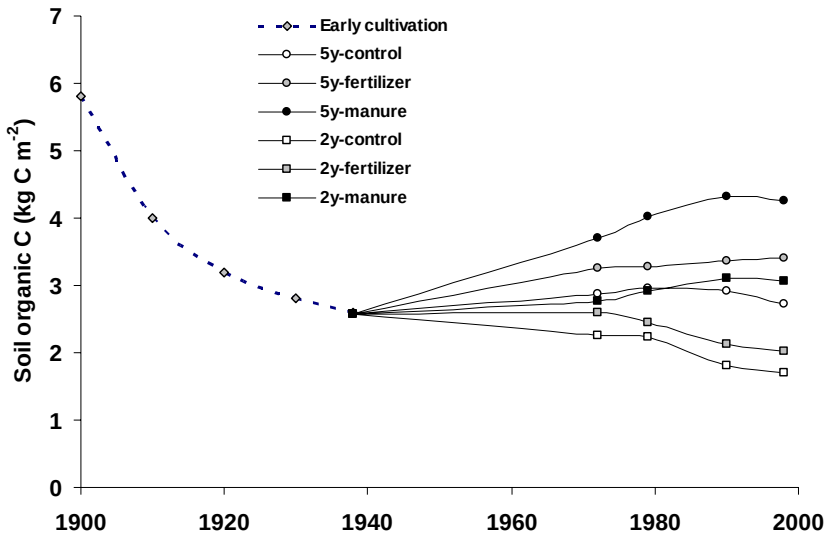
- EPIC is a process-based model built to describe climate-soil-management interactions at point or small watershed scales
  - Crops, grasses, trees
  - Up to 100 plants
  - Up to 12 plant species together
- Key processes simulated
  - Weather
  - Plant growth
    - Light use efficiency, PAR
    - CO_2 fertilization effect
    - Plant stress
  - Erosion by wind and water
  - Hydrology
  - Soil temperature and heat flow
  - Nutrient cycling
  - Tillage
  - Plant environment control: fertilizers, irrigation, pesticides
  - Pesticide fate
  - Economics

Long-term experiments: essential tools to understand management effects on soil organic C dynamics

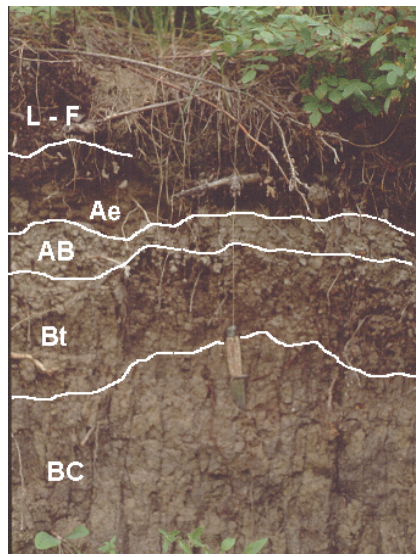
- Forest to agriculture (~1900)
- Breton Plots initiated in 1930
- Current treatments (1938)
  - Two crop rotations: a) fallow-wheat, b) five year (wheat-oats-barley- forage-forage)
  - Fertility treatments: a) control, b) fertilizer, c) manure

Aerial view of Breton Classical Plots

Photo: RC Izaurralde

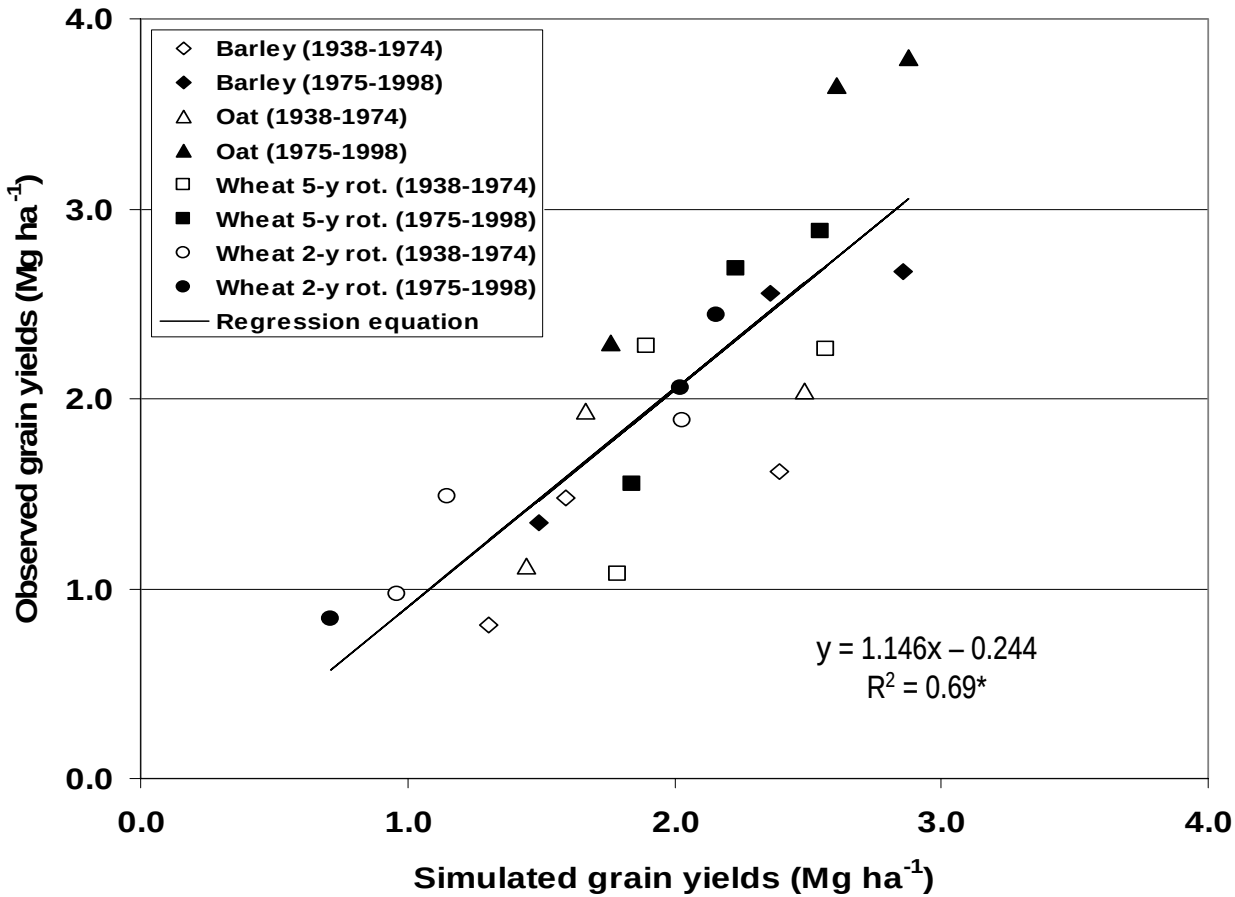


Izaurralde et al. (2001)



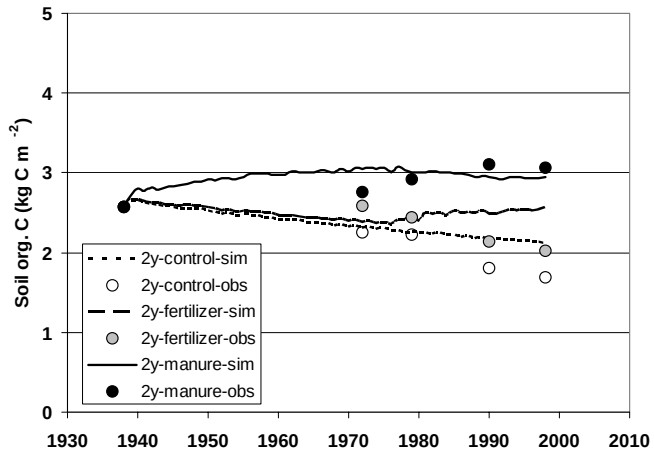
Breton loam

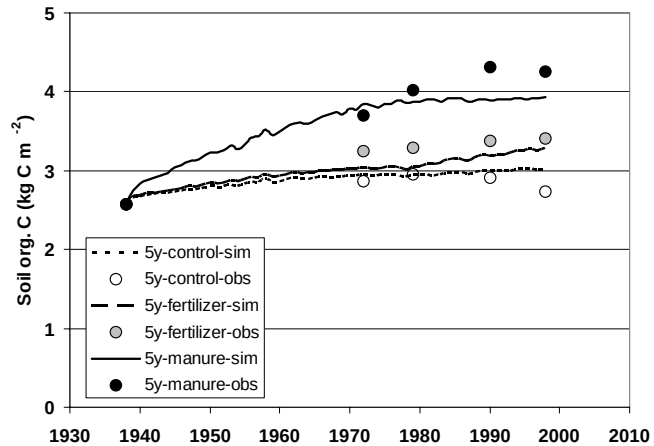
EPIC provided realistic yield simulations of cereal and forage crops at the Breton Classical Plots

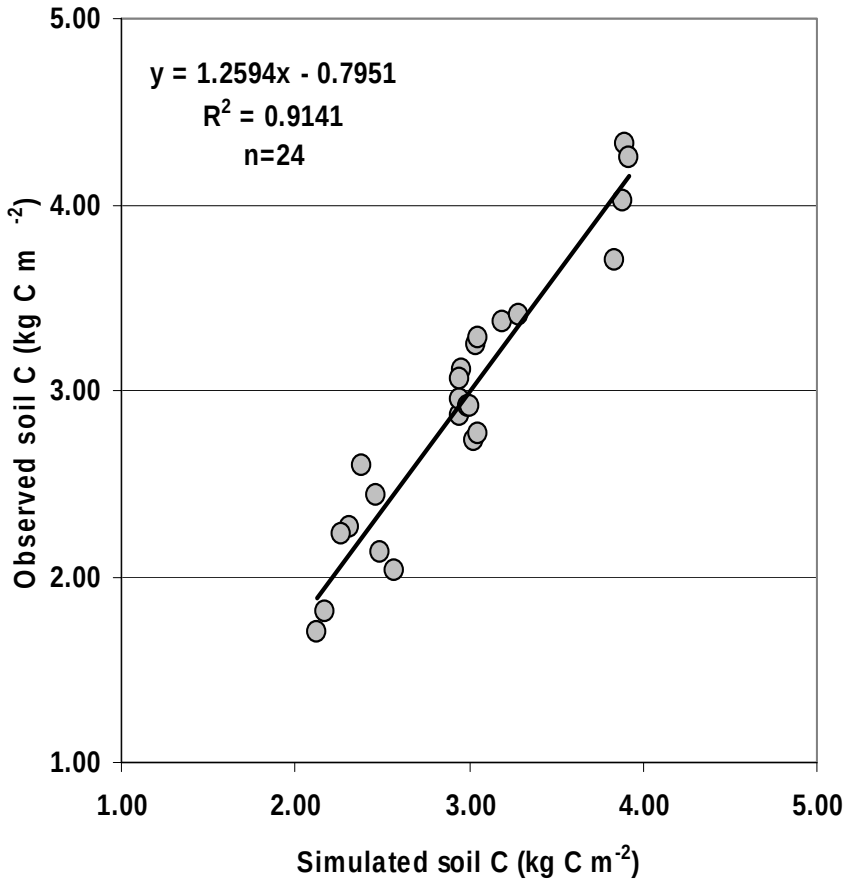


Izaurralde et al. (submitted)

EPIC captured the soil organic C (SOC) dynamics at Breton although it overpredicted at low SOC values and underpredicted at high ones

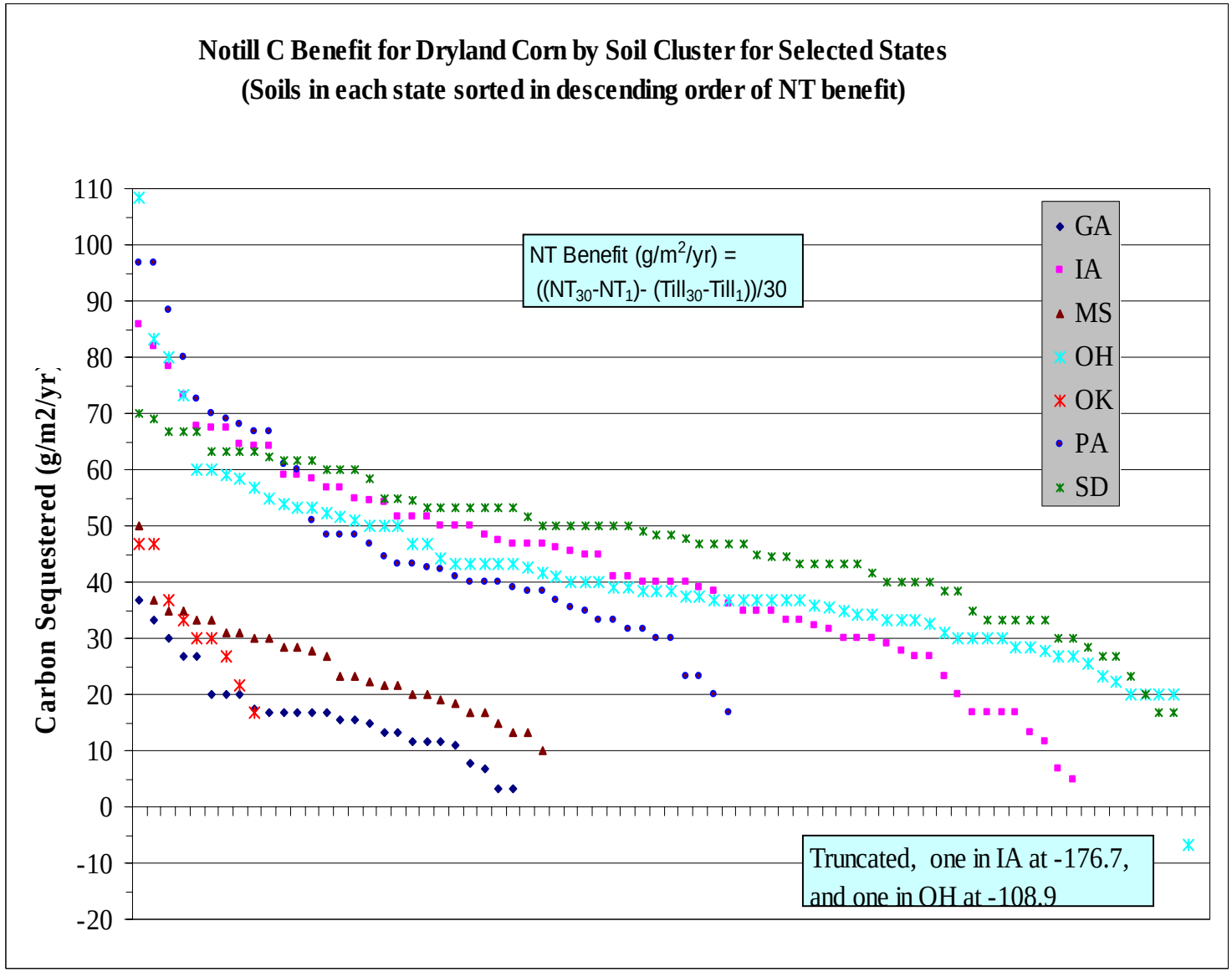






Izaurralde et al. (submitted)

National runs with EPIC



Atwood et al. (2004)

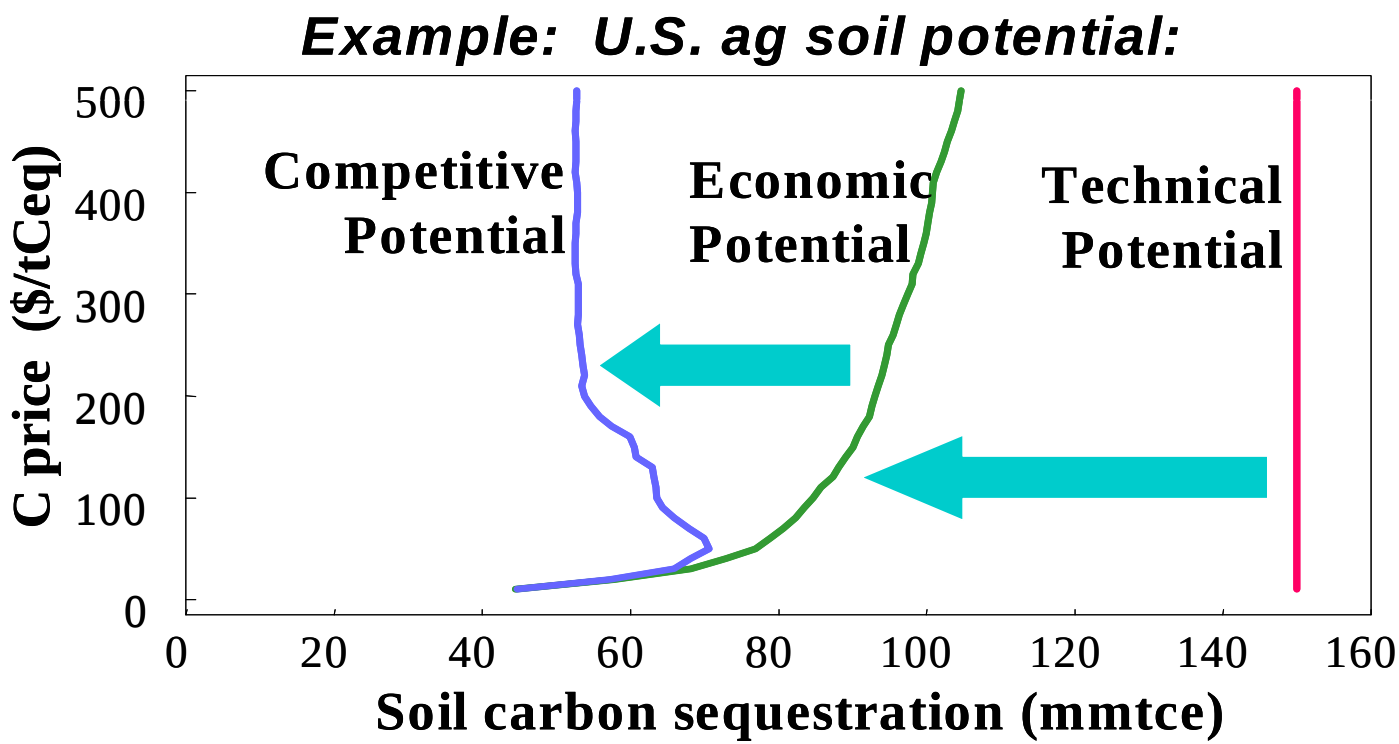
FASOMGHG Overview

- Intertemporal, mathematical programming model depicting land transfers and other resource allocations among agricultural and forestry sectors in the U.S.
- 10-year time steps through 2100
- Endogenous variables
  - Commodity and factor prices
  - Production, consumption, export, and import quantities
  - Management strategy
  - Resource use
  - Economic welfare
- Greenhouse gas accounting
  - Carbon dioxide emissions and absorption
  - Methane emissions
  - Nitrous oxide emissions

FASOMGHG Activities

		GHG affected		
Mitigation strategy	**Strategy Nature**	**CO_2**	**CH_4**	**N_2O**
Biofuel production	Offset	X	X	X
Crop mix alteration	Emission, Sequestration	X		X
Rice acreage reduction	Emission		X	
Crop fertilizer rate reduction	Emission	X		X
Other crop input alteration	Emission	X		
Crop tillage alteration	Sequestration	X		
Grassland conversion	Sequestration	X		
Irrigated /dry land conversion	Emission	X		X
Livestock management	Emission		X	
Livestock herd size alteration	Emission		X	X
Livestock system change	Emission		X	X
Liquid manure management	Emission		X	X

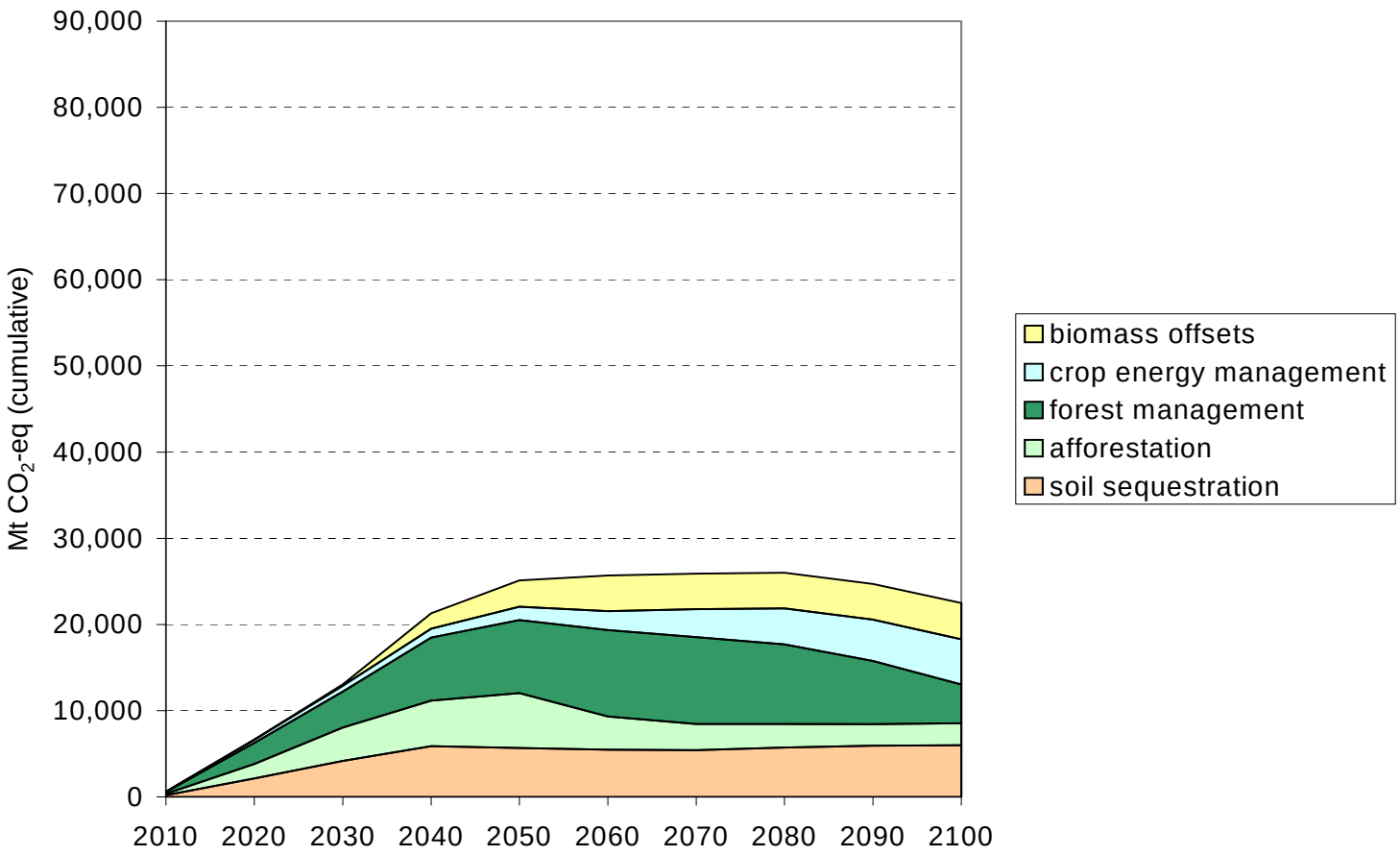
Concepts for Assessing Mitigation Potential



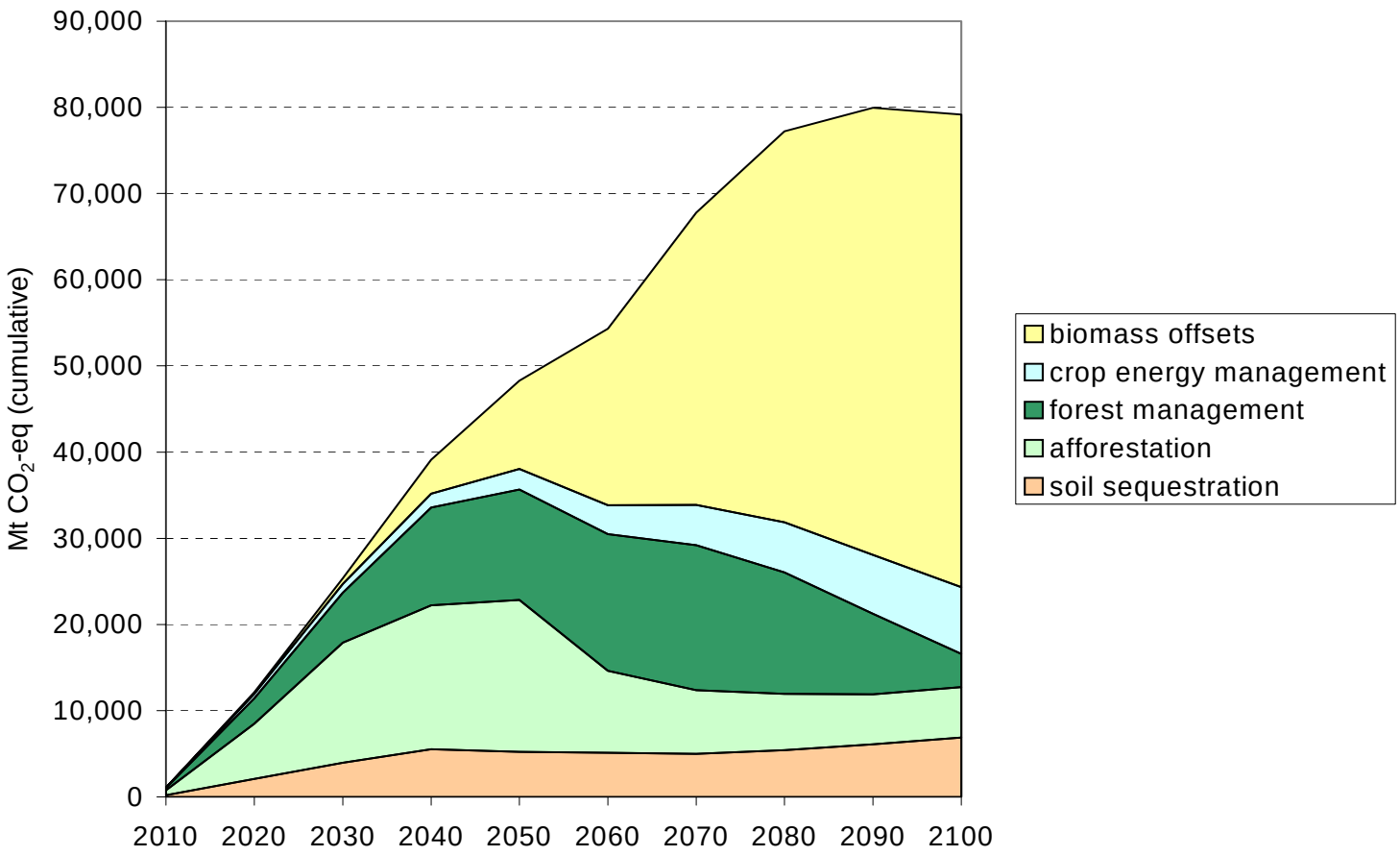
FASOMGHG Results

- Results reported as cumulative amount of CO_2-eq sequestered or emissions avoided over time
  - More accurate picture of dynamics
  - Soil sequestration saturates after three decades
  - Quantity of sequestered carbon may decline in later decades, especially when trees are harvested
- Charts shown for $15 and $30 per t CO_2-eq for 2010 through 2100

FASOMGHG Results ($15 per t CO_2-eq)



FASOMGHG Results ($30 per t CO_2-eq)



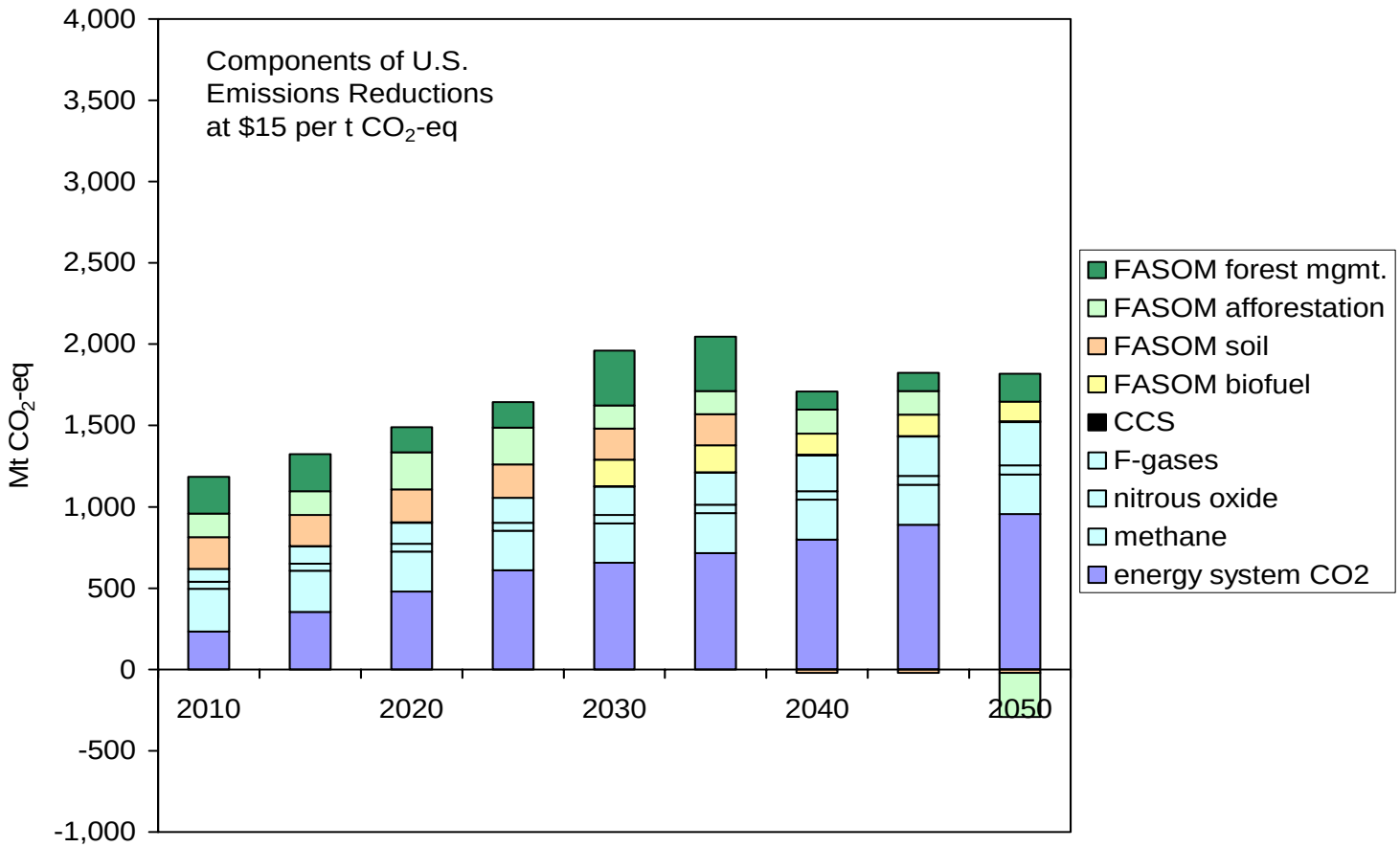
Greenhouse Gas Mitigation Options (SGM with FASOMGHG)

- Terrestrial
  - Soil sequestration
  - Forest management
  - Afforestation
  - Biofuel offsets
  - Crop energy management
- Non-CO_2 greenhouse gases
  - Exogenous marginal abatement cost curves
  - Developed by U.S. EPA for Energy Modeling Forum
  - Covers agriculture and industry
- Energy efficiency and fuel switching
- CO_2 capture and storage (CCS)

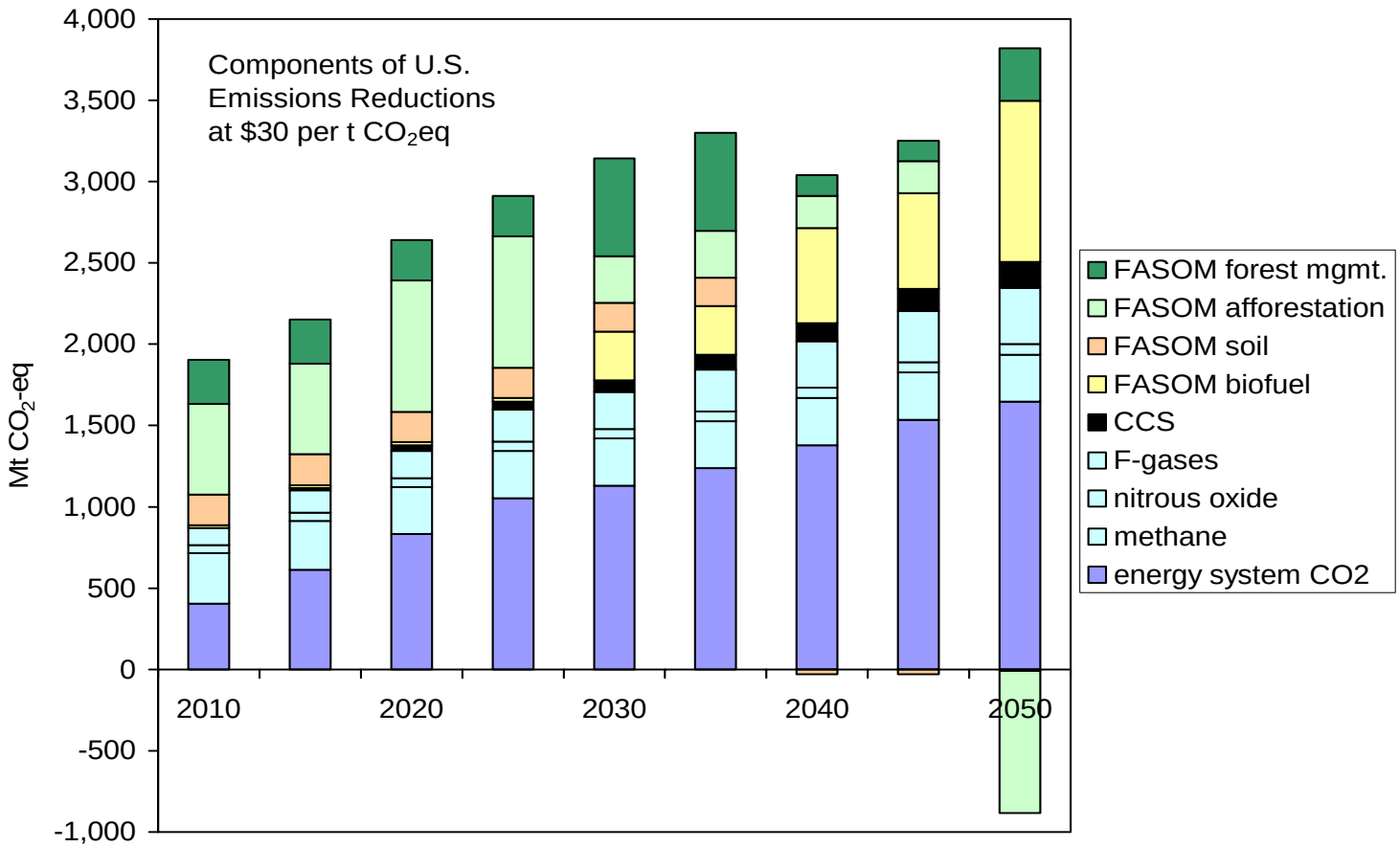
Second Generation Model

- SGM characteristics
  - Computable general equilibrium model of United States and other world regions
  - Five-year time steps from 1990 through 2050
  - Capital stocks are industry specific with a new vintage for each model time step
- CO_2 capture and storage with electric power
  - Engineering cost model for capture process from David and Herzog, 2000, “The Cost of Carbon Capture,” Proceedings of the Fifth International Conference on Greenhouse Gas Control Technologies
  - Constant cost of carbon disposal ($40 per tC)

Combined Results ($15 per t CO_2-eq)



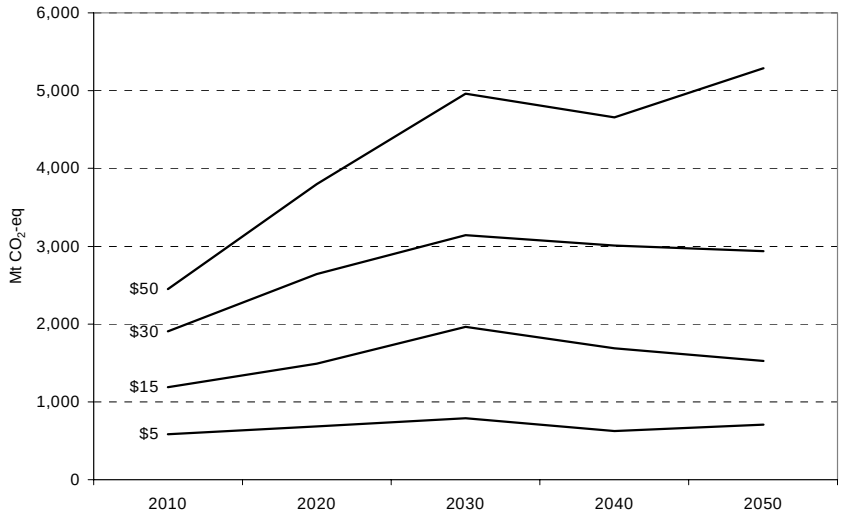
Combined Results ($30 per t CO_2-eq)



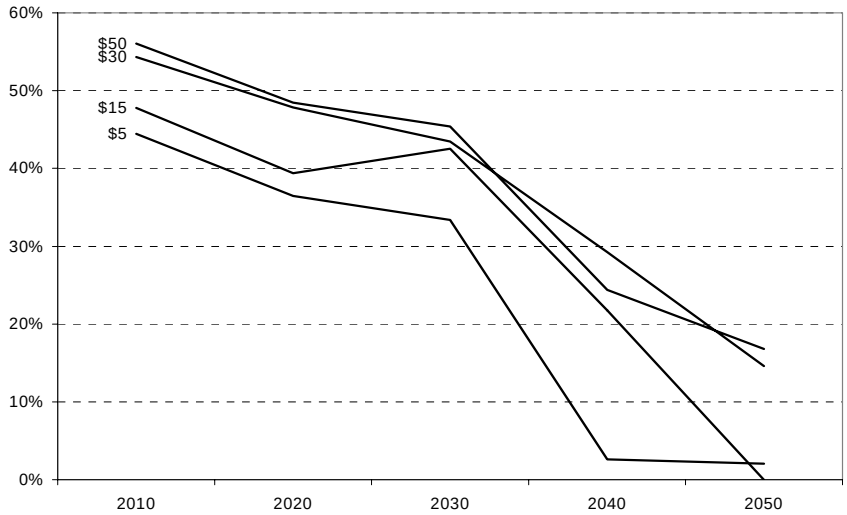
Strategic Comparison (1)

- Total mitigation potential across time and carbon prices
- Mitigation potential increases with CO_2 price, as expected
- Masks underlying trends in individual options

Total Mitigation Potential



Strategic Comparison (2)

- Contribution of terrestrial options
  - Large percentage of total in first three decades, even at high carbon prices
  - Biofuel offsets provide most of terrestrial contribution in later decades, but only at higher carbon prices

Terrestrial Fraction of Mitigation