

Land Use Simulation in AgLU: Advanced Methods

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 - Statistics of land allocation mechanism
 - Data for U.S. land classes
- ▶ U.S. Environmental Protection Agency

Overview

- ▶ Energy Model Forum (EMF-22) Land Use Subgroup
- ▶ Modeling Approaches
- ▶ PNNL Agriculture and Land Use Model (AgLU)
 - Brief history
 - Land allocation mechanism
 - AgLU treatment of forests
 - Typical scenarios
- ▶ Disaggregation into land classes
- ▶ How can we improve agriculture and forestry representation in CGE models?

EMF-22 Land Use Subgroup

▶ Meetings

- Stanford, May 2005: methodology
- Washington, February 2006: methodology and a few scenarios

▶ Intended Products

- 1st set of papers on methods and baseline scenarios
- 2nd set of papers on mitigation and impacts

▶ Type of Models Participating

- Ag/Forestry (single country)
- Global partial-equilibrium
- Global general-equilibrium

Approaches

- ▶ Intertemporal Optimization
 - Typical for sector-specific models (e.g. forestry)
- ▶ Intertemporal Equilibrium (perfect foresight)
 - Efficiency conditions (first order necessary conditions) from intertemporal optimization model become system equations
 - Allows integration with other types of economic systems (agricultural and energy system)
- ▶ Recursive Equilibrium
 - Absence of look-ahead capability makes it difficult to model forestry
- ▶ Steady-State Equilibrium
 - Exploratory tool
 - Steady-state modeling of forestry may be able to inform recursive models

Brief History of AgLU

- ▶ First version completed in 1996
- ▶ Design
 - Top-down
 - Partial equilibrium
 - Can be run stand-alone or as part of MiniCAM
- ▶ Studies
 - Role of biomass in carbon policy
 - Impact of ENSO on North America
 - U.S. climate impacts

Methodology Highlights

- ▶ 15-year Time Steps from 1990 through 2095
- ▶ Land Allocation
 - Land owners compare economic returns across crops, biomass, pasture, and future trees
 - Underlying probability distribution of yields per hectare
- ▶ Forest Dynamics
 - Trees in AgLU grow for 45 years
 - Two forest markets (current and future) needed for model stability

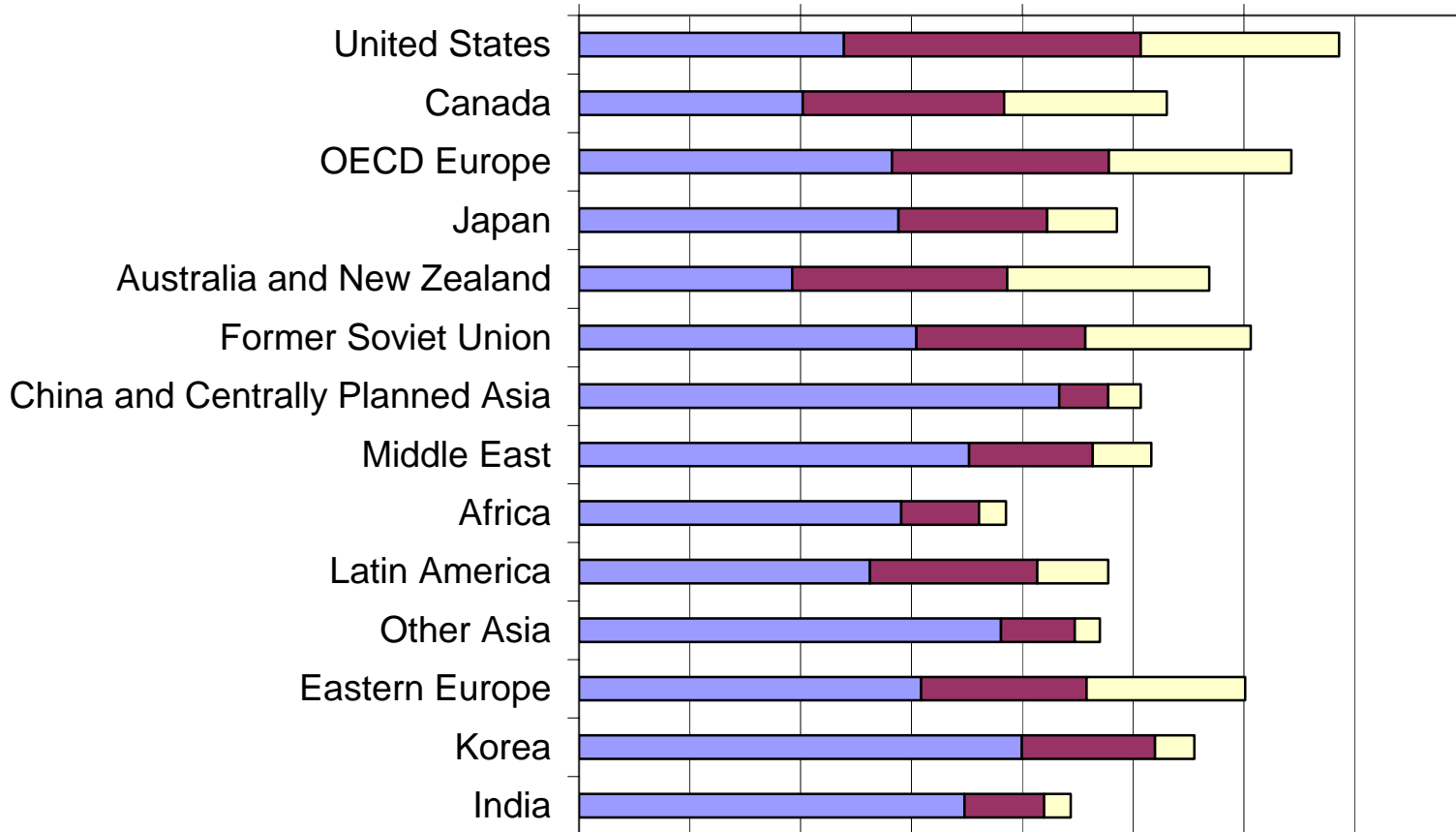
Products in AgLU

- ▶ Crops (calories)
 - Rice and Wheat
 - Coarse Grains
 - Oil Crops
 - Other Crops
- ▶ Processed Crops (calories)
 - Vegetable Oils
 - Sweeteners and Alcoholic Beverages
- ▶ Animal Products (calories)
 - Beef and other Ruminant Livestock
 - Pork and Poultry
- ▶ Commercial Biomass (calories or metric tons)
- ▶ Forest Products (cubic meters)

Food Consumption by AgLU Region

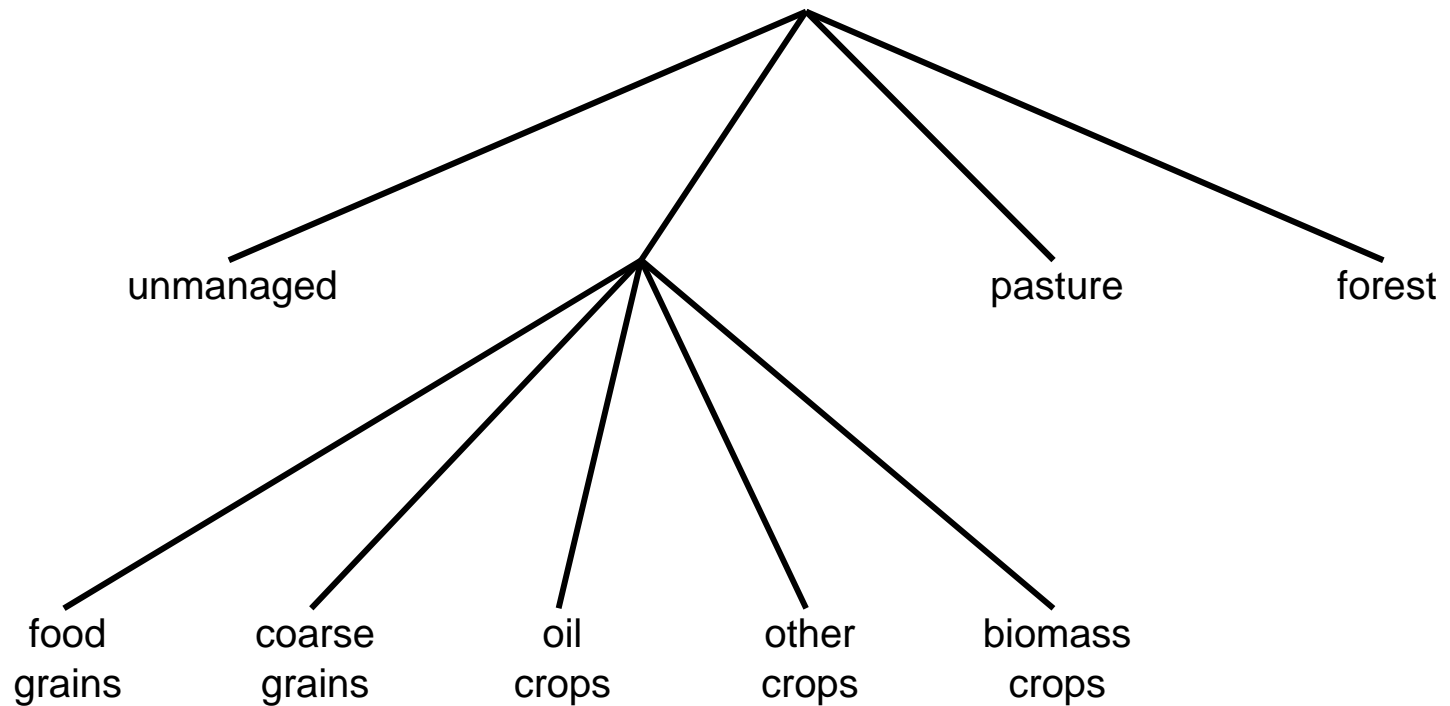
kcal per person per day

0 1,000 2,000 3,000 4,000



■ Crops ■ Processed Crops ■ Animal Products

AgLU Land Allocation



Calculation of Land Shares

$$S_i = \frac{\bar{\pi}_i^{1/\lambda}}{\sum_k \bar{\pi}_k^{1/\lambda}}$$

$$\bar{\pi}_i = \bar{y}_i (P_i - G_i)$$

Land share for land use i is an increasing function of profit rate (lambda is positive).

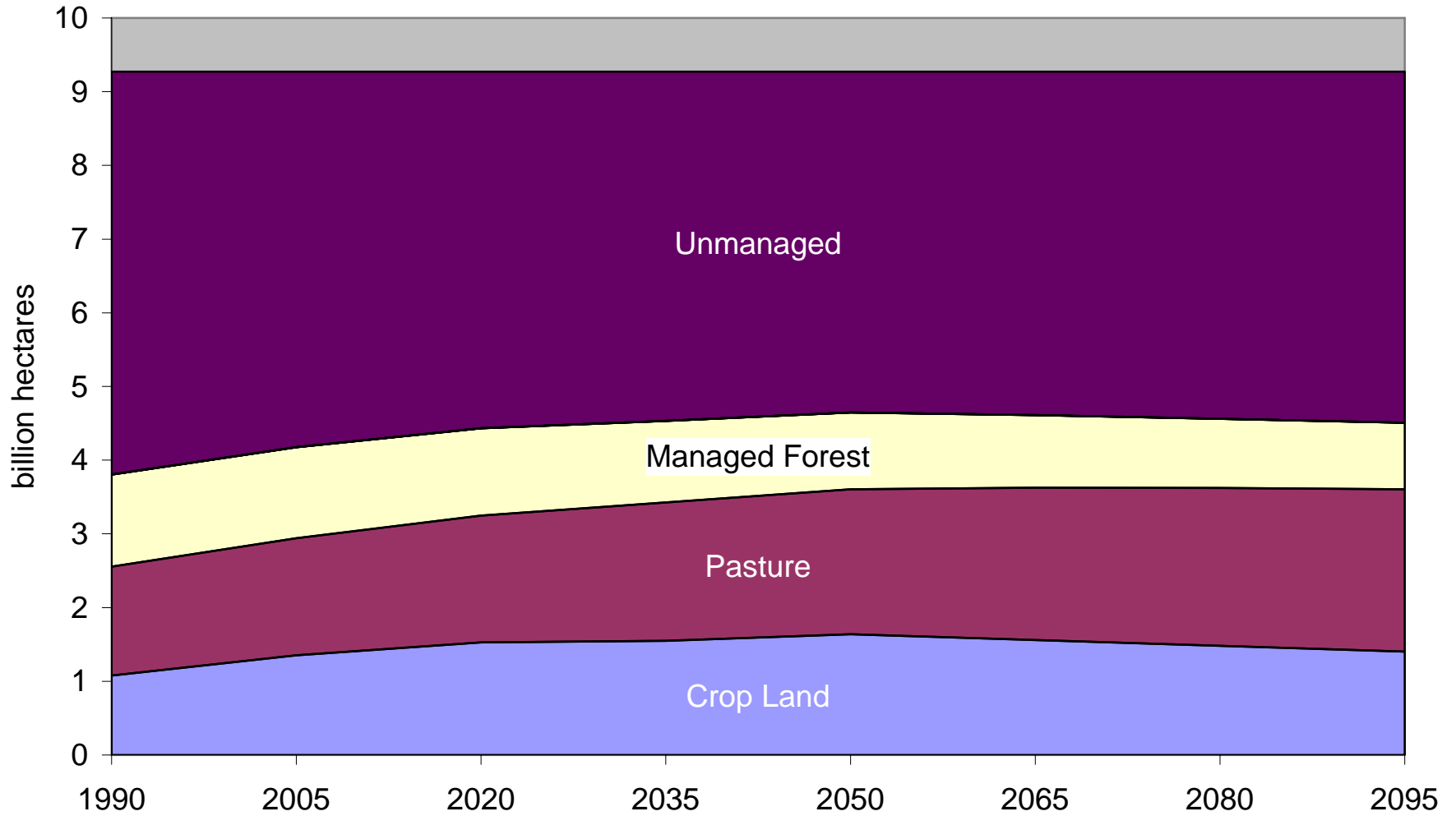
Profit rate equals average yield times price received less non-land cost of production.

Efficiency Condition

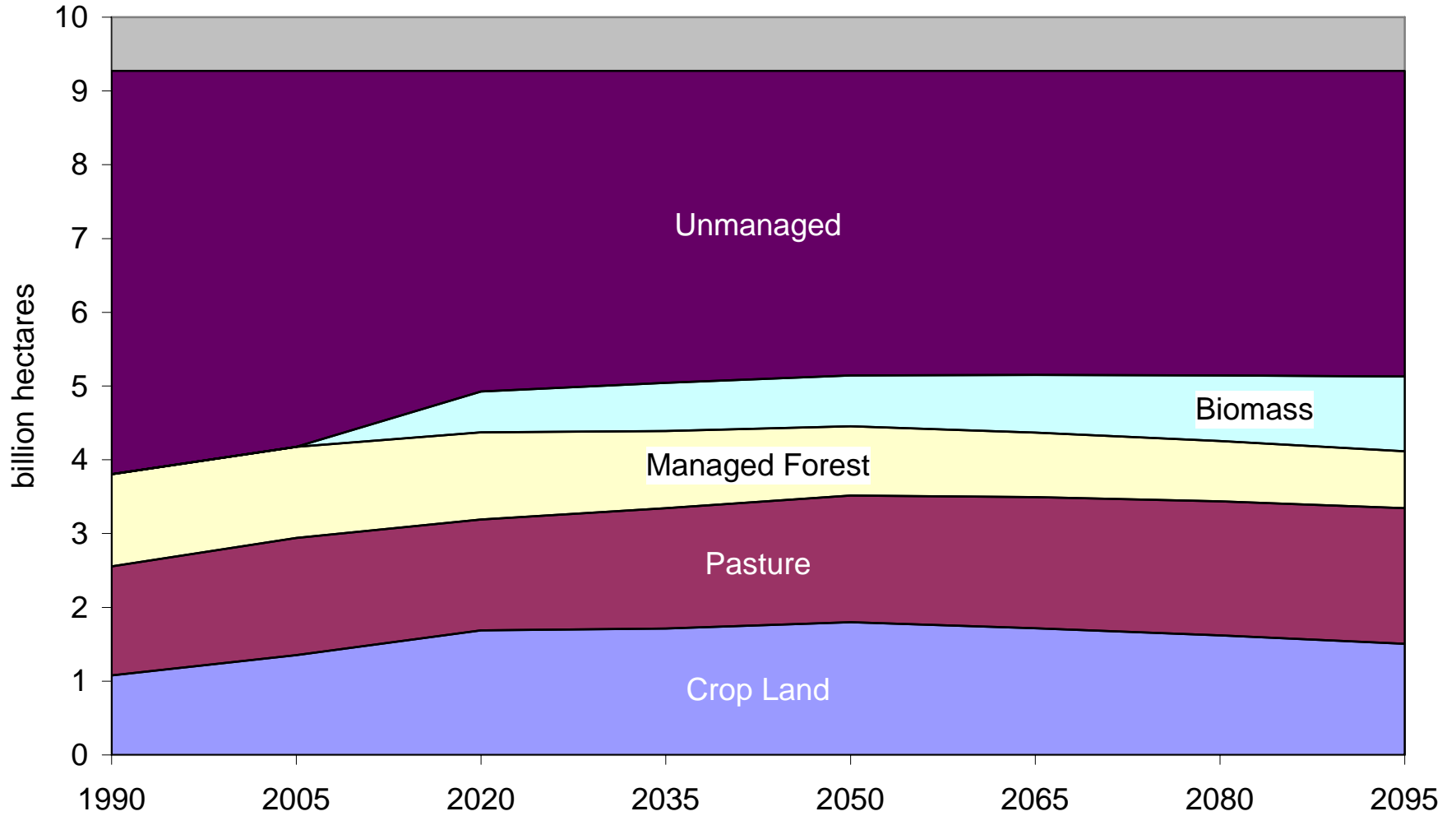
- ▶ Price received for forest at harvest time must cover land rent over lifetime of tree plus cost of harvesting
- ▶ All terms are discounted to the present for comparison (intertemporal efficiency condition)
- ▶ AgLU approximation

$$\bar{\pi}_{forest} = \frac{r}{(1+r)^{45} - 1} \bar{y}_{forest} \left(\tilde{P}_{forest} - G_{forest} \right)$$

Land Use (without carbon policy)



Land Use (with carbon policy)



Land Classification

▶ Alternative Definition of Land Uses

- Arable Land
 - Crops: food grains, coarse grains, oil crops, other food crops, hay, biofuel crops
 - Managed forest land
 - Unmanaged: unmanaged forest, other arable land
- Non-arable land: grazing

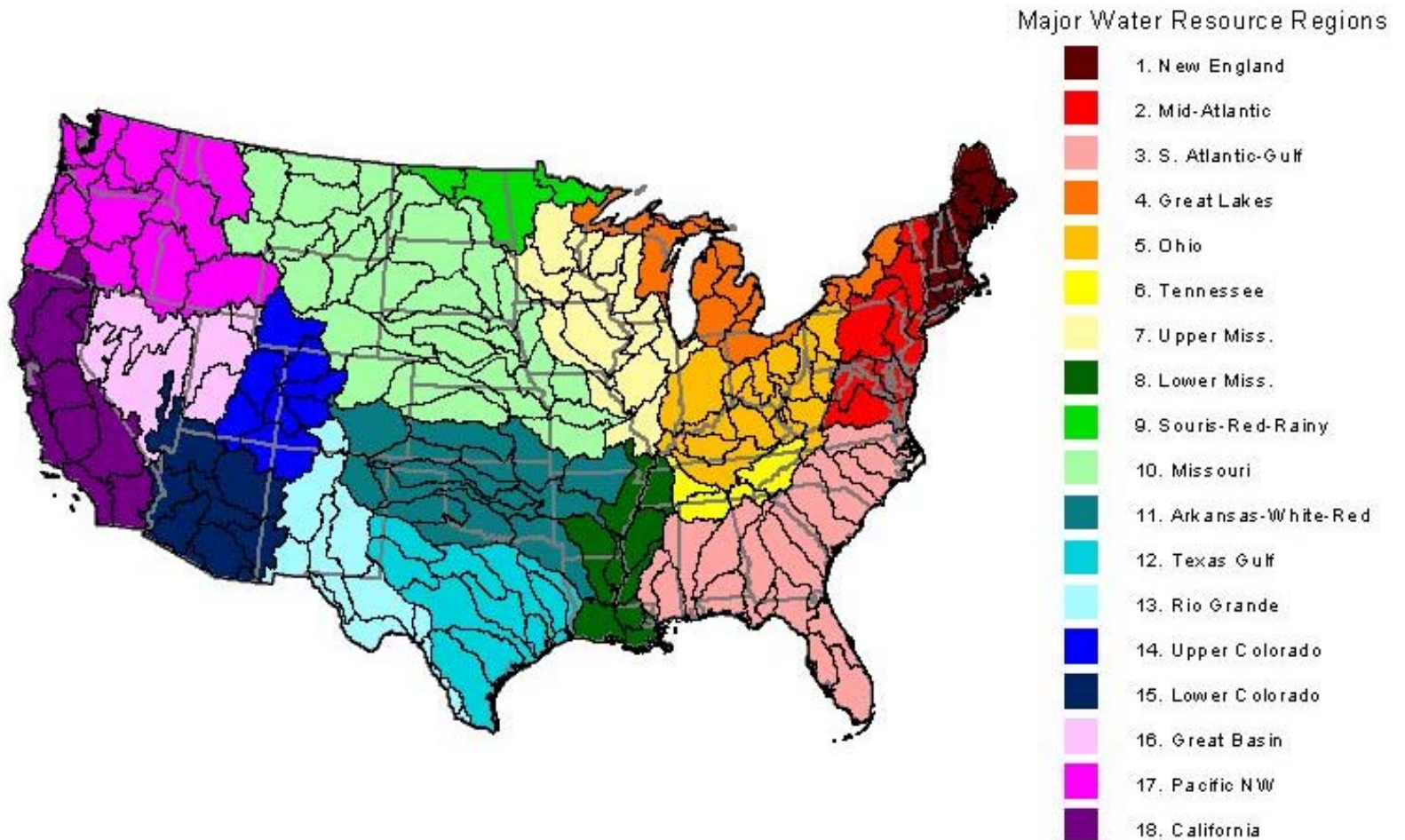
▶ Approaches to Defining Land Classes

- Hydrologic Unit Areas: allows future link to water supply
- Agroecological Zones: based on climate variables

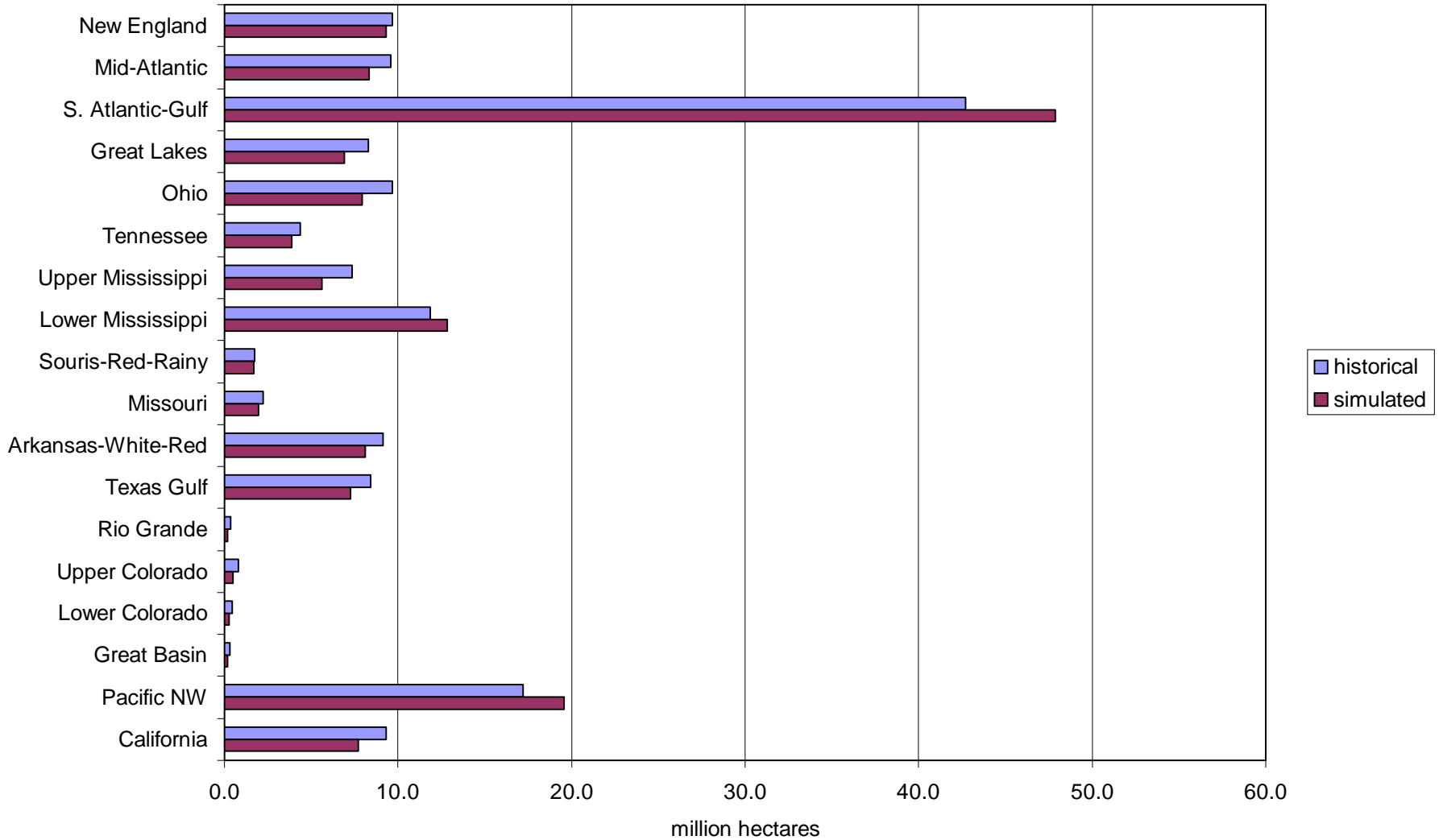
US Land Classes

- ▶ Why Disaggregate?
 - Capture geographical heterogeneity
 - Terrestrial mitigation opportunities vary by land class
 - Climate impacts will vary by land class
- ▶ Hydrologic Unit Areas (HUAs)
 - 18 two-digit water basins in US
 - Fixed location
 - Useful for climate impact studies
 - Link to water supply will be important for future work on water and potential for biofuels
- ▶ Base-Year Calibration
 - No unique way to calibrate base year (calibration is something of an art)
 - Not easy to calibrate all of the following: land area by product and land class, output by product and land class, prices, costs of production
 - Exact calibration doesn't tell you where your model structure can be improved

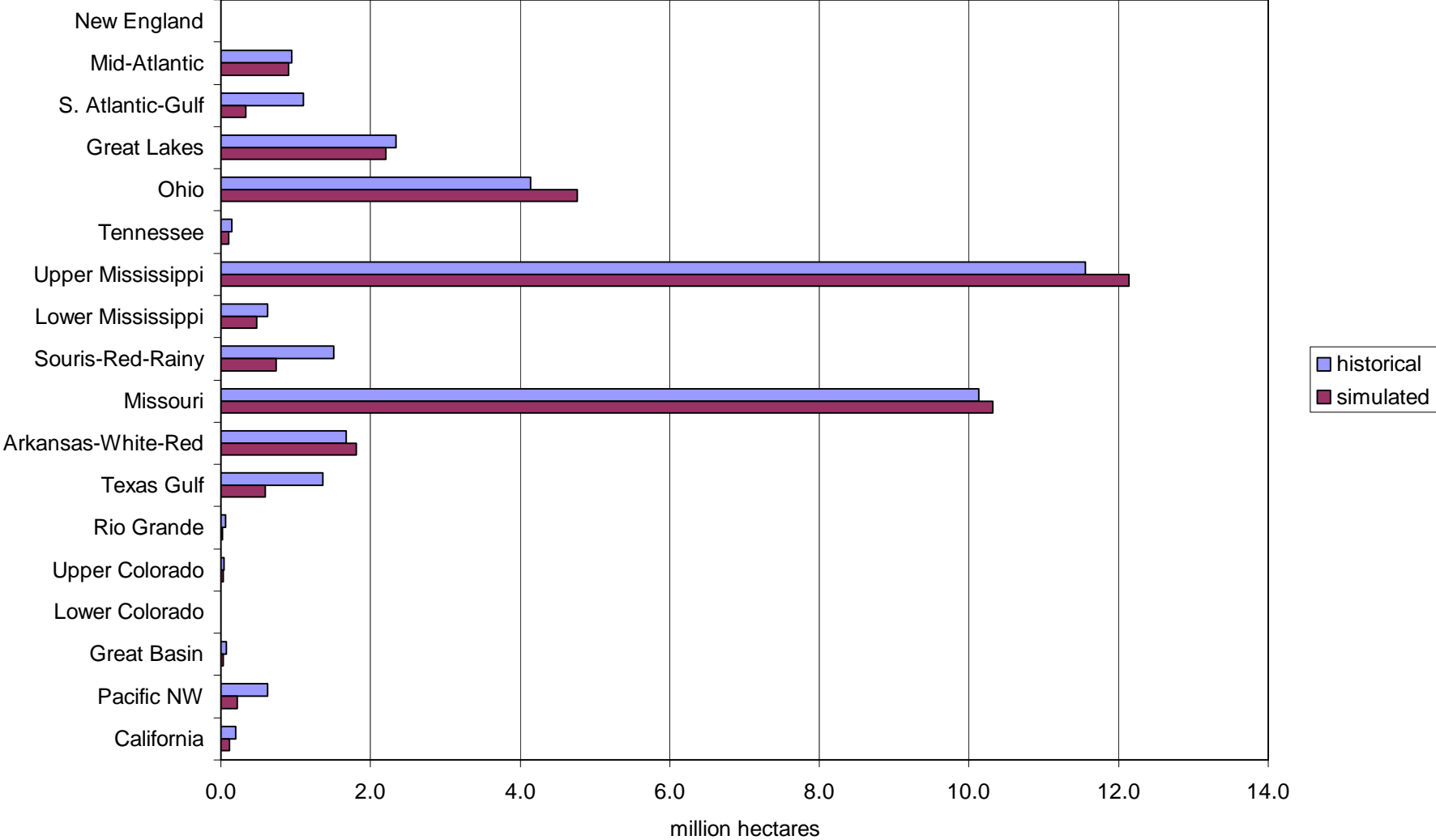
Major Water Resource Regions



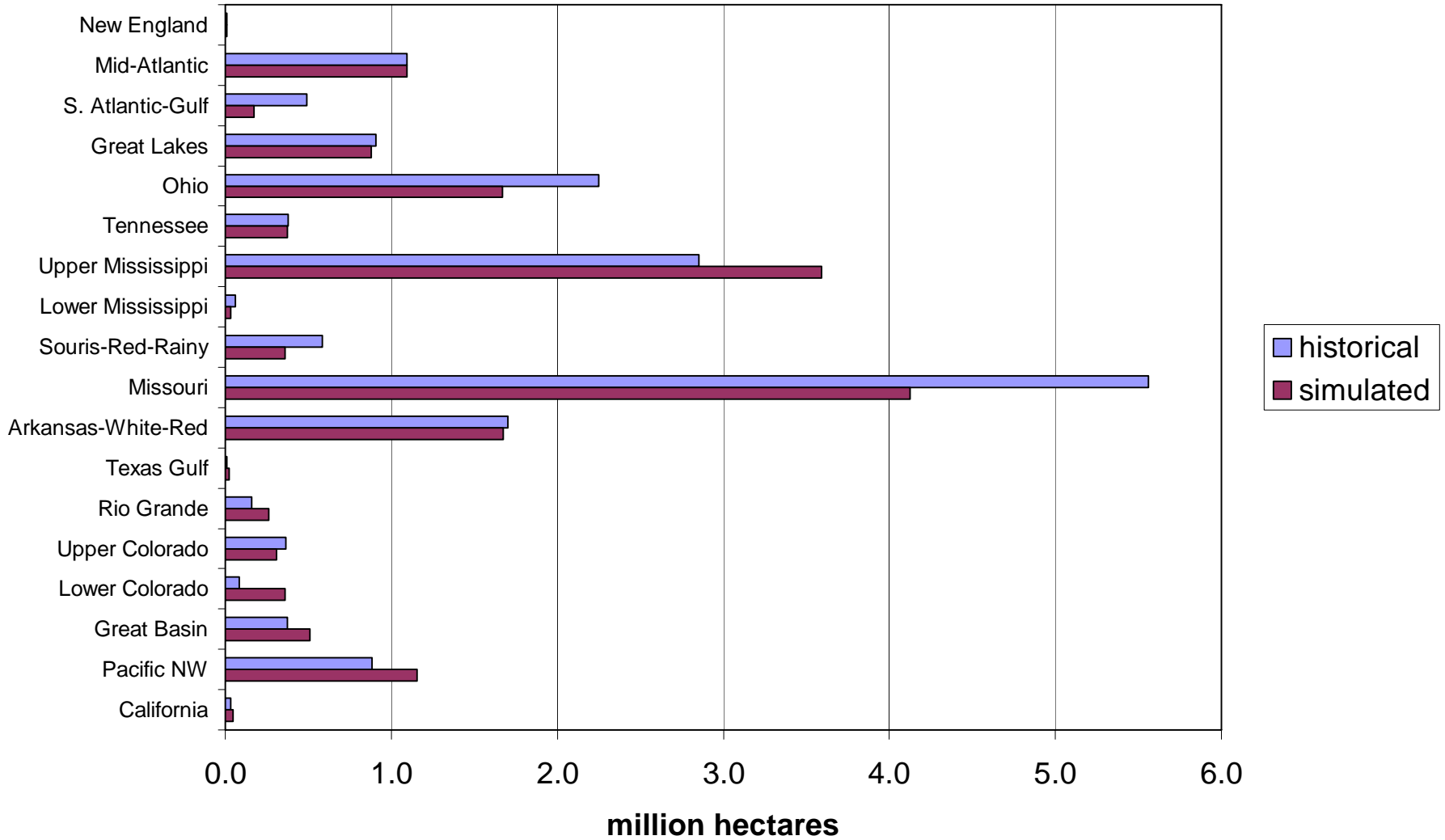
Forest Area



Coarse Grains Area



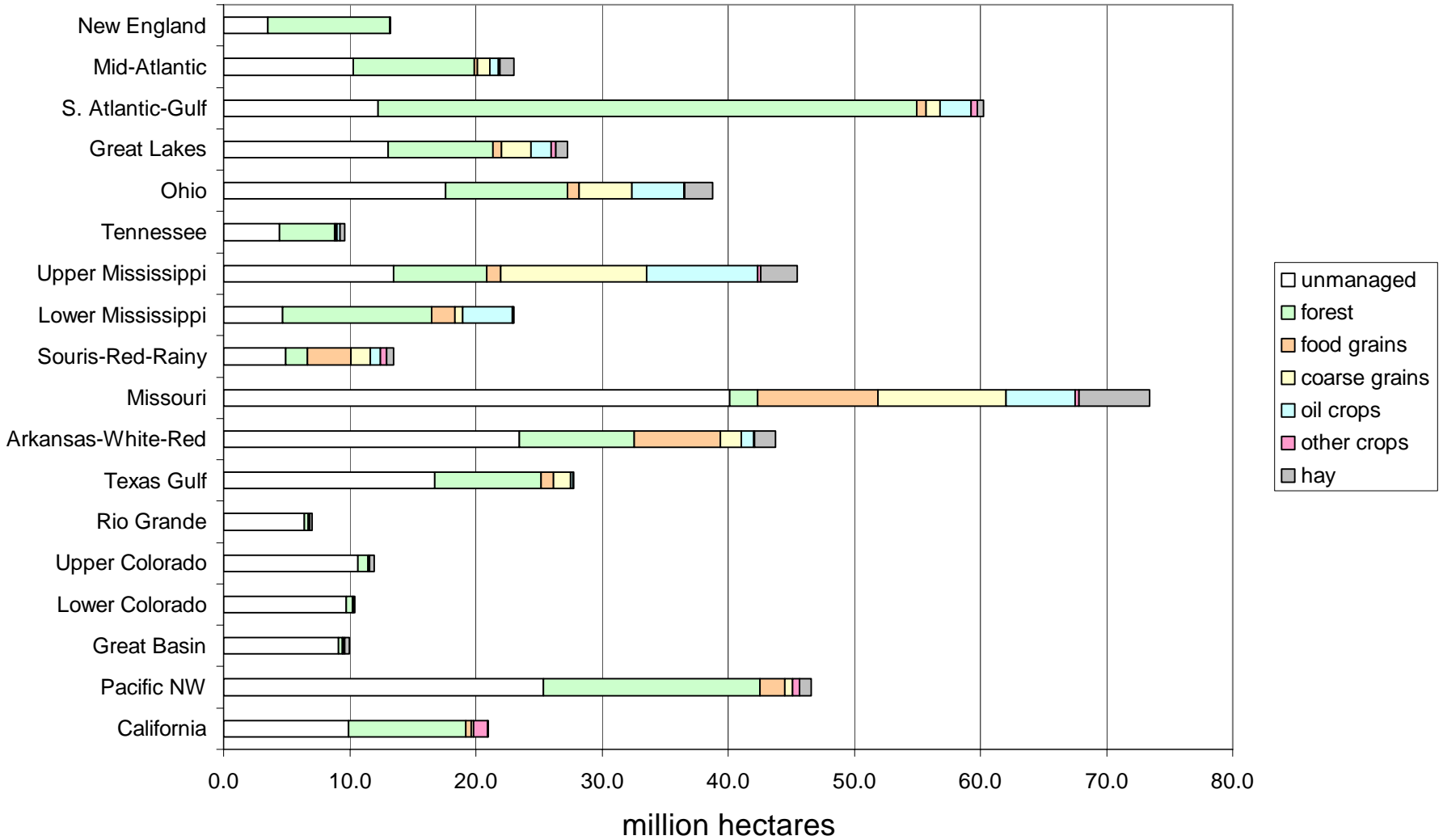
Hay Area



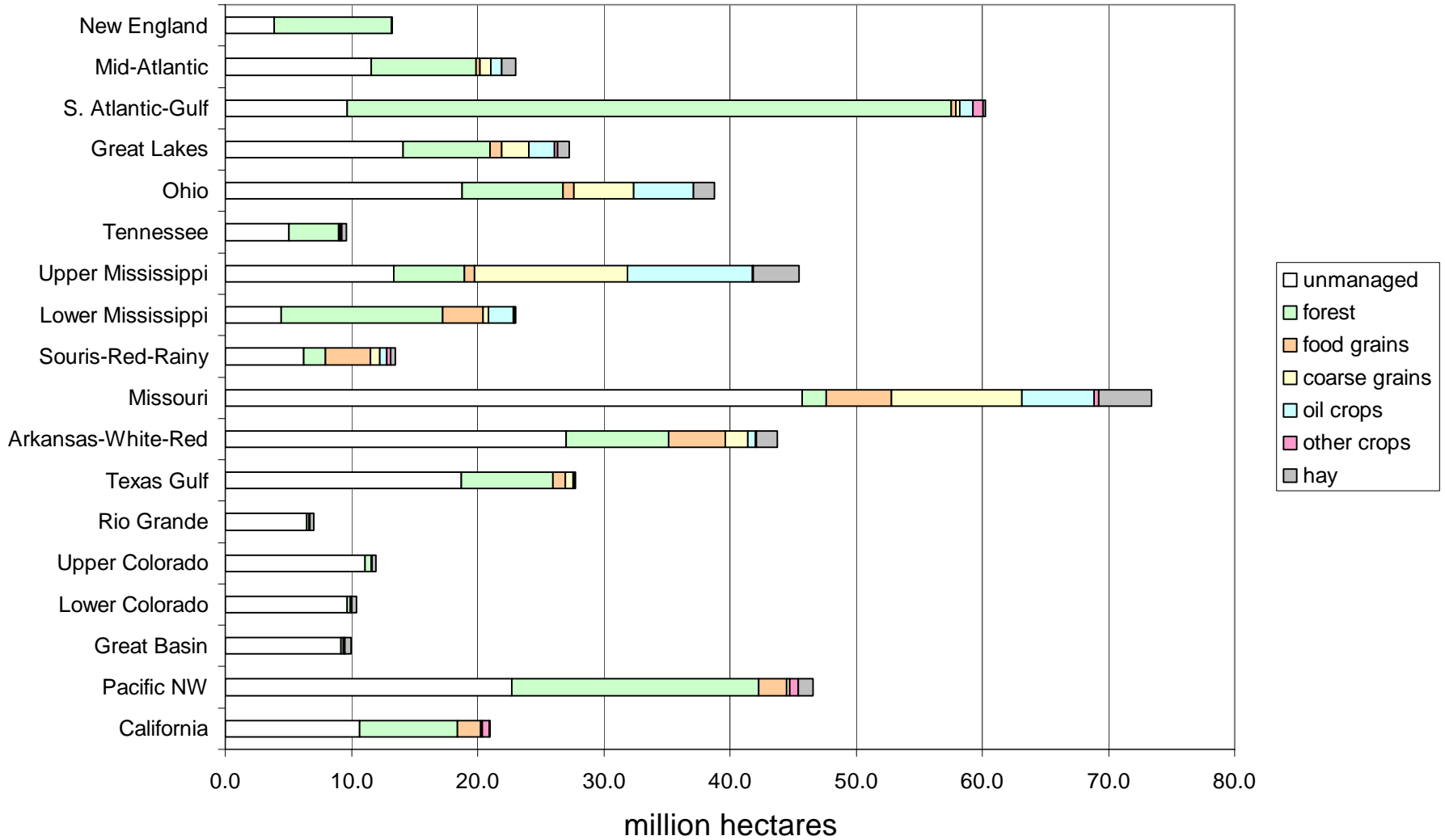
U.S. Examples

- ▶ Land Use Change over Time (+ 50 years)
 - Population growth at 1% per year
 - Agricultural and forestry productivity growth at 0.5% per year
 - Economic growth in “everything else” sector
 - Trade in agricultural and forestry products held constant at base-year levels
- ▶ Climate Impacts
 - UIUC general circulation model with 2.5 degree climate sensitivity
 - With and without CO₂ fertilization effect

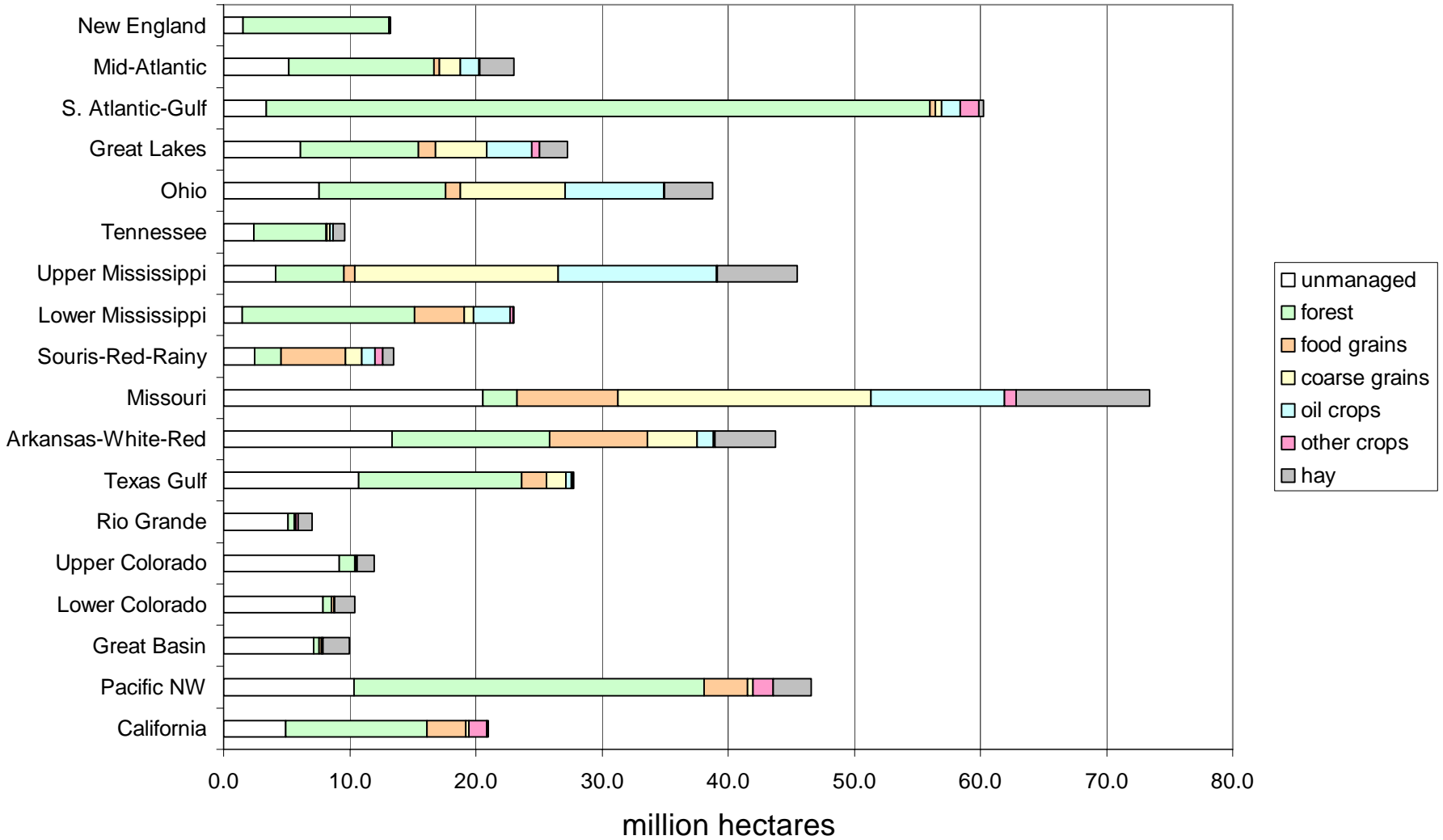
Historical Land Use



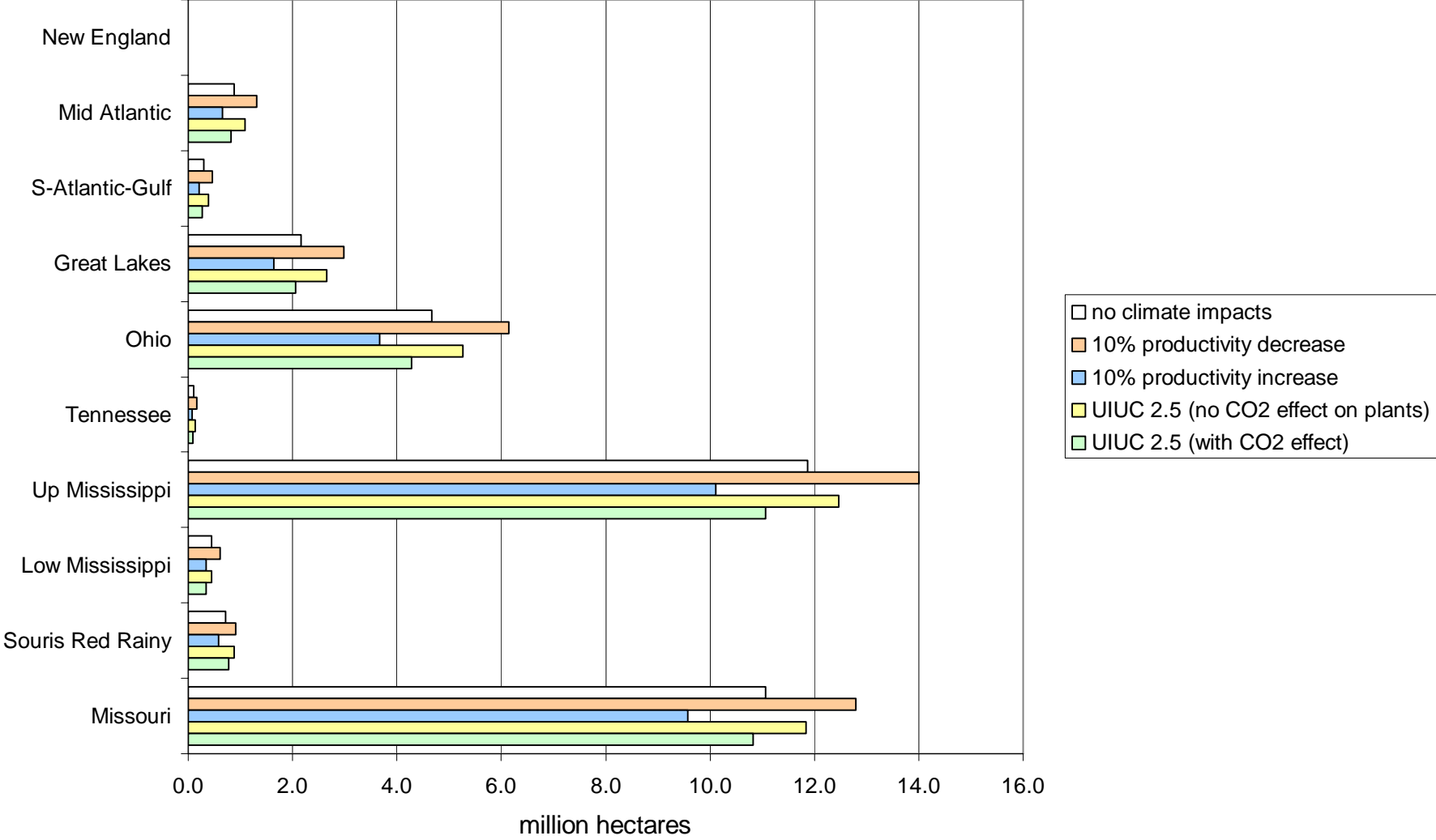
Simulated Land Use (base year)



Simulated Land Use (+50 years)



Coarse Grains Area



Toward a CGE Framework

- ▶ It is possible to embed partial-equilibrium AgLU in a CGE framework
- ▶ This demonstration combines AgLU for the US with an everything else (ETE) sector
- ▶ Approach is to combine system equations for AgLU with CGE system equations
 - Market clearing for labor and capital
 - Market clearing for ETE
 - Zero-profit condition for ETE
- ▶ Benefits of CGE formulation
 - Consistent treatment of mitigation opportunities across energy, agricultural and forestry systems
 - Utility-based consumer demand system
 - Walras' Law test helps find accounting errors

AgLU-CGE: Equations that Solver must handle

	Equation	Unknowns
Primary Agriculture		
Crop1: Food Grains	market clearing	price
Crop2: Coarse Grains	market clearing	price
Crop3: Oil Crops	market clearing	price
Crop4: Other Food Crops	market clearing	price
Crop5: Hay	market clearing	price
Forestry	market clearing	price
Other Products		
Processed Food	market clearing	price
Feed1	market clearing	price
Pork/Poultry	market clearing	price
Feed2	market clearing	price
Beef	market clearing	price
Other Products		
Processed Food	zero-profit condition	output level
Feed1	zero-profit condition	output level
Pork/Poultry	zero-profit condition	output level
Feed2	zero-profit condition	output level
Beef	zero-profit condition	output level
ETE	zero-profit condition	output level
Primary Factors		
labor	market clearing	factor rental
capital	market clearing	factor rental
Dropped Equation (Walras' Law test)		
ETE	market clearing	numeraire price

Final input-output table in values (thousand US dollars)

	Crop1	Crop2	Crop3	Crop4	Crop5	Proc. Food	Feed1	Pork/Poultry	Feed2	Beef	Forestry	ETE	value of consumption	value of net exports
Crop1: Food Grains						46,141	490,592		724,724				2,076,476	4,000,906
Crop2: Coarse Grains						1,094,790	2,002,028		2,957,481				172,560	2,089,959
Crop3: Oil Crops						4,462,393	107,146		158,280				152,649	2,814,694
Crop4: Other Food Crops						1,703,032	22,986		33,956				3,312,797	280,713
Crop5: Hay									6,587,805				0	0
Processed Food													7,156,757	149,599
Feed1								2,622,752					0	0
Pork/Poultry													2,557,180	65,572
Feed2										10,462,245			0	0
Beef													11,392,566	-930,320
Forestry													29,677,690	-5,543
ETE													4,350,000,071	0
Land	2,338,839	3,316,818	2,695,163	353,483	1,587,805						15,740,929			
Labor	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	0	0	0	0	0	0	3,750,000,061		
Capital Stock	0	0	0	0	0	0	0	0	0	0	0	600,000,010		
Interest												13,931,218		

Model Development

- ▶ Set up land classes in other world regions
- ▶ Reflect carbon price in land allocation decision
- ▶ Include water
 - Irrigated agriculture as a separate land use
 - Water availability limits amount of irrigated agriculture within each hydrologic unit area
- ▶ Embed AgLU in a computable general equilibrium model (SGM)
 - Full set of inputs to production
 - Land allocator replaces land market
 - Biomass as a link between agricultural and energy systems
 - Parameterize to reflect biomass response in FASOM-GHG